Determining the Enthalpy of a Neutralization Reaction

The neutralization of hydrochloric acid with sodium hydroxide solution is represented by the following equation.

\[
\text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}_{(l)}
\]

Using a coffee-cup calorimeter, you will determine the enthalpy change for this reaction.

**Question**

What is the heat of neutralization for hydrochloric acid and sodium hydroxide solution?

**Prediction**

Will the neutralization reaction be endothermic or exothermic? Record your prediction, and give reasons.

**Safety Precautions**

If you get any hydrochloric acid or sodium hydroxide solution on your skin, flush your skin with plenty of cold water.

**Materials**

- 100 mL graduated cylinder
- 400 mL beaker
- 2 polystyrene cups that are the same size
- Polystyrene lid
- Thermometer
- Stirring rod
- 1.00 mol/L \text{HCl}_{(aq)}
- 1.00 mol/L \text{NaOH}_{(aq)}

**Procedure**

1. Your teacher will allow the hydrochloric acid and sodium hydroxide solution to come to room temperature overnight.

2. Read the rest of this Procedure carefully before you continue. Set up a graph to record your temperature observations.

3. Build a coffee-cup calorimeter, using the diagram above as a guide. You will need to make two holes in the polystyrene lid—one for the thermometer and one for the stirring rod. The holes should be as small as possible to minimize heat loss to the surroundings.

4. Rinse the graduated cylinder with a small quantity of 1.00 mol/L \text{NaOH}_{(aq)}. Use the cylinder to add 50.0 mL of 1.00 mol/L \text{NaOH}_{(aq)} to the calorimeter. Record the initial temperature of the \text{NaOH}_{(aq)}. (This will also represent the initial temperature of the \text{HCl}_{(aq)}.) **CAUTION** The \text{NaOH}_{(aq)} can burn your skin.
5. Rinse the graduated cylinder with tap water. Then rinse it with a small quantity of 1.00 mol/L HCl\(_{aq}\). Quickly and carefully, add 50.0 mL of 1.00 mol/L HCl\(_{aq}\) to the NaOH\(_{aq}\) in the calorimeter. **CAUTION** The HCl\(_{aq}\) can burn your skin.

6. Cover the calorimeter. Record the temperature every 30 s, stirring gently and continuously.

7. When the temperature levels off, record the final temperature, \(T_f\).

8. If time permits, repeat steps 4 to 7.

**Analysis**

1. Determine the amount of heat that is absorbed by the solution in the calorimeter.

2. Use the following equation to determine the amount of heat that is released by the reaction:

\[
-Q_{\text{reaction}} = Q_{\text{solution}}
\]

3. Determine the number of moles of HCl\(_{aq}\) and NaOH\(_{aq}\) that were involved in the reaction.

4. Use your knowledge of solutions to explain what happens during a neutralization reaction. Use equations in your answer. Was heat released or absorbed during the neutralization reaction? Explain your answer.

**Conclusion**

5. Use your results to determine the enthalpy change of the neutralization reaction, in kJ/mol of NaOH. Write the thermochemical equation for the neutralization reaction.

**Applications**

6. When an acid gets on your skin, why must you flush the area with plenty of water rather than neutralizing the acid with a base?

7. Suppose that you had added solid sodium hydroxide pellets to hydrochloric acid, instead of adding hydrochloric acid to sodium hydroxide solution?

(a) Do you think you would have obtained a different enthalpy change?

(b) Would the enthalpy change have been higher or lower?

(c) How can you test your answer? Design an investigation, and carry it out with the permission of your teacher.

(d) What change do you need to make to the thermochemical equation if you perform the investigation using solid sodium hydroxide?

8. In Investigation 5-A, you assumed that the heat capacity of your calorimeter was 0 J/°C.

(a) Design an investigation to determine the actual heat capacity of your coffee-cup calorimeter, \(C_{\text{calorimeter}}\). Include equations for any calculations you will need to do. If time permits, have your teacher approve your procedure and carry out the investigation. **Hint:** If you mix hot and cold water together and no heat is absorbed by the calorimeter itself, then the amount of heat absorbed by the cold water should equal the amount of heat released by the hot water. If more heat is released by the hot water than is absorbed by the cold water, the difference must be absorbed by the calorimeter.

(b) Include the heat capacity of your calorimeter in your calculations for \(\Delta H_{\text{neutralization}}\). Use the following equation:

\[
-Q_{\text{reaction}} = (m_{\text{solution}} \times c_{\text{solution}} \times \Delta T) + (C_{\text{calorimeter}} \times \Delta T)
\]

If you have access to probeware, do Probeware Investigation 5-A, or a similar investigation from a probeware company.
Section Summary
In this section, you measured the enthalpy change of a reaction by calorimetry. You may have noticed that the reactions you studied in this section involved relatively small energy changes. How do chemists work quantitatively with some of the large energy changes you examined in section 5.1? In the next section, you will learn how to calculate the heat of reaction for virtually any chemical reaction or physical change. This powerful skill will allow you to find heats of reaction without carrying out experiments.

Section Review

1. Distinguish between heat capacity and specific heat capacity.
2. What properties of polystyrene make it a suitable material for a constant-pressure calorimeter? Why are polystyrene coffee cups not suitable for a constant-volume calorimeter?
3. Suppose that you use concentrated reactant solutions in an experiment with a coffee-cup calorimeter. Will you make the same assumptions that you did when you used dilute solutions? Explain.
4. Concentrated sulfuric acid can be diluted by adding it to water. The reaction is extremely exothermic. In this question, you will design an experiment to measure the enthalpy change (in kJ/mol) for the dilution of concentrated sulfuric acid. Assume that you have access to any equipment in your school’s chemistry laboratory. Do not carry out this experiment.
   (a) State the equipment and chemicals that you need.
   (b) Write a step-by-step procedure.
   (c) Set up an appropriate data table.
   (d) State any information that you need.
   (e) State any simplifying assumptions that you will make.
5. A chemist mixes 100.0 mL of 0.050 mol/L potassium hydroxide with 100.0 mL of 0.050 mol/L nitric acid in a constant-pressure calorimeter. The temperature of the reactants is 21.01°C. The temperature of the products is 21.34°C.
   (a) Write a thermochemical equation for the reaction.
   (b) If you performed this investigation, would you change the procedure? If so, how?
6. Explain why a bomb calorimeter may not provide accurate results for determining the enthalpy of a reaction.
7. From experience, you know that you produce significantly more heat when you are exercising than when you are resting. Scientists can study the heat that is produced by human metabolism reactions using a “human calorimeter.” Based on what you know about calorimetry, how would you design a human calorimeter? What variables would you control and study in an investigation using your calorimeter? Write a brief proposal outlining the design of your human calorimeter and the experimental approach you would take.