Wizardry and Chemistry Lab Handout

BACKGROUND

The key instrument of every successful wizard is his/her wand. This wand is chosen by the up-in-coming wizard and is unique to that wizard.

> *"Harry took the wand. He felt a sudden warmth in his fingers. He raised the wand above his head, brought it swishing down through the dusty air and a stream of red and gold sparks shot from the end like a firework, throwing dancing spots of light onto the walls."*

However, in the Muggle world, we never use magic wands, but perhaps use something similar to a wand—SPARKLERS! Why the sparkler? This fantastic spell (light) caster is unique to the creator and ignites with brilliant colors, just as Harry's wand did for him.

Today you are muggle chemists making your own fast-acting magic wands. To complete this task, you must read and understand the cautionary note below. ⬇

CAUTION!! The ingredients that you will be using are reactive when exposed to certain conditions and are to be handled as instructed and with care.
Following the instructions ensures that the materials are safe for handling.

MATERIALS

Sparkler 1: "Gryffindor"
- 5 g iron powder (-200 mesh)
- 1.0 g magnesium powder (-325 mesh)
- 7.0 g aluminum powder (-40 + 325 mesh)
- 6 g barium nitrate
- 25 g potassium nitrate

Sparkler 2: "Slytherin"
- 10 g iron powder (-200 mesh)
- 1.0 g magnesium powder (-325 mesh)
- 2.0 g aluminum powder (-40 + 325 mesh)
- 6 g potassium nitrate
- 25 g barium nitrate

Other General Materials:
- 9 g dextrin (starch)
- 20 ml distilled water
- 20 cm length 2 mm diameter Fe wire
- 150 ml beaker
- stir rod
- hot plate
- 18 x 150 mm test tube and test tube rack
- oven capable of 120°C
- apron, goggles and fume hood
- wash bottle
- (optional) hair dryer

PROCEDURE

1. Place 9 g of dextrin in a 150 ml beaker and add 15ml distilled water.

2. While stirring, heat the starch mixture gently; heat until it makes a paste.

3. Using separate weighing dishes under the fume hood, measure to the nearest gram the listed ingredients. Make sure all container lids are sealed tightly after each use.

4. Remove the beaker from the heat and add inorganic ingredients to the starch solution and stir. Perform this step under the fume hood until the mixture is uniform.

5. Pour/scrape the entire mixture into a test tube.

6. Quickly, dip iron wire into test tube, making sure to have an even coat along the length of the submerged wire. NOTE: If the mixture is too dry, add a few drops of distilled water and mix.

7. Pull the coated wire out of test tube and begin drying the paste using a hair dryer positioned approximately 10 cm away from the coated wire.

8. During drying, rotate the wire to keep the paste on the wire.

9. Once the mixture is no longer runny, stand the coated wire in the test tube rack.

10. To dry thoroughly, place the rack in an oven set at 120° C for one to three hours.

11. Give waste material in test tube to your teacher for proper disposal.

12. Wash all glassware using a wash bottle, taking care to dispose of the liquid and remaining sludge into a material waste container.

13. When finished cleaning up, complete the problem set.

*** Problem Set on Next Page ***

Wizardry and Chemistry Problem Set

1. Nitrates are stable at room temperature but decompose rapidly when sufficient heat is applied. Additionally, when nitrates decompose they form nitrites. For barium and potassium nitrates the newly formed nitrites are unstable. What happens if the newly formed nitrites are not stable? Do they react to form new products? Write a brief explanation along with the overall decomposition reaction for barium nitrate and potassium nitrate. Make sure your chemical equations are balanced.

   Answers
   - **If nitrites are not stable, they rapidly decompose, liberating the remaining oxygen atoms and nitrogen to produce N_2 and O_2 gas to react with surrounding metal particles. If they are stable, then the necessary oxygen would not be completely liberated along with nitrogen. Hence the ejection power decreases along with metal powder oxidation.**
   - **$2Ba(NO_3)_{2(s)} \rightarrow 2BaO_{(s)} + 2N_{2(g)} + 5O_{2(g)}$ (complete decomposition reaction)**
   - **$4KNO_{3(s)} \rightarrow 2K_2O_{(s)} + 2N_{2(g)} + 5O_{2(g)}$ (complete decomposition reaction)**

2. Sparklers eject glowing metal particles for entertainment. What reaction products from the above equations propel these metal particles?

   Answer
   - **Diatomic nitrogen and diatomic oxygen**

3. Fe, Al and Mg are very reactive in the presence of oxygen at elevated temperatures. Write and balance the respective reactions. Show which element is the oxidizing agent and which is the reducing agent.

   Answer
   - **$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$ (O = oxidizing agent, Mg = reducing agent)**
   - **$2Fe_{(s)} + O_{2(g)} \rightarrow 2FeO_{(s)}$ (O = oxidizing agent, Fe = reducing agent)**
   - **$4Al_{(s)} + 3O_{2(g)} \rightarrow 2Al_2O_{3(s)}$ (O = oxidizing agent, Al = reducing agent)**

4. Based on your sparkler chemistry what is the gas composition produced from the overall decomposition of potassium nitrate?

Answer (Gryffindor sparkler)

$$25g\ KNO_3 * \left(\frac{1\ mol\ KNO_3}{101.11\ g\ KNO_3}\right) * \left(\frac{2\ mol\ N_2}{4\ mol\ KNO_3}\right) = 0.124\ mol\ N_2$$

$$25g\ KNO_3 * \left(\frac{1\ mol\ KNO_3}{101.11\ g\ KNO_3}\right) * \left(\frac{5\ mol\ O_2}{4\ mol\ KNO_3}\right) = 0.309\ mol\ O_2$$

$$n_{tot} = n_{O_2} + n_{N_2}$$

$$mol\%\ N_2 = \frac{0.124\ mol\ N_2}{0.124 + 0.309} * 100 = 28.64\%\ N_2$$

$$mol\%\ O_2 = \frac{0.309\ mol\ O_2}{0.124 + 0.309} * 100 = 71.36\%\ O_2$$

Answer (Slytherin sparkler)

$$6g\ KNO_3 * \left(\frac{1\ mol\ KNO_3}{101.11\ g\ KNO_3}\right) * \left(\frac{2\ mol\ N_2}{4\ mol\ KNO_3}\right) = 0.030\ mol\ N_2$$

$$6g\ KNO_3 * \left(\frac{1\ mol\ KNO_3}{101.11\ g\ KNO_3}\right) * \left(\frac{5\ mol\ O_2}{4\ mol\ KNO_3}\right) = 0.074\ mol\ O_2$$

$$n_{tot} = n_{O_2} + n_{N_2}$$

$$mol\%\ N_2 = \frac{0.030\ mol\ N_2}{0.030 + 0.074} * 100 = 28.85\%\ N_2$$

$$mol\%\ O_2 = \frac{0.074\ mol\ O_2}{0.030 + 0.074} * 100 = 71.15\%\ O_2$$

5. Based on your overall barium nitrate and potassium nitrate decomposition equations, calculate the enthalpy (KJ) for each reaction at room temperature. Are both reactions exothermic or endothermic? Predict the sign of the entropy term and explain the temperature dependence this term has on the spontaneity of each reaction.

Enthalpies of formation at room temperature (KJ/mol)			
$Ba(NO_3)_2$	KNO_3	BaO	K_2O
-988.00	-494.628	-548.104	-363.171

Answer calculation is based on one sparkler type. Same procedure applies for both.
o **Gryffindor reaction 1: barium nitrate**

$$\Delta H = \sum n_{products} * \Delta H^o_{298\,products} - \sum n_{Reactants} * \Delta H^o_{298\,reactants}$$

$$\Delta H = 0.0230 * (-988) - \left(0.0230 * (-548.104)\right) = -10.118\ KJ, Exothermic$$

o **Gryffindor reaction 2: potassium nitrate**

$$\Delta H = \sum n_{products} * \Delta H^o_{298\,products} - \sum n_{Reactants} * \Delta H^o_{298\,reactants}$$

$$\Delta H = 0.247 * (-494.628) - \left(0.1235 * (-363.171)\right) = -77.321\ KJ, Exothermic$$

Answer: Entropy for both nitrate decomposition reactions will most likely be positive considering the solid decomposes into a solid plus additional gas.

Answer: Because the entropy term is largely positive along with a large negative enthalpy, both reactions are spontaneous over all temperatures.

6. Given the thermodynamic data below, calculate the free energy and equilibrium constant for each metal powder oxidation reaction. Rank the reactions in order from least spontaneous to most spontaneous and explain what this means in terms of reactivity with oxygen.

Gibb's free energy of formation (KJ/mol)		
Al_2O_3	MgO	FeO
-1569.663	-568.945	-251.429

Answer
o $\Delta G_{FeO} = 2 * (-251.429) = -502.858 \frac{KJ}{mol}$, **least spontaneous**

o $\Delta G_{MgO} = 2 * (-568.945) = -1137.89 \frac{KJ}{mol}$, **second most spontaneous**

o $\Delta G_{Al_2O_3} = 2 * (-1569.663) = -3179.326 \frac{KJ}{mol}$, **most spontaneous**

Answer
o **Most spontaneous species react with oxygen first until all has been consumed. Whatever excess oxygen remains reacts with the second most spontaneous species; then least.**

o **This tells you that aluminum and magnesium are strong oxygen scavengers. Deoxidizers is the technical term.**

7. At room temperature, barium nitrate and potassium nitrate decomposition is spontaneous. However, both are relatively stable at room temperature and begin to decompose when the temperature is raised. Explain the following: Room temperature decomposition kinetics; temperature influence on reaction rate; reaction rate between the two nitrates based on their thermodynamic nature.

Given:
ΔG_{rxn} KNO_3 Decomposition = -934.232 KJ/mol

ΔG_{rxn} $Ba(NO_3)_2$ Decomposition = -544.436 KJ/mol
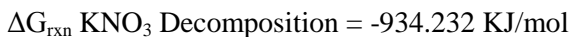
Answer
- o **At room temperature, both reaction kinetics are extremely slow, which accounts for the stability of both nitrates at room temperature.**

- o **However, application of heat to either nitrate supplies the necessary driving force to drive both reactions to completion. This can be explained by an energy barrier present intermediate to the start and finishing state.**

- o **Once both reactions proceed, the potassium nitrate proceeds at a faster rate. This might be explained by the large amount of sensible heat available from decomposition. This heat must be absorbed by the reaction products, which raises the temperature of the products. This temperature increase may supply an additional driving force to react the remainder of potassium nitrate.**

- o **Potassium nitrate may react at a lower temperature than barium nitrate, reducing the driving force needed for reaction.**

8. Assuming that all of the barium nitrate and potassium nitrate completely decompose, how much oxygen is available to react with the powder metals present in your sparkler composition? Calculate the amount of excess oxygen present, if any. *HINT: More spontaneous reaction preferentially react first, then the second and finally the third reaction.*

Answers: (NOTE: The calculations below are for Gryffindor sparklers only. The procedure is identical for Slytherin sparklers.)

$$25g\ KNO_3 * \left(\frac{1\ mol\ KNO_3}{101.11\ g\ KNO_3}\right) * \left(\frac{5\ mol\ O_2}{4\ mol\ KNO_3}\right) = 0.309\ mol\ O_2$$

$$6g\ Ba(NO_3)_2 * \left(\frac{1\ mol\ KNO_3}{261.33\ g\ KNO_3}\right) * \left(\frac{5\ mol\ O_2}{4\ mol\ KNO_3}\right) = 0.0574\ mol\ O_2$$

$$O_{2\ Total} = 0.309 + 0.0574 = 0.366$$

$$7g\ Al * \left(\frac{1\ mol\ Al}{26.98\ g\ Al}\right) * \left(\frac{3\ mol\ O_2}{4\ mol\ Al}\right) = 0.195\ mol\ O_2\ Consumed$$

$$.75g\ Mg * \left(\frac{1\ mol\ Mg}{24.305g\ Mg}\right) * \left(\frac{1\ mol\ O_2}{2\ mol\ Mg}\right) = 0.015\ mol\ O_2\ Consumed$$

$$5g \, Fe * \left(\frac{1 \, mol \, Fe}{55.85 \, g \, Fe}\right) * \left(\frac{1 \, mol \, O_2}{2 \, mol \, Fe}\right) = 0.045 \, mol \, O_2 \, Consumed$$

$$O_{2 \, Excess} = 0.366 - 0.195 - 0.015 - 0.045 = 0.111$$

- o **Answer Cont: Slytherin sparkler**

$$O_{2 \, Excess} = 0.313 - 0.056 - 0.015 - 0.090 = 0.152$$

- o **Answer Cont: Excess O_2 may be contributing to oxide ejection along with N_2.**