SODIUM HYDROXIDE AND HYDROCHLORIC ACID

(A study comparing the heats of a multi-step reaction to the same reaction done in 1 step)

SAFETY CAUTION: Sodium hydroxide, NaOH, is a strong base and hydrochloric acid, HCl(aq), is a strong acid. These substances are extremely corrosive to metals and to flesh. Do not place solid NaOH directly on the balance pans, use a sealed vial. If small amounts of solutions are spilled, use the appropriate compound from the spill kit to neutralize or wash the area thoroughly with water. If these substances get on you or your clothes, wash the affected area immediately under a stream of water. If large spills occur, inform the instructor immediately.

You will be investigating the enthalpy changes of a series of related reactions in this experiment.

I. **Reaction #1**

NaOH(s) → NaOH(aq)

A. Carefully place a clean, dry 150 mL beaker inside a 250 mL beaker (***WHY?***). Place a magnetic stir bar in the 150-mL beaker. Using appropriate glassware, dispense 100.0 mL of room temperature deionized water to the 150-mL beaker. Clamp the temperature probe so that the tip is immersed but not too close to the stir bar. The stir bar should be spinning fast enough to make a slight "dimple" in the surface of the solution, but should not pull a vortex into the liquid.

B. Computer program set up: Open Logger Pro. The system should automatically set up for a temperature vs. time experiment. Adjust the data collection limits to permit at least 360 *seconds* of reaction time, sampling each second.

C. Duplicate the table for Reaction #1 shown below in your lab notebook. Weigh between 4.0-7.5 grams of NaOH pellets, ***as assigned by your instructor***, in the vial. Record the mass of NaOH to ±0.001g. Be sure to replace the lid on the reagent bottle and the vial as soon as possible and close it tightly.
Record the "baseline" temperature of the water before the NaOH is added by clicking the *Collect* button on the tool bar (if prompted to 'Erase latest', select Yes.). When the temperature appears to be stable (after a few seconds), add the weighed sample of solid NaOH. Be sure that the stirring continues. Continue collecting data until 2-3 minutes beyond the point at which the temperature is highest. {Click the *Stop* button to end the data acquisition before 360 seconds if necessary.} When data collection is complete, cover the beaker containing the NaOH solution with Parafilm™, label the beaker "Reaction #1" and ***save it*** for use in Part IV. Rinse the temperature probe thoroughly with distilled water and dry it with a tissue.

Reaction #1

a. Volume of water (mL)	________
b. Temperature before adding NaOH(*s*), T_i (˚C)	________
c. Extrapolated temperature of mixture, T_f (˚C)	________
d. Temperature rise ΔT OF THE WATER (˚C)	________
e. heat produced BY THE REACTION, q(J)	________
f. mass of NaOH(*s*) used (g)	________
g. moles of NaOH(*s*)	________
h. heat/mol NaOH(*s*), ΔH_1 (kJ/mol)	________

Class Mean (ΔH_1) (kJ/mol)_________ ± ________kJ/mol

II.A Determination of Temperature Rise, ΔT (˚C)
Note that in this experimental setup, the "system" (the solution in the beaker) is **not** an isolated system and finding ΔT is **not** a trivial exercise. You should discuss with your instructor the proper method for determining ΔT.

Be sure that each person saves or prints a properly formatted Time vs. Temperature graph.

B. Calculate the number of moles of NaOH, the heat produced during the dissolution and the heat produced per mole of NaOH(*s*) for this reaction. You may *assume*, as an approximation, that:

1. The specific heat of the solution is the same as that of H_2O (4.184J/g·˚C),
2. The mass of the solution is the mass of the water only, and
3. The density of the solution is the density of water, i.e.1.00 g/mL.

These approximations will have an effect on the error in your measurements and must be discussed in order for you to receive full credit.

C. Pool your group's data with other groups in your lab for the heat/mole of NaOH data for reaction #1. Be sure that the pooled data covers values from the whole range of masses studied (4-7.5 g of NaOH).

III. **Reaction #2**

$$\mathbf{NaOH(s) + HCl(aq) \rightarrow H_2O(l) + NaCl(aq)}$$

A. Duplicate the table for reaction #2 and #3 shown below and record the exact concentration of stock HCl solution in your lab notebook. Obtain about 200 mL of stock HCl (~ 2 M) solution in a labeled beaker and use the appropriate glassware to transfer 100.0 mL of the solution into a clean, dry 150 mL beaker nested in a 250 mL beaker as in reaction #1. If you use the same beaker as you did in reaction #1 be sure that it has cooled down to room temperature before adding the solution to it. {This is a source of error in this experiment.} Set up the temperature probe and turn the stirrer on as before.

B. Weigh approximately the same mass of NaOH pellets as before. Record the mass to ±0.001 g. Stir the HCl solution and begin recording "baseline" temperature data as before. Transfer the weighed solid NaOH sample to the HCl solution and be sure that stirring continues during data collection. When you are finished collecting data, use litmus paper to test for the acidic/ basic nature of the resulting solution. Which reagent was excess and which was limiting?

C. Determine ΔT for this run and calculate ΔH_2 for reaction #2.

IV. **Reaction #3**

$$\mathbf{NaOH(aq) + HCl(aq) \rightarrow H_2O(l) + NaCl(aq)}$$

A. Using a clean, dry graduated cylinder measure 50.0 mL of the NaOH solution from Part I and pour it into a clean, dry 150-mL beaker nested inside a 250-mL beaker.
Using another clean, dry graduated cylinder measure 50.0 mL of the ~2.0 M stock HCl solution and leave it in the graduated cylinder. Use the temperature probe to measure the temperature of both the HCl solution and the NaOH solution before mixing. Rinsed and dry the temperature probe before moving it from one solution to the other.

B. Begin recording baseline temperature data for the NaOH solution as before and then carefully and quickly add the 50.0-mL of HCl solution from the graduated cylinder to the NaOH solution (do not splash the solution). Continue recording data for 2-3 minutes beyond the time when the highest temperature is reached, and test the final solution with litmus paper to determine the limiting reagent.

C. Determine ΔT for reaction #3. If the initial temperatures of the two solutions are different, how should these temperatures be handled in determining ΔT for the reaction?

Concentration of Stock HCl solution (M) _______________

Reaction #2 (NaOH solid)		**Reaction #3** (NaOH solution)	
a. solution volume (mL)	________	a. Initial temp. of NaOH (*aq*), (˚C)	________
b. temperature just before adding NaOH(*s*), T_i (˚C)	________	b. Initial temp. of HCl(*aq*), (˚C)	________
c. Extrapolated temperature of mixture, T_f (˚C)	________	c. Mean initial temp, T_i (˚C)	________
d. ΔT (˚C)	________	d. Extrapolated temperature of mixture, T_f (˚C)	________
e. heat produced, q(J)	________	e. Temp rise ΔT (˚C)	________
f. mass of NaOH(*s*)	________	f. Total solution volume (mL)	________
g. moles of NaOH(*s*)	________	g. heat produced, q (J)	________
h. moles of HCl in 100.0mL	________	h. mass of NaOH(*s*) used	________
i. litmus test result*	________	i. moles of NaOH(*s*) used	________
j. limiting reagent	________	j. moles of HCl used	________
k. heat/mol NaOH(*s*), ΔH_2 (kJ/mol)	________	k. litmus test result*	________
		l. limiting reagent	________
		m. heat/mol NaOH(aq), ΔH_3 (kJ/mol)	________

*litmus test is performed after the completion of data acquisition.

Reaction #2 Class Avg. (ΔH_2) kJ/mol ________ ± ________kJ/mol

Reaction #3 Class Avg. (ΔH_3) kJ/mol ________ ± ________kJ/mol

VA. Calculate the number of moles of NaOH, the joules of heat produced by reaction #3, and the joules <u>per mole of NaOH</u> for reaction #3. You may make the same assumptions as above.
Note that calculations are part of a complete report/hand-in so don't just let your partner do the calculations; know how to do them yourself.

B. Again, pool your group's data with other groups in the laboratory and determine the class average value for the heat per mole of NaOH for reactions #2 and #3.

Include the titled Time vs. Temperature graphs for reactions #2 and #3, and all calculations and data tables with your hand-in or report.

VI. **This section is a large part of what the whole experiment is about. You should address the following items in your report/hand-in.**

A. Consider the reaction at the 'atomic, ionic/molecular level' in each of the three reactions you studied. What is really happening in each one? How are the three reactions *related* to each other?

B. Is there a relationship between the (ΔH_i) values for the three reactions that is consistent **(within experimental error)** with the relationship between the reactions themselves that you noted in VI.A above? If so, explain your reasoning carefully.

C. The principle you have discovered here is generally associated with the name of the chemist who first described this principle. Find in your text the name of this chemist and write out the way the principle is stated in your text. Note: This will be much easier to do using your text instead of Google!

VII. **Other Acid/Base Reactions: Net-Ionic Equations**

In this section we will be investigating the role that each of the ions has on the reactions that we have been studying in the previous sections. You will have two additional solutions available to you: KOH(aq, ~1.5 M) and HNO_3(aq, ~2 M). Using these new solutions and any solutions from the earlier sections, design and carry out two additional reactions that are similar in reaction type to that of Reaction #3 above (strong aqueous base reacting with a strong aqueous acid). **CAUTION: Before proceeding with your planned reactions discuss your plan with your laboratory instructor. If you have bad data because your experiments are poorly planned it is impossible to interpret the data correctly and as a result your grade for this experiment will suffer.**

For <u>each</u> of the reactions you perform in this section do the following.

A. Give the reaction a number (#4 – #6) and write a balanced chemical equation for the reaction in your laboratory manual being sure to include the state of each reactant and product.

B. Before performing the reaction prepare a data table in your lab manual similar to the table used for Reaction #3 above. Note that the grams of NaOH line is not needed for these reactions. You can find the moles of the base from the volume and molarity of the base.

C. When dispensing the acids and bases use beakers to obtain enough of the reagent to bring back to your bench. Do not dispense more than you anticipate using as this wastes reagents and adds to disposal costs. Think before dispensing chemicals.

D. Measure the temperature change for the reaction and print/save a copy of the graph of time vs. temperature for the reaction.

E. Calculate the enthalpy change, ΔH_i, for the reaction in kJ/mol of base used.

F. Find at least three other groups in the lab that did the same experiment as you did and obtain their value of ΔH° for the exact same reaction. Using your and your classmates values for ΔH°, calculate the error for the reaction, that is, the ± _____ kJ/mol value for ΔH°.

G. Write the net-ionic equation for the reaction.

VIII. **This section is the rest of what the whole experiment is about. You should address the following items in your report/hand-in.**

A. How do the values of ΔH for the reactions you designed compare with the value of ΔH_3 **(within experimental error)** determined for reaction #3? Is this what you would expect considering the net-ionic equations for **all** of these different reactions? Explain your answer.

B. **Application**

Consider the following chemical reaction and its associated value of ΔH.

Reaction #7 $KOH(s) \rightarrow KOH(aq)$

$\Delta H_7 = -57.4^{kJ}/_{mole}$

Using the concepts developed in sections VI and VII, predict the ΔH for the reactions below. Explain in words the basis of your prediction.

Reaction #8 $KOH(s) + HCl(aq) \rightarrow KCl(aq) + H_2O$

Reaction #9 $KOH(s) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O$

C. Finally, in the lecture portion of this course you should have learned how to calculate the expected value of $\Delta H_{rxn}°$ by using tabulated values (either $\Delta H_f°$, or $\Delta H_{ac}°$) for reactants and products.
Calculate $\Delta H_{rxn}°$ using the approach you learned in lecture for the reactions you performed. Explain any differences between the ΔH˚ values determined from your experiments and the values calculated only from tabulated enthalpy data. It might be a good idea to make a small table showing the experimental and calculated values for these reactions as well as a % difference for each reaction.