Experiment 6: Enthalpy of Solution and Reaction

Learning Objectives:
1. Determine the heat of solution of a compound, and the heat of neutralization of a reaction.
2. Observe that compounds can either absorb or release energy when dissolving in solvent.
3. Determine how heat energy changes are related to chemical and physical interactions.

Prelab:
- Bring a USB drive or floppy disk to save your work for your lab day.
1. In a graph of Temperature vs. Time, what variable is likely to be the independent variable, and on which axis should this variable be placed?
2. If a chemical reaction takes place in water, and the temperature of the water increases:
   a. Is the reaction endothermic or exothermic?
   b. Is heat absorbed or released by the water?
   c. What is the sign of q for the water?
   d. What is the sign of q for the chemical reaction?
3. Write the equation from the text that allows you to calculate the quantity of heat that a substance has gained or lost, based on mass and temperature change.
4. A student performs the following experiment: A coffee cup calorimeter contains 50.0 g of water at 20.0 °C. A student pours an unknown amount of warm water at 55.0 °C into this cup. The final temperature of the combined water is 34.6 °C.
   a. Calculate the amount of heat absorbed by the cool water, including the sign of q.
   b. Calculate the amount of heat released by the warm water, including the sign of q.
   c. Calculate the mass of warm water, in g, that was added to the calorimeter.
5. Write the equation for the neutralization reaction that you will perform in this lab.
6. Draw a box that is 1.0 cm × 1.0 cm × 1.0 cm. This is 1.0 cc of volume.
7. What will be the assumed specific heat for all of the solutions used in this lab?
8. Prepare a data table (Table 3) for Part III of the experiment. Make it neat and well labeled. There is a notation by most of the data that should be included in the table.

Procedure:

All waste can go down the drain.

Part I: Qualitative: How does dissolving a solid affect the temperature of water?

1. Place about 10-15 mL of tap water into a small beaker. Measure the initial temperature of the water using the thermometer in your drawer. Record your data in Table 1.
2. Place about 1-2 cm³ of anhydrous MgSO₄ into the water. Stir for about 30 seconds with the thermometer and record your observations.
3. Repeat this procedure using fresh tap water and ammonium nitrate, recording your observations.

Part II: Making Sure it Works (or, measuring the heat released for a known substance before you do the real experiment)

4. Set up the lap top computer and Vernier system with ONE temperature probe.
5. Measure the mass of 2 nested styrofoam cups. Record the data in Table 2.
6. Measure 50.0 mL of room temperature DI water in a graduated cylinder.
7. Add the water to your nested cups, and record the combined mass. Calculate the mass of the water.
8. Suspend the Vernier temperature probe into the water to measure it’s temperature.
9. Be careful with the Teflon coated stir bar from the stockroom window. You MUST return this. Do not eat, take home (it won’t work on your stove) or dump down the drain.
10. Obtain about 5-6 g of ammonium nitrate solid in your plastic weigh boat.
11. Set up the calorimeter following the text box and picture below:

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  a. Add the stir bar to a polystyrene cup.
  b. Place on a stir plate, and set to stir at a moderate speed (do not allow water to splash out).
  c. Check to see that the bottom of the thermistor is in the liquid.
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12. Click to begin collecting data. After approximately 1 min. of stirring, when the temperature of the room temp water is stable, proceed to Step 13.
13. Add the NH₄NO₃ solid into the calorimeter. Make sure that the stirring continues, vigorous enough to rapidly dissolve the solid without splashing the solution. If some solid is stuck in the weigh boat, record the mass and determine the mass of NH₄NO₃ added by subtraction.
14. Continue stirring and collecting data for about 2 minutes after the addition of the solid, until there is a stable baseline of data. Click to stop.
15. Save your data. You can determine the ΔT by the following method:
16. First click the Autoscale button to make the graph fill the screen.
17. Click the “Cross Hair” button. This will allow you to drag the mouse around the screen and a display will show you $T_{\text{init}}$ and $T_{\text{final}}$ values where you place the cross hairs. Record these values.

18. Rinse your calorimeter apparatus, and repeat the experiment at least 3 times.

19. Calculate the heat gain (or loss) for each sample, based on the mass of the water and temperature change of the water. For all thermochemistry experiments in this class, assume the specific heat is 4.18 J/g °C.

20. Calculate the heat change per mole for the dissolution.

21. Show your data to your instructor before you proceed.

**Part III: Heat of Reaction for KOH and HCl solutions**

22. Add a second temperature probe to the Vernier interface.

23. Record the mass $DT$ of 2 nested clean, dry Styrofoam cups.

24. Using a graduated cylinder, carefully measure 50.0 mL of the HCl solution into the nested cups. Record the mass of the solution + cups $DT$ so that the mass of HCl solution can be determined $DT$. Add the stirbar to the nested cups, and set up the apparatus as before.

25. Obtain 50.0 mL of KOH solution in a 2nd graduated cylinder.

26. Insert one temperature probe into the HCl solution, and the 2nd into the KOH solution.

27. Click to begin collecting data. After approximately 1 min. of stirring, when the temperatures of both solutions are stable on the plot, proceed.

28. Remove the 2nd temp probe from the KOH solution, and quickly transfer the KOH solution into the HCl solution, while mixing thoroughly with the stir bar. The 2nd temp probe will be recording useless data at this point.

29. Record data for about 2 minutes, or until a stable baseline of data has been obtained. Click

30. Determine $\Delta T DT$ as before. If the initial temperatures of the two solutions $DT$ are different, use the average value of these two temperatures.

31. Record the mass of the combined solution $DT$ so that the mass of the KOH solution and the mass of the combined solutions can be determined. The calculations are detailed below.

32. Repeat this portion of the experiment at least 2 more times $DT$.

33. Record the molarity $DT$ of your KOH and NaOH solutions.

**Calculations for $\Delta H$ of Neutralization:** (Show sample calculations, include in data table 3.)

a. Calculate the limiting reactant $DT$ for the reaction in **Part III**, based on volume and concentration.

b. Calculate the $q DT$ of the water for the reaction, based on the mass of the substance that changed temperature. See **Part II** for information about the specific heat of the solution.
c. From the above $q$, calculate the $q^{DT}$ for the reaction of HCl(aq) and KOH(aq). Make sure the sign of $q$ is compatible with the temp changes.
d. Determine the enthalpy of neutralization for the acid + base reaction, per mol$^{DT}$ of reactant (see your LR calculation above).

Questions:

1. In Part I, two salts were dissolved in water. Were the results identical? From the qualitative observations in Part I, make a statement for each substance about which attractive forces are stronger, the attraction of the cation to the anion, or some other attractive forces.

2. Using your value for the heat of solution of NH₄NO₃, calculate how much heat would be released if 4.55 kg of NH₄NO₃ were dissolved in water.

3. A certain commercial process relies on the addition of NH₄NO₃ to a solution of their proprietary compound. The Junior Apprentice Chemist develops a plan to add 4.55 pounds of NH₄NO₃ to 12.0 gallons of water. The water in the factory is typically at an initial temperature of 18.0 °C, and the temperature of the water cannot drop below 15 °C, or the reaction will be too slow. Will the above plan work?

4. Calculate the theoretical value of $\Delta H_{\text{neutralization}}$ from the net ionic equation of the neutralization reaction in Part III using data in App. C of your text and the equation that relates $\Delta H_f$ of products and reactants to $\Delta H$ of a reaction.

5. Calculate the percent error of your experimental value for $\Delta H_{\text{neutralization}}$ and the theoretical value. Comment on your accuracy, and sources of actual error of measurement. Do not simply cite “human error.”

6. The heat of solution of HCl(g) is $-17,900 \text{ cal/mol}$. What is the temperature change when 359 g of HCl is dissolved in 2.50 L of water (assume no volume change)?

7. Extra Credit: A mental model to represent the dissolution reaction
   \[ \text{MgSO}_4(s) \rightarrow \text{Mg}^{2+}(aq) + \text{SO}_4^{2-}(aq). \]
   a. Draw a picture that illustrates how heat is gained or lost at the level of atoms and molecules for the MgSO₄ system. Consider question #1 when drawing the picture.
   b. Draw a second picture that illustrates heat gain or loss for the solution of NH₄NO₃.
   c. Explain how your pictures explain heat gain or loss.

To Turn in: Please place the following in the order shown and label each section

   a. Answers to the questions
   b. Sample Calculations
   c. Completed Data Tables
   d. Original data
Table 1: **Heat of Solution:**

<table>
<thead>
<tr>
<th></th>
<th>MgSO₄(s)</th>
<th>Initial temp</th>
<th>Final temp</th>
<th>ΔT</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>NH₄NO₃(s)</td>
<td>Initial temp</td>
<td>Final temp</td>
<td>ΔT</td>
</tr>
</tbody>
</table>

Table 2: **Determination of Heat of Solution of NH₄NO₃**

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<td>Mass:</td>
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<td>Mass of NH₄NO₃</td>
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<td>Moles NH₄NO₃</td>
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<td><strong>ΔT</strong></td>
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<td><strong>heat change, q</strong></td>
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<td><strong>q per mole of NH₄NO₃</strong></td>
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<tr>
<td>Mean</td>
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**Show sample calculations below.**