EXPERIMENT 12M

FV 6/6/12

INVESTIGATING FACTORS THAT AFFECT ΔT, q_{rxn}, AND ΔH OF NEUTRALIZATION

MATERIALS: Coffee cup and lid, stir bar, magnetic stir plate, digital thermometer, two 100 mL graduated cylinders (for transport and measure of the acids and bases). Approximately 175 mL 1.0 M HCl, 50 mL 2.0 M HCl, 25 mL H_2SO_4, 300 mL 1.0 M NaOH, 50 mL 2.0M NaOH.

PURPOSE: To determine the temperature change, heat of reaction, and enthalpy change for a series of acid-base neutralization reactions.

OBJECTIVES: By the end of this experiment, the student should be able to:

1. Calculate ΔH for a given reaction using thermodynamic data from tables.
2. Determine ΔH experimentally for a given reaction using a coffee cup calorimeter.
3. Predict how thermodynamic values change when varying the quantity or concentration of reactants.

PRE-LAB: Read the entire lab guide and instructions and complete the attached pre-lab assignment.

BACKGROUND:

The neutralization of an acid with a base in aqueous solution is an exothermic process. The heat transferred in this process (q_{rxn}) can be measured using a calorimeter. Calorimeters can be very complicated and expensive (bomb calorimeters, isothermal calorimeters, differential scanning calorimeters, etc.) however a simple aqueous calorimeter can be made from any well insulated cup, such as a styrofoam coffee cup.

In this experiment, we will assume that no heat escapes or is absorbed by the coffee cup. Making this assumption, the energy transferred to the liquid inside the cup approximates the total energy released by the reaction. Therefore the heat of the calorimeter (q_{cal}) approximates the heat transferred to the liquid (q_{soln}) and it is the negative of q_{rxn}.

$$q_{cal} \approx q_{soln} \approx -q_{rxn} \tag{1}$$

The heat evolved by the neutralization reaction is transferred to the solution and can be measured as a temperature change where:

$$q_{soln} = m_{soln} \cdot s_{soln} \cdot \Delta T_{soln} \tag{2}$$

In addition, we will assume that the specific heat of the solution is the same as that of the solvent (water), therefore s_{soln} = 4.184 J/g °C.

ΔH_{rxn} (the enthalpy change for a reaction) is often expressed in units of kJ/mol. When expressed in this unit, ΔH_{rxn} is the amount of heat released or absorbed (at constant pressure) **per mole of reaction**. (The unit for ΔH_{rxn} is sometimes written as kJ/mol_{rxn} to emphasize this point.) In this lab you will calculate ΔH_{rxn} as the enthalpy change associated with the formation of one mole of H_2O through the process of acid/base neutralization. Since every mole of reaction produces one mole of water, this is also the enthalpy change for one mole of reaction. The total amount of heat produced by a reaction is given by:

$$q_{rxn} = n\Delta H_{rxn} \tag{3}$$

where n is moles of reaction (moles of water produced) so:

$$\Delta H_{rxn} = \frac{q_{rxn}}{n} = -\frac{q_{cal}}{n} \approx -\frac{q_{soln}}{n} \tag{4}$$

You will calculate q_{soln} using equation 2 and your measured temperature change. You will calculate the moles of water produced (n) using the moles of reactants added and the stoichiometry of the reaction. You will assume that the reaction goes to completion (the limiting reactant is completely consumed).

PROCEDURE:

(Caution: Hydrochloric acid, sulfuric acid, and sodium hydroxide are corrosive and toxic.)

1. Construct a polystyrene-cup calorimeter, as demonstrated by your instructor.

2. For each of the five experimental conditions (below), perform the following protocol:

   a. Place the acid in the calorimeter and monitor the temperature for 1 min, in order to ensure a stable initial temperature. Do not puncture the calorimeter with the thermometer.

   b. Record the initial temperature.

   c. Add the base to the calorimeter, and quickly stir the solution.
   (Make sure that you use a different graduated cylinder for the acid and base solutions to avoid mixing the reagents before the experiment is started.)

   d. Monitor the temperature of the solution as it rises, and record the maximum temperature once it begins to drop again.

   e. Dispose of the reaction solution by pouring down the drain and rinse the stir bar and calorimeter with distilled water. There is no need to dry the cup between expts.

Experiment 1: 50.0 mL 1.00 M hydrochloric acid and 50.0 mL 1.00 M sodium hydroxide.
Experiment 2: 100.0 mL 1.00 M hydrochloric acid and 100.0 mL 1.00 M sodium hydroxide.
Experiment 3: 50.0 mL 2.00 M hydrochloric acid and 50.0 mL 2.00 M sodium hydroxide.
Experiment 4: 25.0 mL 1.00 M hydrochloric acid and 75.0 mL 1.00 M sodium hydroxide.
Experiment 5: 25.0 mL 1.00 M sulfuric acid and 75.0 mL 1.00 M sodium hydroxide.

3. Calculate the ΔT for each experiment. Compare your ΔT values to those of the group next to you. If any ΔT values differ by more than $0.5^{\circ}C$, repeat that experiment together.

Clean-up/Disposal:

1. All solutions can be rinsed down the drain with plenty of water.
2. Rinse your calorimeter, stir bar, and any other glassware used.
3. Return equipment to their proper locations and clean up your lab area.

Name ____ Section # ______________

EXPERIMENTAL DATA – Expt. 12M:

Experiment #	Initial Temp (°C)	Maximum Temp (°C)	ΔT (°C)

DATA TREATMENT:

Calculate the following for each of your five experiments:

a. number of moles of H^+ initially present
b. number of moles of OH^- initially present
c. number of moles of H_2O produced
d. temperature change
e. heat released during the reaction (in joules)
f. enthalpy for the reaction (in *kilojoules per mole of water formed*)

Record your answers in the table provided below:

Experiment number	Initial mol H^+, mol	Initial mol OH^-, mol	mol H_2O produced, mol	ΔT, °C	Mass of solution g	q_{rxn}, J	ΔH_{rxn}, kJ/mol

QUESTIONS:

1. In Pre-Laboratory Question 3, you made temperature change predictions for four variations of Experiment 1. Does your experimental data support your predictions? For each incorrect prediction, describe the error in your initial reasoning.

2. a. Does doubling the volumes of acid and base in a neutralization reaction double the amount of heat released? Explain.

   b. Does doubling the concentrations (but not the volumes) of acid and base in a neutralization reaction double the amount of heat released? Explain.

3. a. Experiments 2 and 3 both produced twice as much heat as experiment 1. Explain why ΔT for experiment 2 was the same as that for experiment 1 and why ΔT for experiment 3 was twice that for experiment 1.

b. Experiments 1 and 4 each have a total reaction solution volume of 100.0 mL and use 1.00 M hydrochloric acid and 1.00 M sodium hydroxide. How do you account for their different q_{rxn} and ΔT?

b. Experiments 4 and 5 each use 25.0 mL of a 1.00 M strong acid and 75.0 mL of 1.00 M sodium hydroxide. How do you account for their different q_{rxn} and ΔT?

4. Despite changes in reaction conditions (volume, concentration, monoprotic vs. diprotic acid), ΔH_{rxn} (in kJ/mol) for each reaction was approximately the same. Explain why.

5. Based on a total reaction volume of 100.0 mL, what volumes of 1.00 M sulfuric acid and 1.00 M sodium hydroxide will produce the greatest amount of heat?

Name ______________________________________ Section # ____________

PRE-LABORATORY ASSIGNMENT – Expt. 12M

Read the Background and Procedure sections of the lab and answer the following questions <u>before</u> the lab period. Show your work for all calculations.

1. a. Write the molecular and **net** ionic equations for the reaction of aqueous hydrochloric acid and aqueous sodium hydroxide.

   b. Write the molecular and **net** ionic equations for the reaction of aqueous sulfuric acid and aqueous sodium hydroxide (assume a ratio of 2 moles NaOH per 1 mole H_2SO_4).

2. a. When 50.0 mL of 1.00 M hydrochloric acid and 50.0 mL of 1.00 M sodium hydroxide react, the temperature rises 6.5°C. Use the total solution volume, density of water, and specific heat of water to calculate the heat absorbed by the solution, q_{soln}, during this reaction. (See equation 2 on page 12M-1.)

   b. Calculate the amount of heat released, q_{rxn}, by this acid-base reaction. (See equation 1.)

   c. Calculate the moles of hydrogen ion and hydroxide ion initially present, and the moles of water produced in this reaction.

d. Calculate the ΔH (in kJ/mol) for the reaction forming 1 mole of water. (See equation 4.)

3. The neutralization of 50.0 mL of 1.00 M hydrochloric acid with 50.0 mL of 1.00 M sodium hydroxide causes a 6.5°C increase in temperature. Predict how the following changes to the experimental protocol would affect the value of the change in temperature. Explain your answers.

   Hint: According to equations 1-3 given above:

$$\Delta T_{soln} = \frac{q_{soln}}{m_{soln} s_{soln}} = -\frac{q_{rxn}}{m_{soln} s_{soln}} = -\frac{n\Delta H_{rxn}}{m_{soln} s_{soln}}$$

   Since ΔH_{rxn} and s_{soln} are constants, the temperature change depends on the moles of water produced (moles of reaction) and the mass of the solution. Assume that the density of each solution is 1.0 g/mL.

   a. using 100.0 mL of 1.00 M hydrochloric acid and 100.0 mL of 1.00 M sodium hydroxide

   b. using 50.0 mL of 2.00 M hydrochloric acid and 50.0 mL of 2.00 M sodium hydroxide

   c. using 25.0 mL of 1.00 M hydrochloric acid and 75.0 mL of 1.00 M sodium hydroxide

   d. using 25.0 mL of 1.00 M sulfuric acid and 75.0 mL of 1.00 M sodium hydroxide (Be careful. Think about the value of n!)