

Name: \_\_\_\_\_

Section: \_\_\_\_\_

### Data and Calculations

#### Part 1

Diameter: \_\_\_\_\_ cm    Radius: \_\_\_\_\_ cm    Height (cylinder part): \_\_\_\_\_ cm

Volume (cylinder part): \_\_\_\_\_  $\text{cm}^3$     Volume (half-sphere part): \_\_\_\_\_  $\text{cm}^3$   
SHOW CALCULATION:                      SHOW CALCULATION:

Total Volume (sum): \_\_\_\_\_  $\text{cm}^3$     Volume (graduated cylinder): \_\_\_\_\_ mL

Average Volume: \_\_\_\_\_ mL    Percent Difference: \_\_\_\_\_ %  
SHOW CALCULATION:                      SHOW CALCULATION:

#### Part 2

Mass of Metal Cylinder \_\_\_\_\_

Diameter \_\_\_\_\_    Length \_\_\_\_\_    Volume calipers \_\_\_\_\_

Volume<sub>water</sub> \_\_\_\_\_    Volume<sub>metal + water</sub> \_\_\_\_\_    Volume<sub>water displacement</sub> \_\_\_\_\_

Density of the Cylinder:    calipers: \_\_\_\_\_    water displacement: \_\_\_\_\_

Handbook Density \_\_\_\_\_

Identity of Metal \_\_\_\_\_

% Error:                      calipers: \_\_\_\_\_    water displacement: \_\_\_\_\_

SHOW CALCULATIONS:

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Part 3

Unknown Number \_\_\_\_\_

Mass of Flask with stopper \_\_\_\_\_

Initial Buret reading \_\_\_\_\_

Sample	Mass Flask+Stopper+Liquid (g)	Mass Liquid Only (g)	Final Buret Reading (mL)	Net Volume (mL)	Density ( $x_m$ ) (g / mL) 4 sig. figs.	d ( $x_m - \bar{x}$ )	d <sup>2</sup>
1							
2							
3							
4							
5							
6							
					sum of $x_m$ :	sum of d <sup>2</sup> :	

Show your calculation of the standard deviation, s, from d<sup>2</sup> below:Mean value ( $\bar{x}$ ): \_\_\_\_\_

Standard Deviation (s): \_\_\_\_\_

Range: \_\_\_\_\_

% NaCl from Table: \_\_\_\_\_

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### Post-lab Questions

1. Calculate the density of a pure gold sphere with a diameter of 2.120 cm and a mass of 94.19 g.
  
  
  
  
  
  
  
  
  
  
2. The density of aluminum is  $2.70 \text{ g/cm}^3$ . Calculate the thickness of a rectangular sheet of aluminum foil with a width of 11.5 cm, a length of 14.0 cm, and a mass of 2.04 g.
  
  
  
  
  
  
  
  
  
  
3. Examine your results from your data table in Part 3. Do you have any values for the density of the salt solution that lie OUTSIDE the range  $(\bar{x} \pm 2s)$ ? If so, list them here:

Recalculate  $\bar{x}$  by omitting values that lie OUTSIDE the range. This is the density value you should use to determine your experimental % NaCl.

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**Pre-lab Questions**

Upon reading the procedure in preparation for this experiment, you should also answer the following questions:

1. Consider Example One in the laboratory discussion. Since measurement 8 lies outside the range, it may be omitted in the calculation of the reported value. Omit measurement 8 and recalculate the mean ( $\bar{x}$ ). Fill in the  $d$  and  $d^2$  columns in the table, then calculate the standard deviation ( $s$ ) and the range.

Recalculated mean ( $\bar{x}$ ), without measurement 8: \_\_\_\_\_

Balance Number	Mass (g) = $x_m$	$d = x_m - \bar{x}$	$d^2$
1	24.29		
2	24.26		
3	24.17		
4	24.31		
5	24.28		
6	24.19		
7	24.33		
<b>8 – OMITTED</b>	<del>24.50</del>		
9	24.30		
10	24.23		
sum of $x_m$ :		sum of $d^2$ :	

Recalculated standard deviation ( $s$ ): \_\_\_\_\_ and range: \_\_\_\_\_

SHOW CALCULATIONS:

2. Now consider Example Two in the laboratory discussion. The student doing the titration repeated the experiment twice more. The following five values were obtained: 0.555 M, 0.565 M, 0.564 M, 0.567 M, and 0.563 M.

A. Use the *Q Test* to demonstrate that the first value should be rejected.

B. Recalculate the values for  $\bar{x}$ , omitting the value 0.555 M. Compare with the original value of  $\bar{x}$ .

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### Data and Calculations

Liquid Unknown # \_\_\_\_\_

<u>Measurement #</u>	<u>Volume (mL)</u>	<u>Mass (g) of beaker + cover + liquid</u>
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____

### Post-lab Questions

1. Using your hand-written graph, determine the density of your unknown (recall that slope =  $\Delta y / \Delta x$ ). When graphing, use all the data points, then draw the best fit straight line. Start at zero for the x axis, and about 10 to 20 grams less than your smallest mass for the y axis. The line may not exactly touch each point. Determine the slope using two points on the best fit line spread apart from each other. Do not use just two data points measured in the experiment as they may not be on the best fit line.
2. Using your hand-written graph, estimate:
  - A. the mass (in grams) of 27.0 mL of your liquid. \_\_\_\_\_
  - B. what volume (in mL) would 17.0 g of your liquid occupy. \_\_\_\_\_
3. Using your Excel<sup>®</sup> plot and constructed trendline, write the slope-intercept equation for your liquid unknown. What is the density of your unknown? Make sure to include the appropriate units. How does this density value compare to your result from question #1 above?

4. Using your slope-intercept equation, determine:

A. the mass (in grams) of 27.0 mL of your liquid.

B. what volume (in mL) would 17.0 g of your liquid occupy.

5. The data for temperature and pressure of a certain sample of gas is found to be:

Temperature (°C)	Pressure (mmHg)
-196	215
-78.5	542
-17.8	711
0.1	761
22.7	824
99.3	1037
189	1287

The researcher seals the gas inside of a container, adjusts the temperature of the container, and then measures the pressure of the gas inside. Therefore, temperature is the independent variable and pressure is the dependent variable.

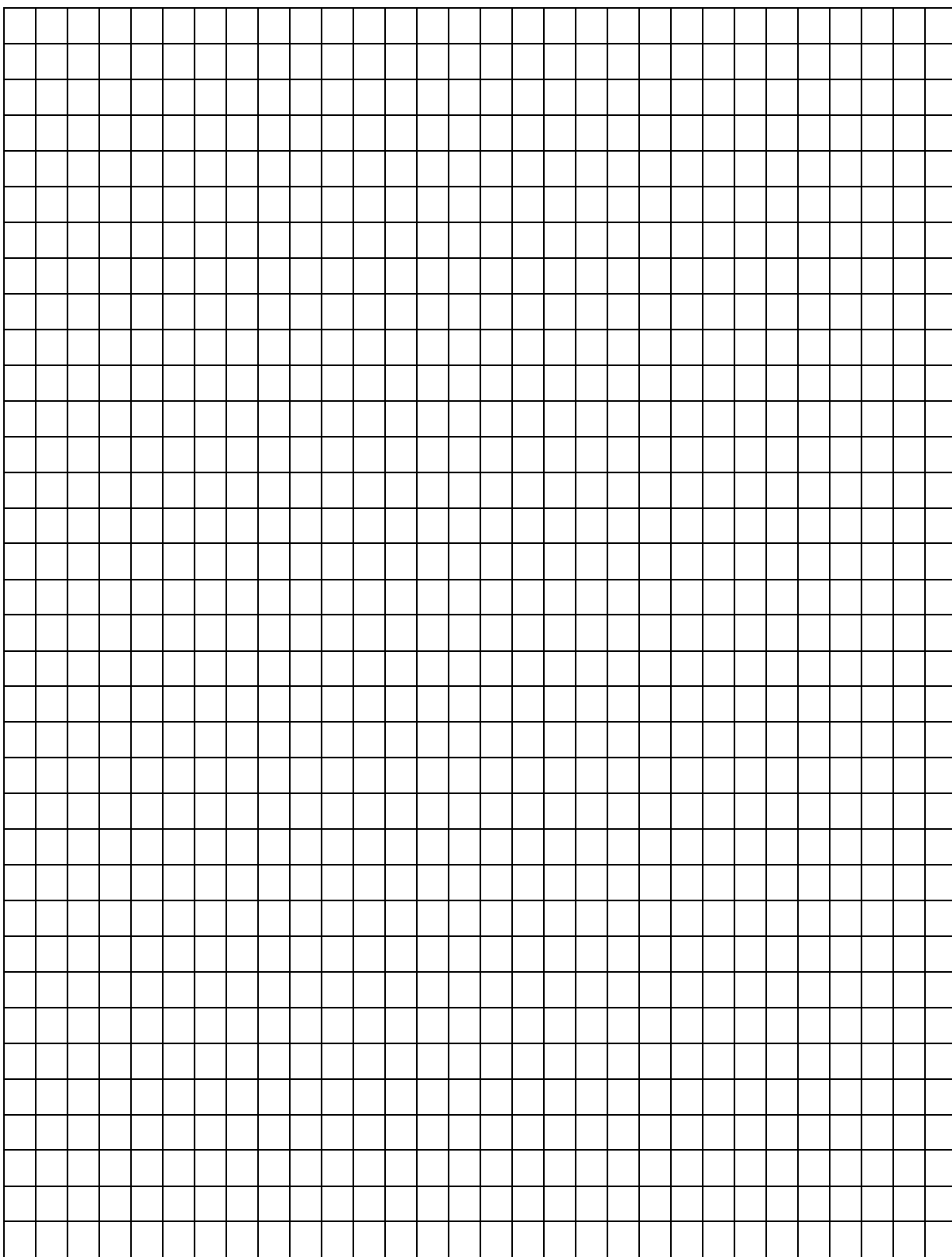
A. Construct an Excel<sup>®</sup> graph of this data with a linear trendline. Make sure to print out a copy of this graph with the slope-intercept equation of the trendline displayed for inclusion with this report. Rewrite the equation, below, using T and P instead of x and y to show the relationship between temperature (T) and pressure (P):

B. Use the equation of the line to calculate the expected pressure of the gas at a temperature of 42.3 °C.

C. Use the equation of the line to predict the temperature of the gas when its pressure is 437 mmHg.

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### Data and Calculations

Mass of empty test tube: \_\_\_\_\_

Mass of the test tube + copper oxide before heating \_\_\_\_\_

Mass of the test tube + solid after 20 minutes of heating \_\_\_\_\_

Mass of the test tube + solid after 30 minutes of heating: \_\_\_\_\_

Mass of the test tube + solid after 40 minutes of heating: \*  
\*if necessary; add more lines if needed \_\_\_\_\_

Mass of the copper oxide *before* you heated: \_\_\_\_\_

Final mass of the copper metal powder: \_\_\_\_\_

Mass that disappeared during the heating: \_\_\_\_\_

What element or compound disappeared from the copper oxide during heating? \_\_\_\_\_

Moles of copper in the pellet: \_\_\_\_\_

SHOW CALCULATION:

Moles of oxide that escaped: \_\_\_\_\_

SHOW CALCULATION:

Empirical formula of the initial copper oxide: \_\_\_\_\_

SHOW CALCULATION:

Mass percentage of copper in copper oxide: \_\_\_\_\_

SHOW CALCULATION:



**Post-lab Questions**

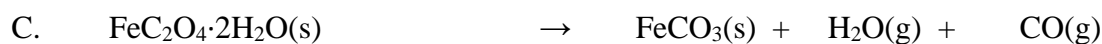
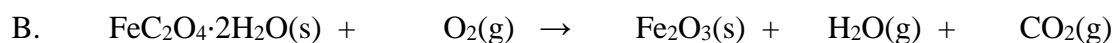
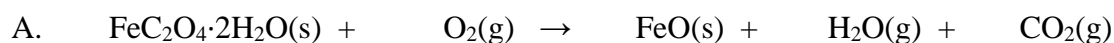
1. Write the balanced chemical equation for the reaction of your oxide using the experimentally determined empirical formula.
  
2. Imagine you had just discovered copper. Which of the following formulas would be *possible* guesses (however unlikely) for the empirical formula of copper oxide? Which would be *good* guesses if you used the periodic table as a guide to understanding copper's probable charge? Briefly explain your choices below.



3. A sample of an iron oxide weighing 1.996 g yields 1.396 g of iron on reaction with methane gas. Determine the percent composition and the empirical formula of the iron oxide from this data. **SHOW ALL CALCULATIONS!** Random guessing will NOT earn you any credit.

**Option Fe: Pre-lab Calculations for the Iron Based Experiment:**

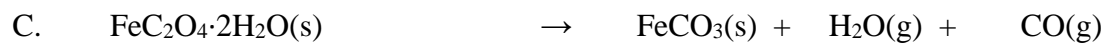
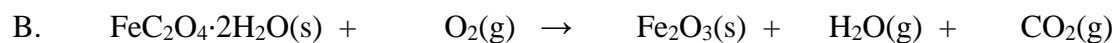
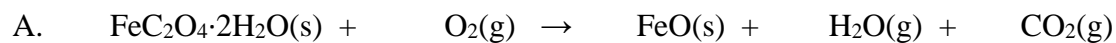
1. Calculate the molar mass of the starting hydrated salt material,  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ .
2. Your oxalate synthesis product will be  $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ . Calculate the molar mass of  $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ .
3. Write a balanced molecular equation that shows your  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , reacting with oxalic acid ( $\text{H}_2\text{C}_2\text{O}_4$ ) to form  $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ . What will be the other product(s) of the double displacement reaction? Water will need to be added somewhere to balance correctly.
4. Pyrolysis of  $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$  will follow one of the following molecular equations. Balance each molecular equation. (*It's OK to keep a fraction when balancing the  $\text{O}_2$  molecule in A or B*)



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5. For each of the possible reactions, calculate the theoretical yield (in grams) of the solid product, assuming that you use 1.0 g  $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$  and that oxygen is the excess reactant. You will need to write in coefficients from question 4 to balance the molecular equations.



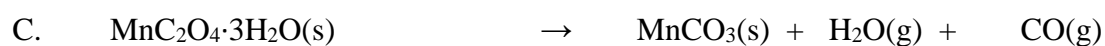
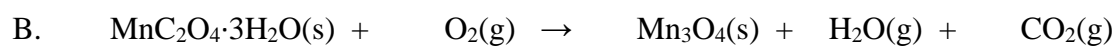
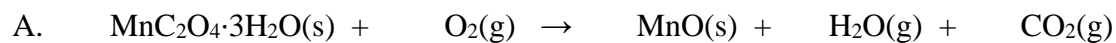
**Option Mn: Pre-lab calculations for the Manganese based experiment:**

1. Calculate the molar mass of the starting hydrated salt material,  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ .
2. Your oxalate synthesis product will be  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$ . Calculate the molar mass of  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$
3. Write a balanced molecular equation that shows  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ , reacting with oxalic acid ( $\text{H}_2\text{C}_2\text{O}_4$ ) to form  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$ . What will be the other product(s) of the double displacement reaction? Water will need to be added somewhere to balance correctly.
4. Pyrolysis of  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$  will follow one of the following molecular equations. Balance each molecular equation. (*It's OK to keep a fraction when balancing the  $\text{O}_2$  molecule in A or B.*)
  - A.  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{MnO}(\text{s}) + \text{H}_2\text{O}(\text{g}) + \text{CO}_2(\text{g})$
  - B.  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{Mn}_3\text{O}_4(\text{s}) + \text{H}_2\text{O}(\text{g}) + \text{CO}_2(\text{g})$
  - C.  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}(\text{s}) \rightarrow \text{MnCO}_3(\text{s}) + \text{H}_2\text{O}(\text{g}) + \text{CO}(\text{g})$

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5. For each of the possible reactions, calculate the theoretical yield (in grams) of the solid product, assuming that you use 1.0 g  $\text{MnC}_2\text{O}_4 \cdot 3\text{H}_2\text{O}$  and that oxygen is the excess reactant. You will need to write in coefficients from question 4 to balance the molecular equations.



**Data and Calculations**Part 1: Synthesis of Metal Oxalate

Determine the identity of the limiting reactant, theoretical yield of the hydrated metal oxalate, and the percent yield of the hydrated metal oxalate product. Complete Table 1.

*Table 1. Synthesis of Metal Oxalate*

a) complete chemical formula of your starting material: (formula found on question 1)	
b) mass of hydrated metal salt used (g) <i>tare your 100 ml beaker and add 1.9-2.1g sample</i>	
c) moles of hydrated metal salt used convert grams from (b) using molar mass in question 1	
d) volume of 0.888M oxalic acid solution used <i>should be close to 25.0mL</i>	
e) moles of oxalic acid used <i>calculate from volume and molarity</i>	
f) mass of filter paper	
g) experimental yield: total mass of hydrated metal oxalate precipitate (grams) after drying by vacuum filtration.  filter paper + salt mass: _____ <i>subtract the filter paper</i>	
h) identify the limiting reactant: either your starting formula in part (a) or oxalic acid <i>Refer to the balanced chemical equation in pre-lab quest. #3 and your moles of each reactant calculated in c and e</i>	
i) theoretical yield of hydrated metal oxalate product (g)	
j) percent yield of hydrated metal oxalate product	

Calculations: Show your calculations. Watch your units and report all answers with the correct number of significant figures.

**Data and Calculations****Part 2: Decomposition (Pyrolysis) of Metal Oxalate**

Complete Table 2. The pyrolysis reaction occurs with near 100% yield, so the actual yield of the pyrolysis reaction should be very close to the theoretical yield you calculated for the correct reaction equation (as calculated in Question #5 of the prelab).

*Table 2. Pyrolysis of Metal Oxalate*

a) Weigh the empty Aluminum dish before adding the filtered product.	
b) Before pyrolysis: mass of hydrated metal oxalate (grams) <i>Ideally between 0.99 to 1.01 gram</i>  Al + oxalate salt mass: _____ <i>subtract the Al dish</i>	
c) After pyrolysis: final mass of pyrolysis product (grams)  Al + pyrolyzed salt mass: _____ <i>subtract the Al dish</i>	
d) theoretical mass of product in reaction <b>A</b> From prelab (quest. #5A):	
e) theoretical mass of product in reaction <b>B</b> From prelab (quest. #5B):	
f) theoretical mass of product in reaction <b>C</b> From prelab (quest. #5C):	
g) Using the above information, which pyrolysis reactions actually occurred, <b>A</b> , <b>B</b> or <b>C</b> ?	
h) What is the expected chemical formula of the pyrolyzed metal salt formed?	

Calculations: Refer to your work from prelab Question #5 from your option. Watch your units and report all answers with the correct number of significant figures.

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### Procedure

1. Set up the apparatus as indicated in the picture.
2. Clean the solid Cu strip with steel wool; wash BOTH Cu strips with dilute NaOH, followed by dilute HNO<sub>3</sub>, and finally rinse with DI H<sub>2</sub>O. At this point, make certain to handle both Cu strips with forceps.
3. Rinse strips with acetone and when dry, weigh and record the mass of the Cu strips.
4. Place the strips in a 250 mL beaker containing about 200 mL of 1M CuSO<sub>4</sub>. DO NOT ALLOW THE STRIPS TO TOUCH.
5. Adjust the current to approximately 0.175 Amp (175 mA) and run the system for 30 minutes. If you cannot maintain a constant amp reading, take readings at 5 minute intervals and average the current.
6. Carefully rinse both Cu strips under a slow stream of DI water, then rinse with acetone, and allow to dry. Weigh and record the mass of each dry Cu strip.

### Data and Calculations

1. Current \_\_\_\_\_ amps
2. Time \_\_\_\_\_ seconds
3. Initial Mass of Copper A (solid) \_\_\_\_\_
4. Final Mass of Copper A (solid) \_\_\_\_\_
5. Change in mass of Copper A (solid) \_\_\_\_\_
6. Initial Mass of Copper B (screen) \_\_\_\_\_
7. Final Mass of Copper B (screen) \_\_\_\_\_
8. Change in mass of Copper B (screen) \_\_\_\_\_
9. Average change in mass of the Copper Strips \_\_\_\_\_





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6. Part D: Transfer the filter paper and solid back to the original beaker. Dissolve the solid copper oxide by adding approximately 10 mL of 3 M  $\text{H}_2\text{SO}_4(\text{aq})$  to the filter paper containing the residue from the previous step. Once the solid has dissolved, remove the filter paper and rinse it with 10 – 20 mL of deionized water. Add the washings to the acid solution, and save the solution for the next step. Note any color change. Also note the reaction that is occurring.
7. Part E: **WORK IN THE HOOD!** Add about 0.40 g of zinc metal to the acidic copper solution. If any blue color remains after the zinc has dissolved, a bit more zinc may need to be added (record in your report!). Note the reaction that is occurring. Dissolve any excess zinc with a small amount (approximately 5 mL) of 3 M  $\text{H}_2\text{SO}_4(\text{aq})$ .
8. Filter the supernatant liquid from the solid and wash the solid 3 times with 20 mL portions of deionized water.
9. Transfer the solid copper onto a large watch glass and place it in the laboratory oven (PS 103 or PS 107) for 15 to 20 minutes at around 100 °C or until dry. Weigh to determine the mass of recovered copper.

### Data Analysis and Calculations

Initial color and form of the copper \_\_\_\_\_

Mass of Cu(s) at the beginning of the experiment \_\_\_\_\_

Mass Recovered \_\_\_\_\_

% Recovery \_\_\_\_\_

Comment and discussion: Do your results support Lavoisier's law of conservation of mass? How does your percent recovery deviate from the expected 100%? Briefly explain.

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### Post-lab Questions

1. Write the symbol or formula for the form of copper that is present in the following parts of the experiment:

A. after adding nitric acid \_\_\_\_\_

B. after adding NaOH, litmus paper turns blue \_\_\_\_\_

C. after boiling \_\_\_\_\_

D. after adding sulfuric acid \_\_\_\_\_

E. after adding zinc \_\_\_\_\_

2. Now give the color of the copper substances in each of the steps above:

A. \_\_\_\_\_ D. \_\_\_\_\_

B. \_\_\_\_\_ E. \_\_\_\_\_

C. \_\_\_\_\_

3. A student reports 115% recovery. How could he/she possibly have more copper at the end of the experiment than he/she started with? Explain.

4. If a student used a penny as the source of copper in this experiment, would it matter if a pre-1982 penny (essentially pure copper) versus a post-1982 penny (copper exterior over a zinc core) was used? Would using a post-1982 penny pose any experimental complications? Briefly explain.

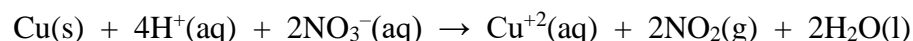
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5. Part A in today's experiment is classified as a redox reaction in which electrons are transferred via oxidation of Cu and reduction of the N in HNO<sub>3</sub>. The balanced molecular equation is:



The net ionic equation for this reaction is:



Write balanced molecular, ionic, and net ionic equations for the other four reactions in this inorganic sequence. Classify the types of each reaction in as many possible ways (i.e. redox, synthesis, combustion, decomposition, single replacement, double displacement, precipitation, neutralization).

Part B:

Part C:

Part D:

Part E:

6. Referring to part E, write the reaction for the reduction of copper(II) ion into solid copper using zinc. Calculate the theoretical mass of zinc needed to carry out the reaction based on the initial mass of copper used. Compare this theoretical mass of zinc with the actual amount used in the laboratory. Justify any differences.

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### Pre-lab Questions

Upon reading the procedure in preparation for this experiment, you should also answer the following questions:

1. Use the outlined procedure to describe:
  - a) a test for determining whether a solution is basic enough.
  
  - b) a test to decide whether enough zinc has been added.
  
2. Write out and classify the molecular, ionic, and net ionic equations that take place when  $\text{H}_2\text{SO}_4$  is added to the excess zinc in part E.
  
  
  
  
  
  
  
  
  
  
3. Does observing a color change always indicate that a chemical change has occurred? Explain why or why not.
  
  
  
  
  
  
  
  
  
  
4. What should the student do if the solution in step E is still blue?

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those solutions, you can make mixtures with the other solutions in which one of the components is known. From the results obtained with those mixtures and the information in the matrix, you can identify other solutions. These can be used to identify still others, until the entire set of ten is finally identified.

### Pre-lab Questions

- Fill in the matrix below to show how various solutions react, as described in the procedure.

											HCl
											H <sub>2</sub> SO <sub>4</sub>
											NaOH
											NH <sub>4</sub> OH
											Al(NO <sub>3</sub> ) <sub>3</sub>
											AgNO <sub>3</sub>
											Ca(NO <sub>3</sub> ) <sub>2</sub>
											Cu(NO <sub>3</sub> ) <sub>2</sub>
											Ni(NO <sub>3</sub> ) <sub>2</sub>
											SnCl <sub>4</sub>
											<b>NOTES</b>
HCl											
H <sub>2</sub> SO <sub>4</sub>											
NaOH											
NH <sub>4</sub> OH											
Al(NO <sub>3</sub> ) <sub>3</sub>											
AgNO <sub>3</sub>											
Ca(NO <sub>3</sub> ) <sub>2</sub>											
Cu(NO <sub>3</sub> ) <sub>2</sub>											
Ni(NO <sub>3</sub> ) <sub>2</sub>											
SnCl <sub>4</sub>											

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2. Which solutions should you expect to identify by simple observations?

3. Outline the procedure you will follow in identifying the remaining solutions. Be specific about what to look for and what conclusions you expect to draw from your observations.

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### QUALITATIVE ANALYSIS Report Sheet

Final Identifications:

No. 1 \_\_\_\_\_ No. 6 \_\_\_\_\_

No. 2 \_\_\_\_\_ No. 7 \_\_\_\_\_

No. 3 \_\_\_\_\_ No. 8 \_\_\_\_\_

No. 4 \_\_\_\_\_ No. 9 \_\_\_\_\_

No. 5 \_\_\_\_\_ No. 10 \_\_\_\_\_

Use the next few pages to write balanced MOLECULAR, IONIC, and NET-IONIC equations for TEN of the reactions that occurred during this laboratory experiment. Make sure to include the physical states of all the products. These equations must be turned in along with this report sheet to receive full credit upon conclusion of the lab.

1. Molecular:

Ionic:

Net-ionic:

2. Molecular:

Ionic:

Net-ionic:

3. Molecular:

Ionic:

Net-ionic:

4. Molecular:

Ionic:

Net-ionic:



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5. Molecular:

Ionic:

Net-ionic:

6. Molecular:

Ionic:

Net-ionic:

7. Molecular:

Ionic:

Net-ionic:

8. Molecular:

Ionic:

Net-ionic:

9. Molecular:

Ionic:

Net-ionic:

10. Molecular:

Ionic:

Net-ionic:

Name: \_\_\_\_\_

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### Data and Calculations

Mass of clean, dry calorimeter: \_\_\_\_\_ g

Mass of calorimeter with solution after conclusion of reaction: \_\_\_\_\_ g

Final mass of reaction solution: \_\_\_\_\_ g

Initial temperature of H<sub>2</sub>SO<sub>4</sub> solution: \_\_\_\_\_ °C

Initial temperature of NaOH solution: \_\_\_\_\_ °C

Average initial temperature of starting solutions: \_\_\_\_\_ °C

Final temperature of mixture: \_\_\_\_\_ °C

Change in temperature of solution ( $\Delta T$ ): \_\_\_\_\_ °C

1. Write the balanced chemical equation for your acid/base neutralization reaction.
  
  
  
  
  
  
  
  
  
  
2. Determine the theoretical yield of water (in grams) of the reaction that you carried out.
  
  
  
  
  
  
  
  
  
  
3. What is the limiting reactant of your reaction?
  
  
  
  
  
  
  
  
  
  
4. Calculate the mass of each reactant that is theoretically left over at the end of your reaction.

\_\_\_\_\_ g of NaOH left over      \_\_\_\_\_ g of H<sub>2</sub>SO<sub>4</sub> left over

Name: \_\_\_\_\_

Section: \_\_\_\_\_

5. Assuming that the specific heat capacity of the solution that you used is equal to  $3.70 \text{ J / g } ^\circ\text{C}$ , calculate the heat ( $q_{\text{solution}}$ ) in kJ that was absorbed by the contents of the coffee cup during the reaction.

6. Calculate  $\Delta H$  of your reaction using the units specified:

\_\_\_\_\_ kJ / g  $\text{H}_2\text{O}$  formed      \_\_\_\_\_ kJ / mol  $\text{H}_2\text{O}$  formed

7. Rewrite your balanced chemical equation and include the value of  $\Delta H$  beside it:

\_\_\_\_\_  $\rightarrow$  \_\_\_\_\_  $\Delta H =$  \_\_\_\_\_ kJ

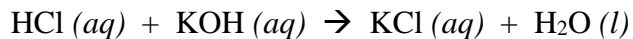
8. Use the  $\Delta H_f^\circ$  values given to calculate the theoretical value of  $\Delta H$  for your reaction.

Substance	$\Delta H_f^\circ$ (kJ / mol)
$\text{H}_2\text{SO}_4 (aq)$	-909.3
$\text{NaOH} (aq)$	-470.1
$\text{H}_2\text{O} (l)$	-285.8
$\text{Na}_2\text{SO}_4 (aq)$	-1387.1

9. Using your results from questions 7 & 8, calculate the percent error in your determination of  $\Delta H$ .

**Pre-lab Assignment**

A student carries out the following reaction in lab by mixing 50.0 mL of a 1.00 M solution of hydrochloric acid with 50.0 mL of a 1.00 M solution of potassium hydroxide:

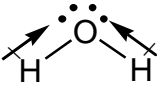
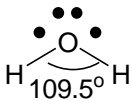


The average initial temperature of the two solutions was 25.00 °C. After mixing, the final temperature of the solution was 31.43 °C. The mass of the resulting solution was 100.2 g.

1. Determine the theoretical yield of KCl (in moles) of the student's reaction.
2. Assuming that the specific heat capacity of the solutions that the student used are equal to the specific heat capacity of pure water, calculate the heat ( $q_{\text{solution}}$ ) in kJ that was absorbed by the contents of the coffee cup from the reaction.
3. Calculate the value of  $\Delta H_{\text{rxn}}$  in the units kJ / mol KCl.
4. For this reaction, the theoretical value of  $\Delta H_{\text{rxn}}$  is  $-55.8$  kJ / mol KCl. What was the student's percent error when determining  $\Delta H_{\text{rxn}}$ ?

Source and Color of Line	a (cm)	b (cm)	d (cm)	Wavelength (cm)	Wavelength (nm)	Frequency (s <sup>-1</sup> )	Energy (J/photon)	Energy (kJ/mole)	Rydberg Eq calculation of $\lambda$ (nm)	
1. H (red) n = 3 → n = 2										
2. H (blue) n = 4 → n = 2										
3. H (violet) n = 5 → n = 2										
4. He (yellow)									X	
5. Hg (green)									X	
6. H n = 2 → n = 1	Show calculation to determine d here:									
7. H n = ∞ → n = 1										
8. H n = 4 → n = 3										
9. H n = ∞ → n = 3										
10. H n = ∞ → n = 2										
										IR, Vis, UV
										IR, Vis, UV
										IR, Vis, UV
										IR, Vis, UV
										IR, Vis, UV

Complete the following table for the indicated species:

Substance	H <sub>2</sub> O	HF	O <sub>2</sub>	CO
<p>a) Draw the best Lewis structure(s), resonances, and structural isomers if any</p> <p>b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom</p> <p>c) Include formal charges if they are not zero</p>	 <p>(does NOT need to be bent at this point!)</p> <p>formal charge <sub>O</sub> = 0</p> <p>formal charge <sub>H</sub> = 0</p>			
Name the electronic geometry around central atom(s)	Tetrahedral			
Give hybridization for central atom(s)	$sp^3$			
Name the shape around central atom(s)	Bent (or angular)			
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?	2 $\sigma$ and 0 $\pi$ bonds			
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?	polar molecule			

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table for the indicated species:

Substance	$\text{NH}_4^{+1}$	$\text{Na}_2\text{S}$	$\text{SO}_3$	$\text{ClO}_2^-$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table for the indicated species:

Substance	$\text{SO}_3^{-2}$	$\text{CH}_2\text{O}$	$\text{CO}_2$	$\text{SCN}^-$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				



Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table for the indicated species:

Substance	$\text{C}_2\text{H}_2\text{Br}_2$	$\text{NF}_3$	$\text{CH}_2\text{Cl}_2$	$\text{CH}_3\text{OH}$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table for the indicated species:

Substance	$C_6H_6$ (ring)	$S_8$	$PO_4^{3-}$	$C_3H_8O$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table for the indicated species:

Substance	$\text{NO}_3^-$	$\text{NO}_2$	$\text{H}_2\text{O}_2$	$\text{C}_2\text{H}_2$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Complete the following table for the indicated species:

Substance	A: $C_2H_4O_2$	B: $C_2H_4O_2$	$C_2H_6$	BaO
<p>a) Draw the best Lewis structure(s), resonances, and structural isomers if any</p> <p>b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom</p> <p>c) Include formal charges if they are not zero</p>	<p>Draw one structural isomer with C–C bond that has one C connected to 3 H and the other to 2 O. This is acetic acid</p>	<p>Draw a new structural isomer keeping all formal charges = 0. More than 5 isomers are possible</p>		
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Complete the following table (the central atom for each species has an expanded octet):

Substance	$I_3^-$	$ICl_5$	$SF_6$	$XeOCl_2$
a) Draw the best Lewis structure(s), resonances, and structural isomers if any				
b) In your structure above, indicate polar bonds with dipole arrows toward the more electronegative atom				
c) Include formal charges if they are not zero				
Name the electronic geometry around central atom(s)				
Give hybridization for central atom(s)				
Name the shape around central atom(s)				
Show 3-D sketch of the structure and label all bond angles				
How many sigma bonds? How many pi bonds?				
Is the substance an ionic compound, a polar molecule, a nonpolar molecule, or a polyatomic ion?				

Name: \_\_\_\_\_

Section: \_\_\_\_\_

### Data and Calculations

Unknown Number \_\_\_\_\_

Atmospheric pressure \_\_\_\_\_ torr = \_\_\_\_\_ atm

	Trial 1		Trial 2
1. Mass of dry flask with stopper	_____	=	_____
2. Mass of flask, stopper, & <u>condensed</u> liquid	_____		_____
3. Mass of <u>condensed</u> liquid	_____		_____
4. Temperature of boiling water	_____		_____
5. Volume of flask (see flask)	_____	=	_____
6. Molecular weight of sample)	_____		_____

*(These values must be within 5 % of each other. If not, a third trial must be run.)*

7. Average Molecular Weight\* \_\_\_\_\_  
\*Average only those values within the limit

SHOW CALCULATIONS:

Name: \_\_\_\_\_

Section: \_\_\_\_\_

**Questions (to be completed while in the laboratory)**

1. Obtain the mass percent composition information of your unknown from your instructor. Solve for the empirical formula, and then using your determined molecular weight, solve for the molecular formula of your compound.

Empirical Formula \_\_\_\_\_

Molecular Formula \_\_\_\_\_

2. Determine your percent error using your experimental molecular weight and the theoretical molecular weight determined via your molecular formula.

3. Write the ideal gas law equation for molecular weight.

Name: \_\_\_\_\_

Section: \_\_\_\_\_

### Post-lab Questions

4. It was found that 0.801 gram of vapor exerted a pressure of 744 torr at 100 °C when confined to a 260 mL flask. If this vapor came from a volatile liquid, what is the molecular weight of the liquid?
  
  
  
  
  
  
  
  
  
  
5. Based on this experiment:
  - A. How do you experimentally determine the temperature of the unknown when it is a gas?
  
  
  
  
  
  
  
  - B. How do you experimentally determine the pressure of the unknown when it is a gas?
  
  
  
  
  
  
  
  
  
  
6. What is the purpose of cooling the flask?
  
  
  
  
  
  
  
  
  
  
7. Why will air rush into the cooled flask when the stopper is removed?



Name: \_\_\_\_\_

Section: \_\_\_\_\_

8. How would each of the following procedural errors affect the calculated molecular weight in this experiment? Give your reasoning in each case.

A. All of the liquid was not vaporized when the flask was removed from the water bath.

B. The flask was not dried before the final weighing with the condensed vapor inside.

C. The flask was left open to the atmosphere while it was being cooled, and the stopper was inserted just before the final weighing.

D. The flask was removed from the bath after all of the liquid had vaporized but before the vapor had reached the temperature of the boiling water.

Name: \_\_\_\_\_

Section: \_\_\_\_\_

### Data and Calculations

1. Unknown sample number \_\_\_\_\_
2. Mass of test tube: \_\_\_\_\_
3. Mass of test tube and sample *before* heating: \_\_\_\_\_
4. Mass of test tube and sample *after* heating: \_\_\_\_\_
5. Mass of sample in the tube *before* heating: \_\_\_\_\_
6. Mass of residue in test tube *after* heating: \_\_\_\_\_
7. Mass of oxygen gas released: \_\_\_\_\_
8. Volume of oxygen gas at room temperature: \_\_\_\_\_
9. Atmospheric pressure: \_\_\_\_\_
10. Vapor pressure of water: \_\_\_\_\_
11. Temperature of water: \_\_\_\_\_

### Questions (to be completed while in the laboratory)

1. Calculate the pressure of the collected oxygen gas (i.e. correct for the vapor pressure of water).
  
  
  
  
  
  
  
  
  
  
2. How much volume would the gas in question #1 occupy at STP?
  
  
  
  
  
  
  
  
  
  
3. Determine the moles of oxygen gas collected from the experimental mass of the oxygen gas.

Name: \_\_\_\_\_

Section: \_\_\_\_\_

4. Use questions #2 and #3 to determine the molar volume (i.e. how many Liters/mole the gas would occupy at STP).
  
  
  
  
  
  
  
  
  
  
5. Determine the % error of your molar volume from that of an ideal gas.
  
  
  
  
  
  
  
  
  
  
6. Along with oxygen gas, potassium chloride is also formed from the potassium chlorate. Write a balanced equation for the reaction. Also describe the purpose of the  $\text{MnO}_2$ . Do you suspect that this "filler" is necessary for this particular reaction? Briefly explain why or why not.
  
  
  
  
  
  
  
  
  
  
7. Calculate the number of grams of potassium chlorate in your original sample.
  
  
  
  
  
  
  
  
  
  
8. Determine the mass percent of  $\text{KClO}_3$  in your original sample. (Remember that the sample was not pure  $\text{KClO}_3$  but has varying amounts of other compounds)
  
  
  
  
  
  
  
  
  
  
9. What would happen if you didn't remove the stopper from the hot test tube?

Name: \_\_\_\_\_

Section: \_\_\_\_\_

### Post-lab Questions

1. A sample of an unknown metal chlorate weighing 1.725 g is heated until all of the oxygen is driven off. The residue remaining in the container weighs 0.859 g. Calculate the percentage of oxygen in this metal chlorate.
  
  
  
  
  
  
  
  
  
  
2. 340 mL of oxygen gas are collected by displacement of water at 33 °C and 742 torr, where the vapor pressure of water at this temperature is known to be 37.8 torr.
  - A. What is the pressure of the oxygen gas?
  
  
  
  
  
  
  
  
  
  
  - B. Determine the volume of the oxygen gas at STP.

Name: \_\_\_\_\_

Section: \_\_\_\_\_

**Data and Results**

Substance	Melting range (check one)	Soluble in xylene?	Soluble in ethanol?	Soluble in water?	Conducts electricity as a solid?	Conducts as an aqueous solution?	<u>Classification:</u> Metallic Ionic Molecular (P) Molecular (NP) Network-Cov.
Known A	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Known B	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Known C	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Known D	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Known E	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Known F	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Unknown A	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						
Unknown B	<input type="checkbox"/> <100 °C <input type="checkbox"/> 100–300 °C <input type="checkbox"/> 300–600 °C <input type="checkbox"/> 600 °C						

Name: \_\_\_\_\_

Section: \_\_\_\_\_

2. Use the reagent pump to add 7.0 mL of 12 M (conc) HCl to the solution and cover with a small watch glass.
3. Place the beaker inside a 250 mL beaker which is about one-third full of DI water. Heat this water bath to a GENTLE boil for about 5 minutes or until a solid material forms in the smaller beaker. Keep the small watch glass on the inside beaker while boiling.
4. Cool the solution by placing the smaller beaker in a cold water bath.
5. Weigh and record the mass of a piece of filter paper. Pour your newly synthesized compound Y mixture through this filter paper so that the liquid drains into a 250 mL Erlenmeyer flask. Wash any remaining solid into the filter paper by rinsing the beaker with small amounts of cold DI water from a wash bottle. Allow the crystals to drain. Wash the precipitate 3 or 4 times with 5 mL portions of cold distilled water.
6. Transfer the crystals and filter paper to a previously weighed large watch glass. Dry the crystals by using one of the following methods: (1) place the watch glass over an appropriate sized beaker about one-third full of boiling water; or (2) place in a drying oven.
7. Once the sample is dry, weigh and record the mass of the watch glass, filter paper, and crystals. Label the crystals as compound Y and keep them in a stoppered test tube in your locker for further analysis. Do not leave the crystals in an open container in your locker, as this may damage the locking mechanism.

Mass of Compound Y: \_\_\_\_\_

## PART II

1. In the fume hood, take a piece of thick copper wire and heat it in a Bunsen burner flame until its glowing. Note the flame color. Let the wire cool for 20 seconds, and dip the wire into a container with Parlon. Cover the tip in the powder, place the compound in the flame and burn it. Observe the color. Parlon contains chlorine, which burns with a distinctive color in the presence of copper.
2. Follow the same procedure using another wire to test a sample of Chemical X. This should not have any unusual color, only burning with the orange color of a typical hydrocarbon fuelled fire.
3. Follow the same procedure using another wire to test a sample of Chemical Y. Does it contain chlorine?

Parlon Flame Color: \_\_\_\_\_ Chemical X Flame Color: \_\_\_\_\_

Chemical Y Flame Color: \_\_\_\_\_

Name: \_\_\_\_\_

Section: \_\_\_\_\_

**PART III**

Use the mel-temp apparatus for melting point determination. To determine the melting point, place a small amount of crystals into a thin-walled capillary tube (about 0.7–1.0 cm). Place the tube into the mel-temp apparatus, turn it on, and record the temperature range at which the sample melts. You can heat quickly to start, but when you get near the melting point (10 – 20 °C), lower the rate of heating so you can get a more accurate reading. If you don't know the melting point, you can do one fast run to get an approximate reading, then do a more careful and gradual second run. Please note that you cannot rerun a sample once it has melted.

The melting point of compound Y is close to 300 °C. Do NOT attempt to take its melting point as the electronic thermometers will fail at such a high temperature.

While you are testing compound X, also test 4-aminobenzoic acid and phenacetin to calibrate your results. The Mel-temp will run three samples at the same time. Perform two separate trials for each substance. These two values should be within 3° of each other.

	<u>Trial 1</u>	<u>Trial 2</u>	<u>CRC Handbook</u>
4-Aminobenzoic Acid	_____	_____	_____
Phenacetin	_____	_____	_____
Compound X	_____	_____	_____
Compound Y	<i>(not experimentally measured)</i>		<u>~300 °C</u>

**PART IV**

Dissolve about 0.2 gram of compounds X and Y separately in a 100 mL beaker containing 40 mL DI water. Use these solutions for all tests in this section.

Compare the solubility of X and Y in water.

X:

Y:

Use pH paper to determine the pH of both solutions: X: \_\_\_\_\_ and Y: \_\_\_\_\_

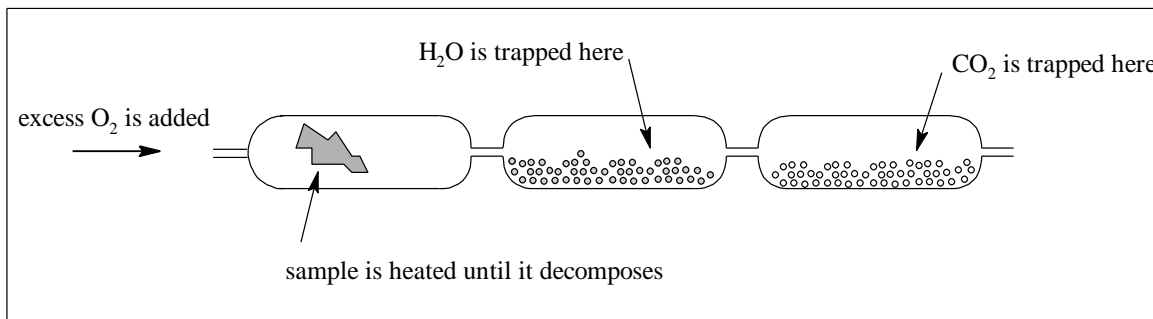
To each solution add a small quantity of Na<sub>2</sub>CO<sub>3</sub>. What happened? What class of compounds causes sodium carbonate to react this way?

X:

Y:

**PART V**

The empirical formula of an organic compound can be determined via combustion analysis. A typical combustion apparatus is shown below:



A sample of the chemical is burned in oxygen in a tube packed with copper oxide to ensure complete combustion. The carbon in the compound is converted to  $\text{CO}_2$ , which is absorbed in a tube packed with ascarite. The hydrogen is converted to water vapor and is absorbed in a tube packed with drierite. The increase in weight of the absorber tubes corresponds to the  $\text{CO}_2$  and  $\text{H}_2\text{O}$  produced during combustion. Compounds X and Y do NOT contain any nitrogen, sulfur, or halogen atoms; both compounds do contain oxygen.

A 1.0542 g sample of X was burned in a combustion apparatus. The results were:

Weight of ascarite tube before combustion	75.2382 g
Weight of ascarite tube after combustion	76.8377 g
Weight of drierite tube before combustion	81.4128 g
Weight of drierite tube after combustion	81.7418 g

Given this data, calculate the empirical formula of compound X: \_\_\_\_\_

A 1.4745 g sample of Y was burned in a combustion apparatus. The results were:

Weight of ascarite tube before combustion	80.7821 g
Weight of ascarite tube after combustion	83.0196 g
Weight of drierite tube before combustion	78.2988 g
Weight of drierite tube after combustion	78.7560 g

Given this data, calculate the empirical formula of compound Y: \_\_\_\_\_



**PART VI**

Before you can titrate your unknowns, you need to first determine the exact molarity of the NaOH solution you are going to use, a process known as standardization. Sodium hydroxide solutions often change concentration if they are exposed to air for long periods, and they are usually checked when first made and after a few days of use.

1. Pour about 150 mL of the approximate 0.2 M NaOH solution into a clean, dry 250 mL beaker which is labeled NaOH. Fill a clean buret with this solution.
2. Into a clean 125 mL Erlenmeyer, place about 0.5 g of KHP acid (KHP = Potassium Hydrogen Phthalate =  $\text{KHC}_8\text{H}_4\text{O}_4$ ; MW of KHP = 204.2 g/mol). Record the exact amount of KHP in the flask.
3. Dissolve the KHP acid in your flask in about 30 mL of DI water. Add about 3 drops of phenolphthalein indicator to the flask.
4. Take the initial buret reading of the level of NaOH, and slowly add NaOH to the flask from the buret. Swirl flask continually. The solution will change from clear to light pink in exactly one drop, so watch closely. If the color disappears with swirling, then you have not reached the endpoint. A dark pink color indicates you have passed the endpoint. When you think you are close to the endpoint, begin to add the NaOH one drop at a time. Record the exact volume of NaOH solution added.
5. Repeat the titration until the molarity is consistent within 0.004 M.

Data for Part VI Standardization:

Recall that at the endpoint, moles  $\text{OH}^-$  = moles  $\text{H}^+$ . Because each mole of KHP contains one acid group, the moles of  $\text{H}^+$  = moles KHP.

Mass KHP acid	_____	_____	_____
Moles KHP acid	_____	_____	_____
Volume of NaOH added	_____	_____	_____
Molarity NaOH	_____	_____	_____
Average Molarity (Use values within limit)	_____	_____	_____

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Now knowing that both compounds X and Y are acidic, you can titrate each using your previously standardized NaOH solution. Moreover, if you could determine the molecular weight using another technique (Part VII), you can ultimately determine how much mass of the compound is “attached” to each acidic proton. This is known as the “gram equivalent weight”.

1. To an empty 250 mL Erlenmeyer flask, add about 0.20 grams of X to the flask (record its exact mass).
2. To the flask, add about 30 mL of DI water and 3 drops of phenolphthalein indicator. Titrate the sample with standardized NaOH solution. The endpoint will be a faint pink color that persists for more than 30 seconds.
3. Repeat the titration until you get two consistent results (within 2%), and compare the mass X / mole  $H^+$  values.

Data for Part VI Titration of Compound X

Mass X	_____	_____	_____
Volume of NaOH added	_____	_____	_____
Moles $OH^-$	_____	_____	_____
Moles $H^+$	_____	_____	_____
Grams X per mole $H^+$	_____	_____	_____
Average grams X per mole $H^+$ (Use values within limit)		_____	
Mole $H^+$ per mole X (Must know molecular weight from Part VII)		_____	

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Repeat the titration using compound Y. Compound Y titrates slowly, and it may take longer for the pink color to persist as Y will still be dissolving during the titration. You may wish to start the titration before Y has completely dissolved. It should dissolve before you are halfway through adding the NaOH solution.

Data for Part VI Titration of Compound Y

Mass Y \_\_\_\_\_

Volume of NaOH added \_\_\_\_\_

Moles OH<sup>-</sup> \_\_\_\_\_

Moles H<sup>+</sup> \_\_\_\_\_

Grams Y per mole H<sup>+</sup> \_\_\_\_\_

Average grams Y per mole H<sup>+</sup>  
(Use values within limit) \_\_\_\_\_

Mole H<sup>+</sup> per mole Y  
(Must know molecular weight from Part VII) \_\_\_\_\_

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Data for Part VII

Mass of compound X \_\_\_\_\_

Mass of H<sub>2</sub>O \_\_\_\_\_Trial 1Trial 2

Freezing temperature of pure water \_\_\_\_\_ = \_\_\_\_\_

Freezing temperature of solution \_\_\_\_\_

 $\Delta T_f$  \_\_\_\_\_

Molecular weight of compound X \_\_\_\_\_

Average Molecular Weight (values must be within 10%): \_\_\_\_\_

**PART VIII**

Chemists generally turn to instrumentation first in most research and industrial settings. In this section, you are going to use two techniques to investigate your compounds.

Mass Spectrometry (MS) is a powerful technique that gives you the molecular weight of most compounds quickly and accurately. It is easy enough to employ that it is used for multiple purposes, for example, to scan luggage for explosive residues in airports. Analysis of the small fragments and exact patterns of the mass spectra is difficult, but finding the molecular weight of the compound is usually trivial. A mass spectrum features various mass-to-charge ratios of charged particles, where unknown compounds are identified by their fragmentation patterns. For this lab, you are looking for the *molecular (or parent) ion* which corresponds to the unknown compound's molecular mass. It is important to note (as you will see) that the molecular ion can be weak with a small height on the actual spectrum; don't assume that the largest peak present in your spectrum necessarily corresponds to the molecular ion peak. Consider the following: does your average molecular weight value from Part VII correlate with any peaks in your mass spectra in Part VIII?

Infrared Spectroscopy (IR), which is more difficult to interpret, gives you information about which type of functional groups are present in a molecule. By comparing peaks to known values, you can determine if your molecule has those types of functional groups.

On the next page are the MS and IR for both compounds. Your instructor will give you guidance about the level of interpretation that is expected. You can find databases of spectra from the SDBS (spectral data base system from Japan's AIST) online to compare these spectra to.

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## Workshop #1: Measurements & Conversions

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1. Round the following numbers to THREE significant figures, and express your final responses using scientific notation.

A. 239,720 \_\_\_\_\_ C. 0.000238505 \_\_\_\_\_

B. 0.09763400 \_\_\_\_\_ D. 7,689,994,656 \_\_\_\_\_

2. Round the following numbers to FOUR significant figures, and express your final responses using scientific notation.

A. 0.00765796 \_\_\_\_\_ C. 423.56 \_\_\_\_\_

B. 56,928.31 \_\_\_\_\_ D. 0.0000555226 \_\_\_\_\_

3. Solve each of the following problems. Express your final answer to the correct number of significant figures in scientific notation. Make certain to include the appropriate units where appropriate.

A.  $382.5 \text{ mL} + 96.31 \text{ mL} - 5.9 \text{ mL}$  \_\_\_\_\_

B.  $\frac{3.496 \text{ ft} + 27.22 \text{ ft}}{5.006 \text{ lb}}$  \_\_\_\_\_

C.  $\frac{(2.661 \times 10^{-3} \text{ cm})(5.11 \times 10^9 \text{ cm})}{7.3 \times 10^7 \text{ cm}}$  \_\_\_\_\_

D.  $\frac{28.62 \text{ s} - 3.5 \text{ s}}{(32.9 \times 10^2 \text{ s})(99.55 \times 10^6 \text{ s})}$  \_\_\_\_\_

E.  $\frac{(6.345 \times 10^{-17})(2.6447 \times 10^{-45})}{4.567 \times 10^5 + 7.89887 \times 10^6}$  \_\_\_\_\_

4. Solve the following problems, conforming to the appropriate number of significant figures. You may need your textbook for certain unit conversions:

A. \_\_\_\_\_ How many centimeters are there in 3.0 miles?

B. \_\_\_\_\_ Convert  $9.06 \times 10^6 \mu\text{m}^2$  to  $\text{mm}^2$ .

Name: \_\_\_\_\_

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- C. \_\_\_\_\_ Convert 45 meters per second to kilometers per hour.
- D. \_\_\_\_\_ Determine the density (in g/mL) of a substance that weighs 0.695 lb and occupies a volume of 3.4 qt.
- E. \_\_\_\_\_ The concentration of carbon monoxide (CO), a common air pollutant, is found in a room to be  $5.7 \times 10^{-3} \text{ mg / cm}^3$ . How many grams of CO are present in the room if the room's dimensions measure  $3.5 \text{ m} \times 3.0 \text{ m} \times 3.2 \text{ m}$ ?
- F. \_\_\_\_\_ A cylindrical piece of metal is 2.03 inches high, has a diameter of 17.0 mm wide, and weighs 31.599 g. Determine its density. Will this object sink or float in water? Volume (cylinder) =  $\pi r^2 h$
- G. \_\_\_\_\_ Zinc sulfide is treated with sulfuric acid, resulting in a solution with some undissolved bits of zinc sulfide and releasing hydrogen sulfide gas. If 10.85 g of zinc sulfide is treated with 50.00 mL of sulfuric acid (density = 1.153 g / mL), 65.15 g of solution plus undissolved solid remain. What is the volume (in L) of hydrogen sulfide gas evolved from this reaction? The density of hydrogen sulfide gas is 1.393 g / L.

5. *APPLICATION!* Nanotechnology, the field of building microscale structures one atom at a time, has progressed in recent years. One potential application of nanotechnology is the construction of artificial cells. The simplest cells could mimic red blood cells, the body's oxygen transporters. For example, nanocontainers, perhaps constructed of carbon, could be pumped full of oxygen and injected into a person's bloodstream. If the person needed additional oxygen, these containers could slowly release oxygen into the blood, allowing tissues that would otherwise die to remain alive. Suppose that nanocontainers were cubic and had an edge length of 25 nanometers.

- A. \_\_\_\_\_ What is the volume (in L) of one nanocontainer?
- B. \_\_\_\_\_ Suppose that each nanocontainer could contain pure oxygen pressurized to a density of 85 g / L. How many grams of oxygen could be contained by each nanocontainer?
- C. \_\_\_\_\_ Normal air contains about 0.28 g of oxygen per liter. An average human inhales about 0.50 L of air per breath and takes about 20 breaths per minute. How many grams of oxygen does a human inhale per hour?
- D. \_\_\_\_\_ What is the minimum number of nanocontainers that a person would need in their bloodstream to provide 1.0 hour's worth of oxygen?

Name: \_\_\_\_\_

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Use the SDS provided in lab to answer the following questions:

1. List other names that are synonyms of sodium hydroxide and its formula.
2. What is its melting point?
3. What is done in case of contact with eyes?
4. How should a small spill be handled?
5. What procedure should be done if the substance is swallowed?
6. What are the NFPA Ratings for Health? Fire? Reactivity? Specific Hazard?
7. List three chemicals that should not be stored with NaOH.
8. How should solid NaOH be properly stored?



Name: \_\_\_\_\_

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Your instructor will assign you a specific chemical compound along with SDS, and you should fill-in the table below with as much information as possible (note: several areas will remain blank) using the various resources listed below:

Name of Substance \_\_\_\_\_

Chemical Formula \_\_\_\_\_

	Reagent Bottle	SDS Sheet	Merck Index	CRC or Lange's
Other Names				
Formula Weight				
State of matter				
Melting point				
Boiling point				
Density				
Percent Composition				
Soluble solvents				
Manufacturer				
Chemical Properties				
Toxicity				

Contrast the differences between the four reference materials used above, and be specific.

Name: \_\_\_\_\_

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## Workshop #3: Nomenclature

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A. Provide a chemical name for the following formulas:

1.  $\text{CuSO}_3$  \_\_\_\_\_

2.  $\text{Hg}_2\text{Cl}_2$  \_\_\_\_\_

3.  $\text{BaCr}_2\text{O}_7$  \_\_\_\_\_

4.  $\text{NO}$  \_\_\_\_\_

5.  $\text{Sr}(\text{OH})_2$  \_\_\_\_\_

6.  $\text{Mn}(\text{NO}_2)_2$  \_\_\_\_\_

7.  $\text{NaHCO}_3$  \_\_\_\_\_

8.  $\text{HNO}_3(\text{aq})$  \_\_\_\_\_

9.  $\text{CsClO}_2$  \_\_\_\_\_

10.  $\text{Ag}_3\text{PO}_3$  \_\_\_\_\_

11.  $\text{V}_2(\text{CrO}_4)_5$  \_\_\_\_\_

12.  $\text{Sn}(\text{MnO}_4)_4$  \_\_\_\_\_

13.  $\text{I}_2\text{O}_7$  \_\_\_\_\_

Name: \_\_\_\_\_

Section: \_\_\_\_\_

B. Provide a formula for the following names:

1. sodium peroxide \_\_\_\_\_

2. copper(II) sulfate pentahydrate \_\_\_\_\_

3. ammonia \_\_\_\_\_

4. sulfurous acid \_\_\_\_\_

5. calcium hydride \_\_\_\_\_

6. ammonium hydrogen phosphate \_\_\_\_\_

7. arsenic(III) sulfate \_\_\_\_\_

8. dichlorine heptoxide \_\_\_\_\_

9. gold(I) iodide \_\_\_\_\_

10. antimony(III) nitride \_\_\_\_\_

11. tin(IV) carbonate \_\_\_\_\_

12. bismuth(III) oxide \_\_\_\_\_

13. mercury(II) perchlorate \_\_\_\_\_

14. pentane \_\_\_\_\_

Name: \_\_\_\_\_

Section: \_\_\_\_\_

C. Provide a chemical name for the following formulas:

1.  $\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$  \_\_\_\_\_

2.  $\text{PbC}_2\text{O}_4$  \_\_\_\_\_

3.  $\text{Au}(\text{ClO})_3$  \_\_\_\_\_

4.  $\text{Cd}(\text{SCN})_2$  \_\_\_\_\_

5.  $\text{CuMnO}_4$  \_\_\_\_\_

6.  $\text{KIO}_3$  \_\_\_\_\_

7.  $\text{ClO}_2$  \_\_\_\_\_

8.  $\text{TiH}_4$  \_\_\_\_\_

9.  $\text{HCl}(\text{g})$  \_\_\_\_\_

10.  $\text{As}(\text{HSO}_4)_3$  \_\_\_\_\_

11.  $\text{SO}_3$  \_\_\_\_\_

12.  $\text{Fe}(\text{OH})_2$  \_\_\_\_\_

13.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$   
(i.e.  $\text{C}_4\text{H}_{10}$ ) \_\_\_\_\_

14.  $\text{CH}_3(\text{CH}_2)_6\text{CH}_3$   
(i.e.  $\text{C}_8\text{H}_{18}$ ) \_\_\_\_\_

Name: \_\_\_\_\_

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D. Provide a formula for the following names:

1. tungsten(V) phosphide \_\_\_\_\_

2. gallium nitrate \_\_\_\_\_

3. carbonic acid \_\_\_\_\_

4. xenon hexachloride \_\_\_\_\_

5. hydrosulfuric acid \_\_\_\_\_

6. lithium dihydrogen phosphite \_\_\_\_\_

7. nonane \_\_\_\_\_

8. lead(IV) oxalate \_\_\_\_\_

9. phosphoric acid \_\_\_\_\_

10. dinitrogen tetroxide \_\_\_\_\_

11. sodium selenate \_\_\_\_\_

12. sodium bicarbonate \_\_\_\_\_

13. hypobromous acid \_\_\_\_\_

14. zinc oxide \_\_\_\_\_

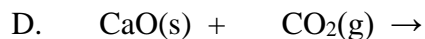
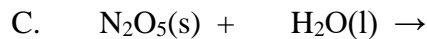
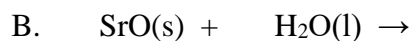
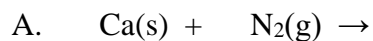
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## Workshop #4: Reactions

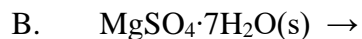
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Predict products and balance the following reactions (write total-ionic and net-ionic where requested). If no reaction takes place, write NR for no reaction. Be sure to include phases.

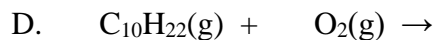
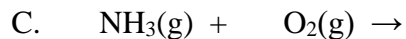
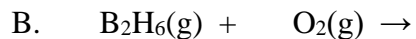
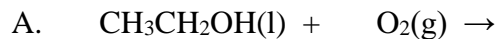
1. Synthesis (Combination or Composition) Reactions:  $A + B \rightarrow AB$

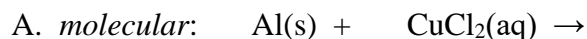
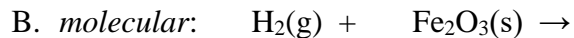
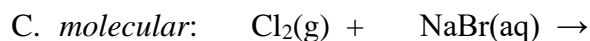
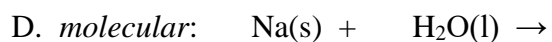
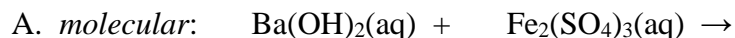
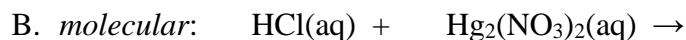


2. Decomposition Reactions:  $AB \rightarrow A + B$



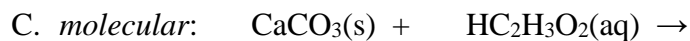
3. Combustion Reactions: *nonmetals* +  $\text{O}_2 \rightarrow$  *nonmetal oxides*:  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{SO}_2$ ,  $\text{NO}_2$



4. Single Replacement (Displacement) Reactions:  $C + AB \rightarrow AC + B$  OR  $CB + A$ *total-ionic:**net-ionic:**total-ionic:**net-ionic:**total-ionic:**net-ionic:**total-ionic:**net-ionic:*5. Double Replacement (Displacement) Reactions:  $AB + CD \rightarrow AD + CB$ *total-ionic:**net-ionic:**total-ionic:**net-ionic:*

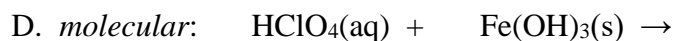
Name: \_\_\_\_\_

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*total-ionic:*

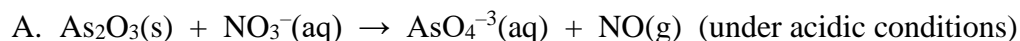
*net-ionic:*



*total-ionic:*

*net-ionic:*

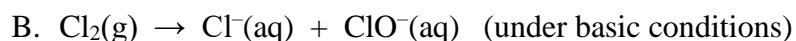
6. Redox (Oxidation-Reduction) Reactions:



*Oxidation half reaction:*

*Reduction half reaction:*

*Balanced reaction:*



*Oxidation half reaction:*

*Reduction half reaction:*

*Balanced reaction:*



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Section: \_\_\_\_\_

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## Workshop #5: Stoichiometry

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Show calculation setups and answers for all problems below.

1. How many molecules are there in a 600.0 g sample of  $\text{Na}_3\text{PO}_4(\text{s})$ ? How many  $\text{Na}^+$  ions are present?

2. A compound of copper and sulfur was produced in the lab by heating copper and sulfur together in a crucible. The following data was collected:

Mass of crucible and cover	28.71 g
Mass of crucible, cover, and copper	30.25 g
Mass of crucible, cover, and copper-sulfur compound	30.64 g

Determine the empirical formula of this compound.

3. Isopentyl acetate ( $\text{C}_7\text{H}_{14}\text{O}_2$ ), the compound responsible for the scent of bananas, can be produced commercially. Calculate the percent composition of  $\text{C}_7\text{H}_{14}\text{O}_2$ .

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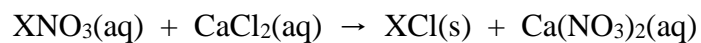
4. A compound consisting of mainly cetyl palmitate is comprised entirely of carbon, hydrogen, and oxygen. Combustion of a 2.3836 g sample of cetyl palmitate produced 6.9807 g of  $\text{CO}_2$  and 2.8575 g of  $\text{H}_2\text{O}$ . Determine the empirical formula of the compound. If the formula weight of the compound is 480.9 g/mol, what is the molecular formula of this compound?
5. Washing soda, a compound used to prepare hard water for laundry, is a hydrate whose formula can be written as  $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$ . When a 2.558 g sample of washing soda is heated at 125 °C, all the water of hydration is lost, leaving behind 0.948 g of the anhydrous salt. Determine the value of  $x$ .

6. Liquid mercury and bromine gas will react under appropriate conditions to produce solid mercury(II) bromide.
- Write the balanced chemical equation for this process.
  - What is the maximum mass of  $\text{HgBr}_2$  that can be produced from the reaction of 10.0 g Hg and 9.00 g  $\text{Br}_2$ ?
  - Determine the remaining mass of each reactant (if any) available upon conclusion of the reaction.
  - If 15.3 g of mercury(II) bromide is produced in this reaction, determine the percentage yield of product.
7. Silicon nitride ( $\text{Si}_3\text{N}_4$ ), a valuable ceramic, is made by the direct combination of silicon and nitrogen at high temperature.
- Write the balanced chemical equation for this process.
  - How many grams of silicon must react with excess nitrogen to prepare 125 g silicon nitride if the yield of the reaction is 85.0%?

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8. Consider the following unbalanced reaction:



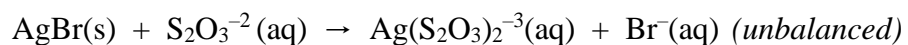
If 30.8 g of  $\text{CaCl}_2$  produced 79.6 g of  $\text{XCl}$ , determine the identity of X. Quantify your response. Random guessing will not earn any credit for this problem!



Name: \_\_\_\_\_

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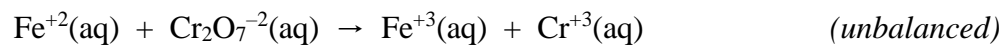
5. The concentration of hydrogen peroxide in a solution is determined by titrating a 10.0 mL sample of the solution with permanganate ion under acidic conditions, producing manganese(II) ion and oxygen gas. If it takes 13.5 mL of 0.109 M  $\text{MnO}_4^-$  solution to reach the equivalence point, what is the molarity of the hydrogen peroxide solution?
  
  
  
  
  
  
  
  
  
  
6. A flask contains 49.8 mL of 0.150 M calcium hydroxide solution. How many milliliters of 0.350 M sodium carbonate are required to react completely with the calcium hydroxide?
  
  
  
  
  
  
  
  
  
  
7. During the developing process of black and white film, silver bromide is removed from photographic film by the fixer. The major component of the fixer is sodium thiosulfate. What mass of silver bromide can be dissolved by 1.00 L of 0.200 M sodium thiosulfate?



Name: \_\_\_\_\_

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8. A 3.33 gram sample of iron ore is transformed to a solution of iron(II) sulfate, and this solution is titrated with 0.150 M potassium dichromate. If it required 41.4 mL of potassium dichromate solution to titrate the iron(II) sulfate solution, what is the percentage of iron in the ore?



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## Workshop #7: Gas Laws

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Show calculation setups and answers for all problems below.

1. A particular balloon is designed by its manufacturer to be inflated to a volume of no more than 2.5 L. The balloon is filled with 2.0 L of helium at sea level (pressure = 1.00 atm), is released, and rises to an altitude at which the atmospheric pressure is only 500.0 mmHg. Assuming that the temperature remains constant, will the balloon burst? Quantify your response and briefly explain.
2. Another balloon is filled with 150 L of helium at 23 °C and 1.0 atm. What volume does the balloon have when it has risen to a point in the atmosphere where the pressure is 220 mmHg and the temperature is -31 °C?
3. Calculate the mass of hydrogen gas needed to fill an 80.0 L tank to a pressure of 2205 psi at 27 °C.
4. What volume does 35 mol of nitrogen gas occupy at STP?
5. The mass of a 3.21 L gas is found to be 3.50 g, measured at 65.0 °C and 500.0 torr. Determine the molar mass of the gas.

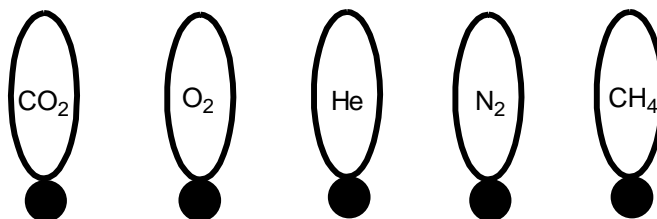


Name: \_\_\_\_\_

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6. Calculate the density of water vapor at 110 °C and 99 kPa.
  
7. A compound with the empirical formula  $\text{BH}_3$  was found to have a vapor density of 1.24 g / L at STP. Determine the molecular weight AND the molecular formula of this gas.
  
8. Consider the reaction of solid copper(I) sulfide with oxygen gas to produce solid copper(I) oxide and gaseous sulfur dioxide.
  - A. Write the balanced chemical equation for this process.
  
  - B. What volume of oxygen gas, measured at 27.5 °C and 0.998 atm, is required to react with 25 g of copper(I) sulfide?
  
9. A sample of solid potassium chlorate is decomposed, forming solid potassium chloride and gaseous oxygen. The oxygen produced was collected by displacement of water at 22 °C at a total pressure of 754 torr. The volume of the gas collected was 0.65 L, and the vapor pressure of water at 22 °C is 21 torr.
  - A. Write the balanced chemical equation for this process.
  
  - B. Determine the mass of potassium chlorate in the sample that was decomposed.

10. Represented below are five identical balloons, each filled to the same volume at 25 °C and 1.0 atm pressure with the pure gases indicated.



- A. Which balloon contains the greatest mass of gas? Explain.
- B. Compare the average kinetic energies of the gas molecules in the balloons. Explain.
- C. Which balloon contains the gas that would be expected to deviate most from the behavior of an ideal gas? Explain.
- D. Twelve hours after being filled, all the balloons have decreased in size. Predict which balloon will be the smallest. Explain your reasoning.
11. Calculate the root-mean-square speed ( $u_{\text{rms}}$ ) for:
- A. a xenon atom at 298 K;
- B. an oxygen molecule at 298 K.
12. Both hydrogen and helium have been used as buoyant gases in blimps. If a small leak were to occur in a blimp filled with both gases, which gas would effuse more rapidly and by what factor?

Name: \_\_\_\_\_

Section: \_\_\_\_\_

13. A gas of unknown molecular mass was allowed to effuse through a small opening under constant pressure conditions. It required 72 s for the gas to effuse. Under identical experimental conditions, it required 28 s for O<sub>2</sub> gas to effuse. Determine the molar mass of the unknown gas.

14. Calculate the pressure exerted by 50.0 g CO(g) in a 1.00 L container at 25 °C by:

Useful information: For CO,  $a = 1.49 \text{ atm L}^2/\text{mol}^2$  and  $b = 0.0399 \text{ L/mol}$

A. using the ideal gas law, and

B. using the van der Waals equation.

15. Compare the results from parts A and B. Does CO(g) behave ideally under these conditions? Briefly explain why or why not.

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## Workshop #8: Thermochemistry

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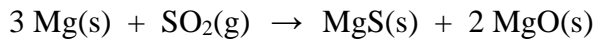
Show calculation setups and answers for each question. *Please note that your instructor may opt to assign specific questions from those listed below.*

1. Calculate the change in internal energy (in J) for a balloon that is heated by adding 215 cal of heat. It expands, doing 422 J of work on the atmosphere.
2. Consider the following *balanced* reaction:  $\text{CH}_3\text{OH}(\text{g}) \rightarrow \text{CO}(\text{g}) + 2\text{H}_2(\text{g})$ , where  $\Delta H = +90.7 \text{ kJ}$ . If the enthalpy change is 16.5 kJ, how many grams of hydrogen gas are produced?
3. A 50.00 g sample of an unknown substance absorbed 2.578 kJ of energy as it changed from a temperature of 25.0 °C to 89.7 °C. What is the specific heat of this unknown substance (in J/g °C)?
4. An alloy of mass 25.0 g was heated to 88.6 °C and then placed in a calorimeter that contained 61.2 g of water at 19.6 °C. The temperature of the water rose to 21.3 °C. Determine the specific heat of the alloy (in J/g °C).
5. 100.0 g of copper metal, initially at 100.0 °C, is added to a calorimeter containing 250.0 g of H<sub>2</sub>O at 15.0 °C. If the specific heat of copper is 0.389 J/g °C, what is the final temperature of the water and copper mixture?

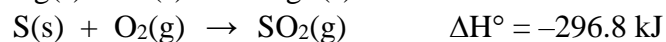
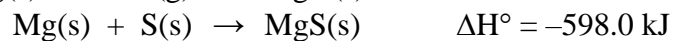
Name: \_\_\_\_\_

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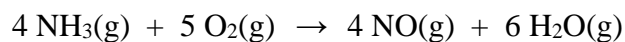
6. The chemical equation for the combustion of magnesium in sulfur dioxide is



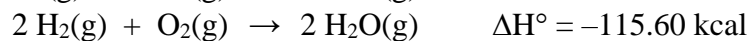
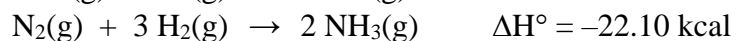
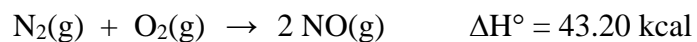
Calculate the  $\Delta H^\circ_{\text{rxn}}$  (in kJ) given the following thermodynamic data:



7. Consider the following thermochemical equation:



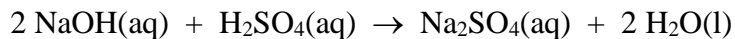
Determine the  $\Delta H^\circ_{\text{rxn}}$  (in kcal) given the following thermochemical data:



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8. Consider the neutralization reaction of sodium hydroxide and sulfuric acid in a coffee-cup calorimeter.



100.0 mL of 1.00 M aqueous NaOH is mixed with 100.0 mL of 1.00 M aqueous H<sub>2</sub>SO<sub>4</sub>, each at 24.0 °C, were mixed. The maximum temperature achieved was 30.6 °C. Calculate the enthalpy change of reaction (in kJ/mol) of Na<sub>2</sub>SO<sub>4</sub> produced. The specific heat of the reaction is known to be 4.184 J/g °C. The density of the reaction mixture is 1.00 g/mL. Assume the volumes are additive.

9. Suppose 50.0 mL of HCl is combined with 100.0 mL of 1.05 M NaOH in a coffee-cup calorimeter. The reaction mixture, initially at 22.0 °C, reached a final temperature of 30.2 °C. Determine the molarity of the HCl solution assuming all of the HCl reacted and that NaOH is present in excess. The specific heat of the reaction is known to be 0.96 cal/g °C, and the heat of neutralization is 13.6 kcal/mol. The density of the reaction mixture is 1.02 g/mL. Assume the volumes are additive.

The simplest atomic spectrum is that of the *hydrogen atom*. In 1886, Balmer showed that the lines in the spectrum of the hydrogen atom had wavelengths that could be expressed by a rather simple equation. In 1913, Bohr explained the spectrum on a theoretical basis with his famous model of the hydrogen atom. According to Bohr's theory, the energies  $E_n$  allowed to a hydrogen atom are all given by the following equation:

$$E_n = \frac{-B}{n^2} \quad (2)$$

where B is the constant,  $2.178 \times 10^{-18}$  J and n is an integer, 1, 2, 3, ..., called a quantum number. It has been found that all the lines in the atomic spectrum of hydrogen can be associated with differences between atomic energy levels which are predicted with great accuracy by Bohr's equation.

There are several ways in which one might analyze an atomic spectrum, given the energy levels of the atom, but a simple and powerful method is to calculate the wavelengths of some of the lines that are allowed and see if they match those which are observed. We shall use this method in our workshop.

### A. Energy Levels of Hydrogen

Given the expression for  $E_n$  in Equation 2, calculate the energy (in joules) for each of the levels of the H atom missing in the table below. Notice that the energies are all negative, so that the lowest energy will have the largest allowed negative value. Enter these values in the table of energy levels below:

Table One

Quantum Number	Energy, $E_n$ , in joules	Quantum Number	Energy, $E_n$ , in joules
1	$-2.178 \times 10^{-18}$ J	6	
2		7	
3		8	
4		10	$-2.178 \times 10^{-20}$ J
5		$\infty$	ZERO Joules

(Workshop continued on next page)

**B. Calculation of Wavelengths in the Spectrum of the Hydrogen Atom**

The lines in the hydrogen spectrum all arise from jumps made by the atom from one energy level to another. The wavelengths in nanometers of these lines can be calculated by Equation 1, where  $|\Delta E|$  is the positive difference in energy between any two allowed levels. By rearranging Equation 1 it is possible to solve for wavelengths:

$$\lambda = \frac{hc}{|\Delta E|} \quad (3)$$

After putting in some constants we can solve for wavelength in nanometers.

$$\lambda = \frac{(6.626 \times 10^{-34} \text{ J}\cdot\text{sec})(3.00 \times 10^8 \text{ m / sec})}{|\Delta E|} \times \frac{1 \text{ nm}}{10^{-9} \text{ m}} \quad (4)$$

Calculate the  $|\Delta E|$  and wavelength for all the jumps indicated in the table below. Write  $|\Delta E|$ , the difference in energy in J between  $E_{n,hi}$  and  $E_{n,lo}$ , in the upper half of the box, and in the lower half of the box, write the  $\lambda$  (in nm) associated with that value. The box for the  $n_2 \rightarrow n_1$  transition is filled in for you.

Table Two

$n_{\text{higher}}$ $n_{\text{lower}}$	6	5	4	3	2	
1					$1.634 \times 10^{-18}$	$ \Delta E $ (J)
					121.6	$\lambda$ (nm)
2					$ \Delta E $ (J)	
					$\lambda$ (nm)	
3				$ \Delta E $ (J)		
				$\lambda$ (nm)		
4			$ \Delta E $ (J)			
			$\lambda$ (nm)			
5		$ \Delta E $ (J)				
		$\lambda$ (nm)				

(Workshop continued on next page)



**C. Assignment of Wavelengths**

Compare the wavelengths you have calculated in Table Two with those listed in Table Three. You should notice that many wavelengths match within the error of your calculation. Fill in the quantum numbers of the upper and lower states for each line whose origin you can recognize by comparison of your calculated values with the observed values. Several wavelengths will not match at all; place those in Table Four and estimate the expected  $n_{hi} \rightarrow n_{lo}$  following the trends. Note that Table Two only covers transitions with  $n_{hi}$  less than or equal to six. Check your estimations by solving for  $\Delta E$  and wavelengths as you did on Table Two using  $n_{hi}$  numbers greater than six.

Table Three

Wavelength	$n_{hi} \rightarrow n_{lo}$	Wavelength	$n_{hi} \rightarrow n_{lo}$	Wavelength	$n_{hi} \rightarrow n_{lo}$
97.25		410.17		1,005.0	
102.57		434.05		1,093.8	
121.57	2 $\rightarrow$ 1	486.13		1,281.8	
388.91		656.28		1,875.1	
397.01		954.62		4,050.0	

Table Four: Wavelengths you cannot assign using Table Two data

Observed Wavelength (in nm)	Predicted transition $n_{hi} \rightarrow n_{lo}$	Calculated $\Delta E$ (in J)	Calculated Wavelength $\lambda$ (in nm)
388.91			

(Workshop continued on next page)

**D. The Balmer Series**

When Balmer formulated his famous series for hydrogen in 1886, he was limited experimentally to wavelengths for the visible and near ultraviolet regions from 250 nm to 700 nm. All the lines in his series lie in this wavelength range. All transitions in the Balmer Series have  $n_{\text{final}} = 2$ .

1. What would be the longest POSSIBLE wavelength for a line in the Balmer Series?

\_\_\_\_\_ nm

2. What would be the shortest POSSIBLE wavelength for a line in the Balmer Series?

\_\_\_\_\_ nm

In a normal hydrogen atom, the electron is in the *lowest* energy state. The maximum energy of an electron in the hydrogen atom is 0 J, at which point the electron is in the  $n = \infty$  state, essentially removed from the atom. At this point, ionization has occurred.

3. How much energy in joules does it take to ionize the hydrogen atom?

\_\_\_\_\_ J

4. The ionization energy you have calculated is for one electron in a single hydrogen atom. Calculate the ionization energy for one mole of H atoms.

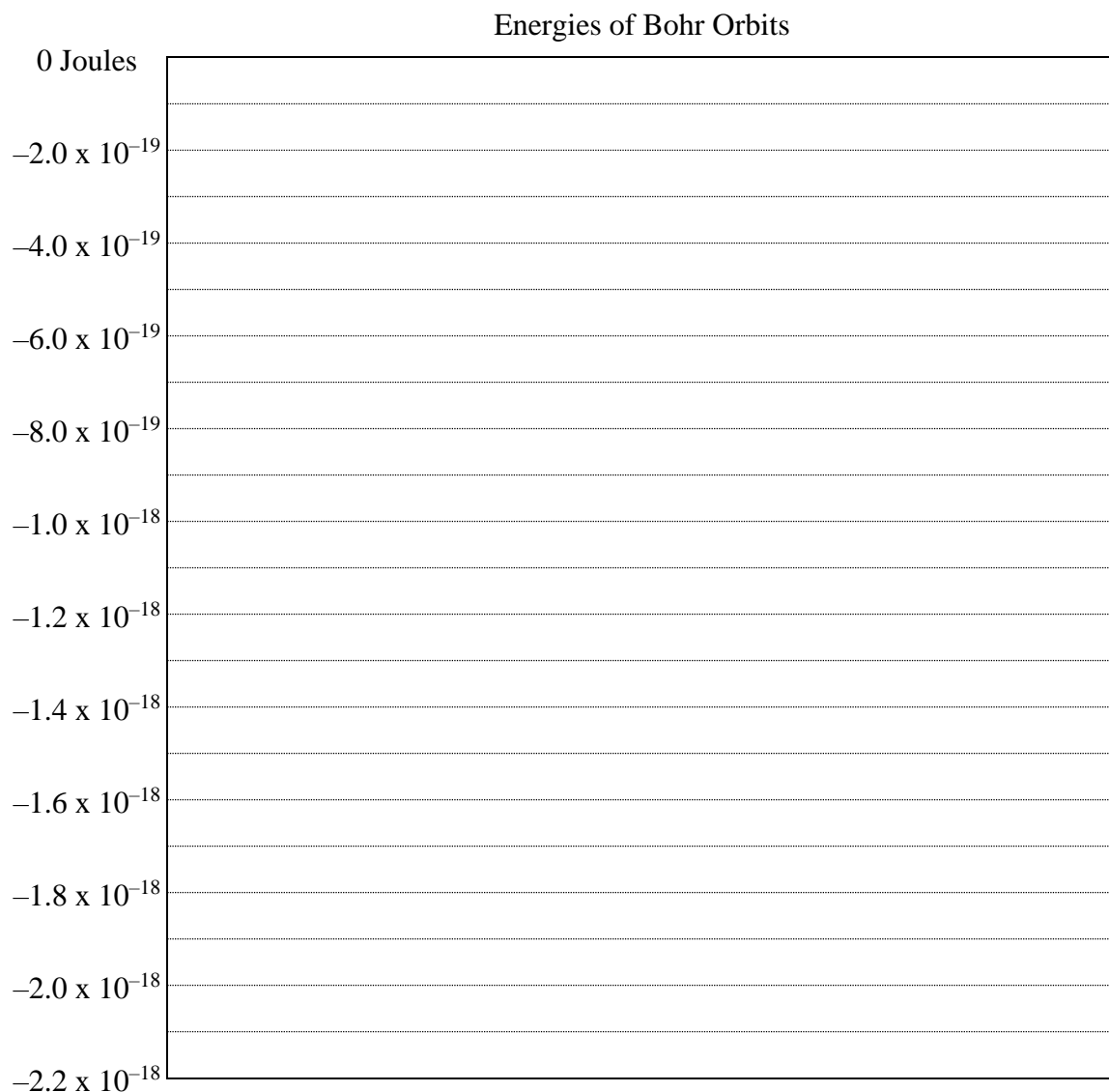
SHOW CALCULATIONS:

\_\_\_\_\_ kJ / mole

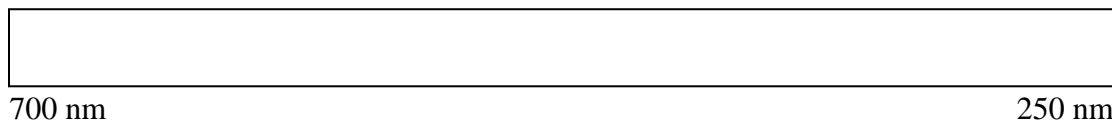
(Workshop continued on next page)

**E. Energy Levels of Hydrogen Atom**

Show each of the first six lowest energy states in the chart below using the values from Table One. Draw horizontal lines for each level and identify them by writing its quantum number on the right side. Use vertical arrows to show the electron transitions calculated in Table Three.

**F. Hydrogen Line Spectra**

Draw the line spectra for hydrogen as it would appear in the visible region showing the lines calculated in Table Three within the Balmer Series.



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## Workshop #10: Quantum Mechanics and Chemical Periodicity

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Many important facts and laws in chemistry are experimentally determined, and then rationalized in terms of a theory or artificial concept. The Periodic Law is one of these. It is based on experiment and rationalized in terms of structural concepts. This form of the Periodic Table may be explained on the basis of the order in which the electrons occupy the various energy levels. Actually, the Periodic Table is based on experiment and serves as a guide to the order in which electron-filling of shells takes place.

A relationship between the *s*, *p*, *d*, and *f* orbitals and the Periodic Table may be observed by noting that the long form of the table can be divided into blocks. One of the blocks is two elements wide, another six elements wide, a third ten elements wide, and a fourth is fourteen elements wide, respectively. Specific sections of each period and each period in the table arise from the filling of orbitals of roughly equal energy.

1. For the first problem, complete the following table for the main group elements:

Group Number	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
Number of valence electrons				4				
Electronic configuration of valence electrons. Omit principle quantum number.				$s^2p^2$				
Common oxidation states.				$\pm 4$				

(Workshop continued on next page)

Name: \_\_\_\_\_

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2. For the next problem, consider the chart below, which represents the main group (representative elements) portion of the Periodic Table.

A. Several trends in atomic properties are listed to the sides and below the chart. Convert the lines into arrows by adding arrow heads to each line to indicate the direction of each trend (i.e.  $\rightarrow$  or  $\leftarrow$ ).

B. In each box, write the electronic configuration of all the valence electrons for that element. Example: see the box containing element 84 (polonium)

	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA or 0
	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18
	19	20	31	32	33	34	35	36
	37	38	49	50	51	52	53	54
	55	56	81	82	83	84 $6s^2 6p^4$	85	86
	87	88						

Nonmetallic Properties IncreaseAtomic Radii IncreaseElectronegativity IncreasesIonization Energy IncreasesMetallic Properties IncreaseAtomic Radii IncreaseIonization Energy IncreasesElectronegativity Increases

(Workshop continued on next page)

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3. In each square shown below, write the principal quantum number and orbital letter of the expected last electron to enter the atom in its ground state. For this exercise, ignore the exceptions. (*Four of them have been done for you.*)

	IA 1											III A 13					IV A 14	V A 15	VIA 16	VII A 17	VIII A 18
1	1																				2
2	3	II A 2	4											5	6	7	8	9	10		
3	11	12	III B 3		IV B 4	V B 5	VI B 6	VII B 7	---VIII B --- 8 9 10		IB 11	II B 12	13	14	15	16	17	18			
4	19	20	21	22	23	24	25	26	27	28	29	30 <i>3d</i>	31	32	33	34	35	36			
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52 <i>5p</i>	53	54			
6	55	56 <i>6s</i>	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
7	87	88	89	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118			

6	58	59	60	61	62	63	64	65	66 <i>4f</i>	67	68	69	70	71
7	90	91	92	93	93	95	96	97	98	99	100	101	102	103

4. A. Fill in the following table:

Quantum number $l$	0			3
Orbital Designation		$p$	$d$	

- B. What  $m_l$  values are possible for the  $d$  orbitals?

- C. What  $m_s$  values are possible?

Name: \_\_\_\_\_

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5. Determine the quantum numbers for all six electrons in the  $4p$  sublevel.

Electron	$n$	$l$	$m_l$	$m_s$
$4p^1$				
$4p^2$				
$4p^3$				
$4p^4$				
$4p^5$				
$4p^6$				

6. For the sets of quantum numbers below, identify its electron configuration (if possible). If not possible, explain what is wrong.

$n$	$l$	$m_l$	$m_s$	electron configuration or explanation of problem
2	0	-1	$-\frac{1}{2}$	_____
4	2	1	$-\frac{1}{2}$	_____
2	0	0	$+\frac{1}{2}$	_____
5	-1	1	0	_____

7. Determine the maximum number of electrons contained in:

A.  $d$  sublevel \_\_\_\_\_      B. valence (outer) shell \_\_\_\_\_  
 C. a single orbital \_\_\_\_\_      D. energy level  $n = 4$  \_\_\_\_\_

8. Write FOUR isoelectronic species for the  $Al^{+3}$  ion, two cations and two anions.

9. Identify the elements which have no electron with the quantum number  $l = 1$ .

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10. Consider the bismuth (Bi) atom.

A. Write the complete (start with 1s) and shortened (noble gas in brackets) electronic configuration for bismuth. Make certain to place brackets around the closed shell (core) electrons and identify valence electrons and pseudo-core electrons.

B. Draw the orbital diagram for all of the electrons in Bi.

C. Is Bismuth paramagnetic or diamagnetic?

D. Write the set of quantum numbers describing only valence electrons in Bi.

E. Write the shortened electronic configuration for the bismuth ions below:

$\text{Bi}^{+3}$  ion \_\_\_\_\_  $\text{Bi}^{+5}$  ion \_\_\_\_\_



Name: \_\_\_\_\_

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11. A. Calculate the wavelength (in nm) of light with frequency  $2.31 \times 10^{14}$  Hz.

B. Visible light has wavelengths between 400 to 700 nm. Slightly longer wavelengths are infrared (IR) and shorter are ultraviolet (UV). Is electromagnetic radiation from  $2.31 \times 10^{14}$  Hz found to be IR, Vis, or UV?

12. A. Solve for the wavelength (in nm) caused by a hydrogen electron jumping from  $n = 6$  to  $n = 3$ .

B. Is this photon in the visible, IR, or UV portion of the spectrum?

C. What is the frequency (in  $s^{-1}$ ) for this photon?

D. Calculate the energy of this photon in both J/photon and in kJ/mol.

13. The compound known as Sunbrella, which is the active ingredient in some sunscreens, absorbs strongly around 266 nm. What is the frequency of the absorption (in MHz)?

Name: \_\_\_\_\_

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14. For the last problem, fill in the following table for the various chemical species

Species	Short electronic configuration	“Short” Orbital Diagram	Quantum numbers of last e <sup>-</sup>	Configuration of valence electrons	Common oxidation state(s)
O	[He] 2s <sup>2</sup> 2p <sup>4</sup>	He] $\begin{array}{c} \uparrow\downarrow \\ 2s \end{array} \quad \begin{array}{c} \uparrow\downarrow \\ 2p \end{array} \quad \begin{array}{c} \uparrow \\ 2p \end{array} \quad \begin{array}{c} \uparrow \\ 2p \end{array}$	2, 1, -1, 1/2	2s <sup>2</sup> 2p <sup>4</sup>	-2
Si					
K					
Sr					
Cr					Varies
Mn					Varies
Ga					
As					
Mo <sup>+2</sup>					N/A
Fe <sup>+3</sup>					N/A
Ag <sup>+</sup>					N/A

Name: \_\_\_\_\_

Section: \_\_\_\_\_

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## Workshop #11: Intermolecular Forces

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For the first part of this workshop, identify the type of crystal structure (Ionic, Molecular Polar, Molecular Nonpolar, Network-Covalent, or Metallic) present. Then determine the type of binding forces present in each (Ionic Bonds, Covalent Bonds, Metallic Bonds, London Dispersion Forces, Dipole Forces, and/or Hydrogen Bonds).

Substance	Type of Crystal	Type of Binding Force(s)
Ar		
CH <sub>3</sub> Cl		
CH <sub>3</sub> OH		
BCl <sub>3</sub>		
CH <sub>3</sub> OCH <sub>3</sub>		
HF		
Hg		
KCl		
N <sub>2</sub>		
SiC		
CH <sub>3</sub> COOH		
Diamond		

Name: \_\_\_\_\_ Section: \_\_\_\_\_

Circle the species with the higher boiling point and *briefly* justify your choice below.

1) Kr \_\_\_\_\_ or Xe \_\_\_\_\_  
Justification:

2) C<sub>2</sub>H<sub>5</sub>OH \_\_\_\_\_ or CH<sub>3</sub>OCH<sub>3</sub> \_\_\_\_\_  
Justification:

3) NaF \_\_\_\_\_ or MgO \_\_\_\_\_  
Justification:

4) N<sub>2</sub> \_\_\_\_\_ or NO \_\_\_\_\_  
Justification:

5) CH<sub>4</sub> \_\_\_\_\_ or SiH<sub>4</sub> \_\_\_\_\_  
Justification:

6) HF \_\_\_\_\_ or HI \_\_\_\_\_  
Justification:

7) CO<sub>2</sub> \_\_\_\_\_ or NH<sub>3</sub> \_\_\_\_\_  
Justification:

8) CH<sub>4</sub> \_\_\_\_\_ or CCl<sub>4</sub> \_\_\_\_\_  
Justification:

9) Cr \_\_\_\_\_ or Si \_\_\_\_\_  
Justification:

10) H<sub>2</sub>O \_\_\_\_\_ or SiO<sub>2</sub> \_\_\_\_\_  
Justification:

11) MgO \_\_\_\_\_ or BaO \_\_\_\_\_  
Justification:

12) CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>3</sub> \_\_\_\_\_ or (CH<sub>3</sub>)<sub>2</sub>CHCH<sub>2</sub>CH<sub>3</sub> \_\_\_\_\_  
Justification:

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## Workshop #12: Vapor Pressure

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The stronger the intermolecular forces that exist between liquid molecules, the less likely they will escape into the vapor phase. Boiling point (which you explored in Workshop #11) and vapor pressure are both good measures of intermolecular forces. In the following problem set, you will analyze some provided “experimental” data in order to calculate the vapor pressure of a liquid.

Vapor pressure is defined as the pressure of a vapor that is in equilibrium with its liquid. It is controlled by 2 factors:

1. temperature – the higher the temperature, the greater kinetic energy the liquid molecules possess; therefore, they vaporize more readily, hence increasing the vapor pressure.
2. molar heat of vaporization,  $\Delta H_{\text{vap}}$  – the energy required to change a liquid to a gas at its boiling point. The stronger the intermolecular forces, the harder it is to pull liquid molecules apart, and therefore the higher its  $\Delta H_{\text{vap}}$ , which decreases its vapor pressure.

The Clausius-Clapeyron Equation relates the three quantities vapor pressure,  $\Delta H_{\text{vap}}$ , and temperature according to the equation:

$$\ln \text{VP} = -\frac{\Delta H_{\text{vap}}}{RT} + B$$

Notice this equation fits the slope-intercept form  $y = mx + b$ , so if  $\ln \text{VP}$  is plotted against  $1/T$ , a straight line results with  $-\Delta H_{\text{vap}}/R$  as the slope. You will use this equation and the provided “experimental” data to calculate an unknown liquid’s  $\Delta H_{\text{vap}}$  and its boiling point at a particular temperature. Consider the following:

	Temperature, t, (in °C)	Heights of Manometer Mercury Levels (in mm)		Vapor Pressure (in mmHg or torr)
		<u>open to atm</u>	<u>atm + VP trapped on gas side</u>	
1.	1.2	250	228	_____
2.	21.1	265	205	_____
3.	40.0	297	142	_____
4.	Boiling Point: 76 °C		Barometric Pressure: 752 torr	

Name: \_\_\_\_\_

Section: \_\_\_\_\_

Now fill in the following table to prepare for the graph:

t, °C	T, Kelvin	1 / T, K <sup>-1</sup>	VP, mmHg	ln VP
1.2				
21.1				
40.0				

Graph ln VP vs. 1 / T on Microsoft Office Excel<sup>®</sup> (see Experiment #2 in this lab manual for directions on using Excel<sup>®</sup>). According to the Clausius-Clapeyron equation, the slope is equal to  $-\Delta H_{\text{vap}} / R$ . Using  $R = 8.314 \times 10^{-3} \text{ kJ / mole}\cdot\text{K}$ , calculate  $\Delta H_{\text{vap}}$  for the liquid:

$$\text{slope} = \Delta y / \Delta x = \Delta(\ln \text{VP}) / \Delta(1/T) = \text{_____} = -\Delta H_{\text{vap}} / R \text{ (rearrange to solve for } \Delta H_{\text{vap}})$$

SHOW CALCULATION:

Therefore,  $\Delta H_{\text{vap}} = \text{_____} \text{ kJ / mole}$

From the graph, you can also calculate what the liquid's boiling point should be at the "experimental" barometric pressure. Recall that boiling point is the temperature where the vapor pressure is equal to the atmospheric pressure.

"Experimental" barometric pressure \_\_\_\_\_ mmHg  
(= the VP needed for boiling)

ln (barometric pressure) \_\_\_\_\_

1 / T at this vapor pressure \_\_\_\_\_ K<sup>-1</sup> (from the graph)

T at this pressure \_\_\_\_\_ K

t at this pressure \_\_\_\_\_ °C (= the predicted boiling point)

"Experimental" boiling point \_\_\_\_\_ °C

*Make sure to submit your properly labeled graph when submitting this Workshop!*

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## Workshop #13: Colligative Properties

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Show calculation setups and answers for all problems below.

1. List the following aqueous solutions in the order of expected DECREASING FREEZING POINT: 0.075 *m* glucose; 0.075 *m* LiBr; 0.030 *m* Zn(NO<sub>3</sub>)<sub>2</sub>.
2. The normal freezing point of pure naphthalene is measured to be 80.29 °C. When 32.21 g of the nonelectrolyte urea (CH<sub>4</sub>N<sub>2</sub>O) is dissolved in 751.36 g of naphthalene, the freezing point is measured to be 75.34 °C. What is the molal freezing point depression constant ( $K_f$ ) for naphthalene?
3. When 132.0 g of C<sub>6</sub>H<sub>6</sub> ( $P^\circ = 93.96$  torr) and 147.0 g of C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub> ( $P^\circ = 224.9$  torr) are combined, what is the total vapor pressure of the ideal solution?
4. Calculate the freezing point of a solution of 22.0 g of carbon tetrachloride dissolved in 800.0 g of benzene ( $K_f = 5.12$  °C / *m*; normal freezing point = 5.5 °C).
5. What mass of NiSO<sub>4</sub>·6H<sub>2</sub>O must be dissolved in 500. g of water to produce 0.33 *m* NiSO<sub>4</sub>(aq)?

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6. What is the normal boiling point of an aqueous solution that has a freezing point of  $-1.04\text{ }^{\circ}\text{C}$ ?

Note: For water,  $K_f = 1.86\text{ }^{\circ}\text{C}/m$ ;  $K_b = 0.512\text{ }^{\circ}\text{C}/m$

7. Assuming complete dissociation, calculate the freezing point of a  $0.100\text{ }m$  aqueous solution of  $\text{K}_2\text{SO}_4$  (ignore any interionic attractions).

Note: For water,  $K_f = 1.86\text{ }^{\circ}\text{C}/m$

8. When  $2.25\text{ g}$  of an unknown nonelectrolyte was dissolved in  $150.\text{ g}$  of cyclohexane, the boiling point increased by  $0.481\text{ K}$ . Determine the molar mass of the compound.

Note:  $K_b(\text{cyclohexane}) = 2.79\text{ K}/m$

9. A  $0.50\text{ g}$  sample of *immunoglobulin G*, a nonvolatile nonelectrolyte, is dissolved in enough water to make  $0.100\text{ L}$  of solution, and the osmotic pressure of the solution at  $25\text{ }^{\circ}\text{C}$  is found to be  $0.619\text{ torr}$ . Calculate the molecular mass of *immunoglobulin G*.



10. When 2.74 g of phosphorus is dissolved in 100.0 mL of carbon disulfide, the boiling point is 319.71 K. Given that the normal boiling point of pure carbon disulfide is 319.30 K, its density is 1.261 g / mL, and its boiling-point elevation constant is  $K_b = 2.34 \text{ K} / m$ , determine the molar mass of phosphorus.
11. A solution of biphenyl ( $\text{C}_{12}\text{H}_{10}$ ), a nonvolatile nonelectrolyte, in benzene has a freezing point of 5.4 °C. Determine the osmotic pressure of the solution at 10 °C if its density is 0.88 g / cm<sup>3</sup>.  
*Note:* normal freezing point (benzene) = 5.5 °C;  $K_f = 5.12 \text{ }^\circ\text{C}/m$
12. Consider these two solutions: Solution A is prepared by dissolving 5.00 g of  $\text{MgCl}_2$  in enough water to make 0.250 L of solution, and Solution B is prepared by dissolving 5.00 g of KCl in enough water to make 0.250 L of solution. Which direction will solvent *initially* flow if these two solutions are separated by a semipermeable membrane?
13. Assuming that the volumes of the solutions described in question #12 are additive and ignoring any effects that gravity may have on the osmotic pressure of the solutions, what will be the *final* volume of solution A when the net solvent flow through the semipermeable membrane stops?