Thermochemistry: The Heat of Neutralization

Safety

Solid NaOH is a severe contact hazard. Avoid touching it! HCl and NaOH solutions are both contact hazards. Wear goggles at all times since NaOH is a severe danger to eyes. Rinse off any spilled solutions with water or neutralizer. Wash your hands thoroughly before leaving lab.

Note: There are two concentrations of HCl on the reagent shelf: 1.00 M and 2.00 M. Be sure to check the concentration required in each procedure below.

Procedure

1. **Neutralization of HCl solution with NaOH solution:** You will use two coffee-cup calorimeters and an accurate digital thermometer. Place about 50 mL (measure it exactly) of 2.00 M HCl in one calorimeter and about 50 mL (measured exactly) of 2.00 M NaOH in the other. Record the **exact volumes** of solutions used in your data table on page 5. Allow the solutions to stand for a couple of minutes, and record the initial temperatures as accurately as possible, rinsing and drying the thermometer between readings. Now pour the NaOH solution into the HCl calorimeter, replace the lid and thermometer, and swirl the calorimeter to mix the solutions. Start timing when the NaOH solution is added, and read and record the temperature every 30 seconds. Continue swirling and recording the temperatures until the temperature has reached a maximum and has remained decreased only slightly for at least **ten** consecutive readings. Rinse the calorimeters.

2. **Heat of dissolution of NaOH:** Measure 100 mL of distilled water (record the exact volume in your data table) into one of the calorimeters, and allow it to come to a constant temp. The stockroom has estimated 4-g samples of NaOH pellets for you. Obtain one vial from the instructor's station and weigh it (including lid and contents). Add the complete contents of the vial to your distilled water in the calorimeter with continuous **vigorous** swirling. Again, start timing at the time of addition, and read the thermometer every 30 seconds until the temperature has reached a maximum and has remained constant (or slightly decreased) for at least the last ten consecutive readings. Be sure that the NaOH pellets dissolve as soon as possible after addition. Reweigh the empty vial (including lid) and subtract this mass from the total mass (pellets, vial, and lid) to obtain the exact weight of NaOH used.

3. **Heat of reaction of solid NaOH and 1.00 M HCl:** Add the second vial (weighed) of NaOH pellets to 100.0 mL of 1.00 M HCl using the same technique as above. Again record the mass of the empty vial and lid when your reaction is complete to determine the exact mass of NaOH used.

Graphing ΔT:

To calculate the enthalpy changes for the reactions, you will need to know the change in temperature for the contents of the calorimeter. If there were no "heat leaks" in the calorimeter, you could just subtract the initial temperature from the final temperature to obtain ΔT. Since a Styrofoam cup is not a perfect insulator, some heat will leak through the walls and top of the cup, and you are not able to observe the highest temperature that would have been achieved for your system. However, you need to know the maximum temperature the solution would have obtained if there had been no "heat leaks" because that is actually your final temperature (T_f). Graphing the experimental data (Excel) will allow you to extrapolate to determine this temperature.

Directions for Using Excel to plot the data

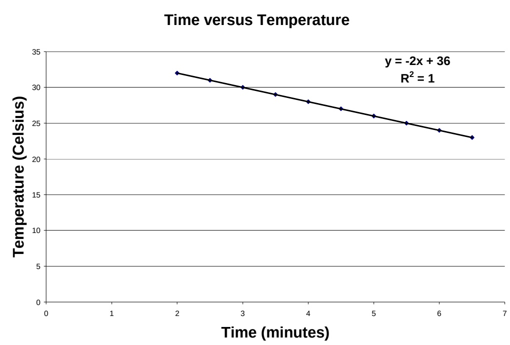
Enter your data with Time in the first column (A) and Temperature in the second column (B).

Select the cells in columns A and B ***starting with the maximum temperature*** and continuing to the end of your data collection. Follow the steps below to insert the data points representing the **decreasing** temperature values as a linear plot.

- Insert (menu option at the top of the page)
  - Select Chart (if you don't see it, maximize the page until it appears)
  - Scatter
  - Select Scatter with only Markers
- Right-click the data points in the graph.
  - Select the "Add Trendline" option.
  - Select the Linear option.
  - At the bottom of the page, select "Display Equation on Chart" and "Display R-squared value on chart". The y-intercept value will represent the Final Temperature for each reaction (if there hadn't been heat leaks).
  - Click OK.
- Double click in the chart.
  - Select the Quick Layout Option in the picture menu at the top of the screen. This will show chart and axis title options. Click in each area to appropriately label you graph and each axis.

Print 1 graph per group for each reaction. Each **group** should turn in 3 graphs total – one graph for each reaction.

In reaction #1, the temperature should increase to the maximum fairly rapidly, since both reactants are in solution. Then the temperature will decrease slowly. The value you will use for final temperature is the **y-intercept**.



Reactions #2 and #3 involve dissolving NaOH pellets. This takes place slowly, and the recorded temperature may not show a steady increase due to "hot spots" near the pellets. Again, determine the y-intercept of the linear portion to find the final temperature.

Calculations:

In general, the heat gained by the contents of the calorimeter is given by

$$q_{contents} = \text{mass x (specific heat) x } \Delta T$$

Use the quantities described below to calculate the heat of each reaction.

The sources of heat exchanged by the neutralization and dissolution processes are the reactions under study. So the heat generated by the reaction equals the heat gained by the contents of the calorimeter, but the q values have opposite signs. Thus,

$$q_{rxn} = - q_{contents}$$

$$q_{rxn} = - \text{mass x (sp. ht.) x } \Delta T$$

You will have to assign q as a negative value. It will not come out to be negative in your calculations.

Calculations for Reaction 1:

- **Mass:** You combined aqueous HCl with aqueous NaOH. Since these are dilute solutions, assume they have the same density as water (1.00 g/mL). For the measured volume of each solution you used, calculate the mass of each solution. (Hint: If you had used 50.0 mL of water how much would the water weigh? Answer: 50.0 g). Add the mass of HCl and the mass of NaOH to give the total mass used, this will be the mass you will use to calculate heat of reaction, q.
- **Specific heat**: The specific heat for reaction 1 can be assumed to be close to that of pure water (4.184 J/g·°C).
- **ΔT**: ΔT is the change in temperature of the solution ($T_f - T_i$). T_f will be determined from the y-intercept of each graph. Watch significant figures when calculating ΔT.
- **q_{rxn} = – mass x (sp. ht.) x ΔT**

Calculations for Reaction 2:

- **Mass**: You combined solid NaOH with water. Find the mass of water used by assuming the density to be 1.00 g/mL. Add the mass of solid NaOH and the mass of water to give the total mass used.
- **Specific heat**: The specific heat for the dissolution of NaOH will use the specific heat of NaOH, 3.90 J/g·°C.
- **ΔT**: ΔT is the change in temperature of the solution ($T_f - T_i$). T_f will be determined from the y-intercept of each graph. Watch significant figures when calculating ΔT.
- **q_{rxn} = – mass x (sp. ht.) x ΔT**

Calculations for Reaction 3:

- **Mass:** You combined solid NaOH with dilute aqueous HCl. Use the density of water again to approximate the mass of HCl. Add the mass of solid NaOH and the mass of HCl to give the total mass used.
- **Specific heat**: The specific heat for reaction 3 can be assumed to be close to that of pure water (4.184 J/g·°C).
- **ΔT**: ΔT is the change in temperature of the solution ($T_f - T_i$). T_f will be determined from the y-intercept of each graph. Watch significant figures when calculating ΔT.
- **q_{rxn} = – mass x (sp. ht.) x ΔT**

Calculating moles of reactants and products:

- For solutions, moles are calculated using concentration and volume.
- For solids, moles are calculated using molar masses.
- Use stoichiometry (mole-to-mole ratios) to determine which reagent is the limiting reagent in each of the 3 experiments you performed.

Enthalpy values are typically reported in kJ/mol, so ΔH_{rxn} can be obtained by dividing the experimentally determined heat of reaction by moles:

$$\Delta H_{rxn} = \frac{q_{rxn}}{moles}$$

For reactions 1 & 3, you will need to calculate the ΔH value in terms of **kilojoules released per mole of water formed**. To determine the number of moles of water formed or NaOH dissolved, you will need to consider which reactant was the limiting reactant.

Thermochemistry: The Heat of Neutralization: Lab Report

Name: ________________________
Partner(s): _____________________

Section Number: ________________

Lab Report - **Turn in pages 4 – 7 for your lab report.**

DATA
Record time and temperature data for all three reactions in the table below until the temperatures level off or steadily decrease for **10** readings. (You may not need to let each reaction run for the whole 16 minutes.) Exact mass and initial temperature data will be collected in the section for each reaction.

Time and Temperature Data

Temperature, ^{o}C				Temperature, ^{o}C			
Min	**Rxn 1**	**Rxn 2**	**Rxn 3**	**Min**	**Rxn 1**	**Rxn 2**	**Rxn 3**
0				8.5			
0.5				9.0			
1.0				9.5			
1.5				10.0			
2.0				10.5			
2.5				11.0			
3.0				11.5			
3.5				12.0			
4.0				12.5			
4.5				13.0			
5.0				13.5			
5.5				14.0			
6.0				14.5			
6.5				15.0			
7.0				15.5			
7.5				16.0			
8.0				16.5			

Mass Data Table: Record the exact volume, concentration, and/or mass of each reactant used in all three reactions. Gray boxes indicate data that is not needed for that reaction.

	Vol. HCl	**Mass HCl**	**Conc. HCl**	**Vol. NaOH**	**Mass NaOH**	**Conc. NaOH**	**Vol. H_2O**	**Mass H_2O**	**Total Mass Used**
Rxn 1									
Rxn 2									
Rxn 3									

Reaction #1, Balanced equation, including phases:

Initial temperature HCl solution _________ Initial temperature NaOH solution _________

Average initial temperature, T_i _________

Final temperature (from graph), T_f _________

ΔT ($T_f - T_i$) _________

Show your calculations for each quantity below. Include appropriate units and watch signs!

a) q_{rxn} _________

Total mass (HCl + NaOH):

Specific heat:

ΔT:

b) Moles HCl used _________

(Use concentration and volume)

c) Moles NaOH used _________

(Use concentration and volume)

d) Moles H_2O formed _________

(Use the limiting reagent)

e) ΔH (kJ/mol H_2O) _________

(Your answer from a divided by your answer from d)

Reaction #2, Balanced equation, including phases:

Mass vial + cap + NaOH _________ Mass vial + cap _________

Mass NaOH _________

Initial temperature of water _________ Final temperature (from graph) _________

ΔT ($T_f - T_i$) _________

Show all work for the calculations below.

a) q_{rxn} __________

Total mass (NaOH + H_2O):

Specific heat:

ΔT:

b) Moles NaOH used __________

(Use molar mass)

c) ΔH (kJ/mol NaOH) __________

(Your answer from a divided by your answer from b)

Reaction #3, Balanced equation, including phases:

Mass vial + cap + NaOH	__________	Mass vial + cap	__________
Mass NaOH	__________		
Initial temperature of HCl	__________	Final temperature (from graph)	__________
ΔT ($T_f - T_i$)	__________		

Show all work for the calculations below.

a) q_{rxn} __________

Total mass (HCl + NaOH):

Specific heat:

ΔT:

b) Moles HCl used __________

(Use concentration and volume)

c) Moles NaOH used __________

(Use molar mass)

d) Moles H_2O formed _________

(Use the limiting reagent)

e) ΔH (kJ/mol H_2O) _________

(Your answer from a divided by your answer from d)

Questions:

1) Rewrite the balanced chemical equations for the three reactions carried out in lab. Beside each reaction, write the ΔH (per mole) you calculated for that reaction. This will determine your accepted value of ΔH.

2) Manipulate the first two chemical equations so that they add up to give the third equation (Hess's Law). Add the enthalpies (per mole) of the first two equations to calculate the enthalpy of the third equation (Hess's Law) – this will determine your **experimental** ΔH value.

3) Determine the percent difference between the experimental and accepted values of ΔH for the third reaction. The **experimental value** is the Hess's Law calculation you completed in question #2 above. The ΔH/mol value you obtained for Reaction #3 is the **accepted value**.

$$\%\ \text{difference} = \left| \frac{\text{Experimental Value - Accepted Value}}{\text{Accepted value}} \right| \times 100$$