# Lab: Heat of Reaction - Hess's Law

The foundation of the study of thermochemistry was laid by the chemist Germain Hess, who investigated heat in chemical reactions during the last century. One statement of the law that bears Hess's name says:

*The enthalpy change for any reaction depends on the products and reactants and is independent of the pathway or the number of steps between the reactant and product.*

In this experiment, the quantity of heat involved in three reactions will be measured and compared. These heats of reaction will be measured using a coffee cup calorimeter. The three reactions are shown below.

Reaction 1: The dissolving of solid sodium hydroxide in water.

$$NaOH(s) \text{ ---> } Na^+(aq) + OH^-(aq) + \text{heat}$$

Reaction 2: The reaction of solid sodium hydroxide with dilute hydrochloric acid.

$$NaOH(s) + H^+(aq) + Cl^-(aq) \text{ ---> } Na^+(aq) + Cl^-(aq) + H_2O(l)$$

Reaction 3: The reaction of sodium hydroxide solution with dilute hydrochloric acid solution.

$$Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \text{ ---> } Na^+(aq) + Cl^-(aq) + H_2O(l)$$

**Objectives:**
To measure and compare the amount of heat involved in three separate but related reactions.
To provide experimental verification of Hess's Law.

**Prelab:**
1. Determine the accepted $\Delta H°_{rxn}$ for Reaction 2. Use the $H°_f$ values from the Appendix C.

**Apparatus and Materials:**

| | |
|---|---|
| 2 large Styrofoam cups | 0.50 M Hydrochloric acid solution |
| 100 mL graduated cylinder | thermometers |
| sodium hydroxide, NaOH(s) | balance |
| 0.50 M sodium hydroxide solution | 250 mL beaker |
| 0.25 M Hydrochloric acid solution | glass stir stick |

**Safety:**
Hydrochloric acid and sodium hydroxide are corrosive. Avoid direct contact. If any touches your skin, wash it off immediately. Solid sodium hydroxide is especially dangerous because it absorbs moisture rapidly from the air, forming an extremely corrosive liquid. Avoid spilling this solid, and if a spill occurs, clean it up immediately. Be sure to close the lids of bottles of sodium hydroxide securely, immediately after using.

Dispose of solutions according to your teacher's instructions. A lab coat or apron is strongly recommended.

**Procedure:**

**Part One:** *The Dissolving of Solid Sodium Hydroxide in Water*

1. Read through the procedure and look carefully at the provided data tables.
2. Put 200 mL of cool distilled water into the nested coffee cup calorimeter. Stir carefully with a glass stirring rod until a constant temperature is reached. Measure and record this temperature.
3. Accurately find and record the mass of about 2 grams of solid sodium hydroxide. Perform this operation as quickly as possible since the solid absorbs moisture from the air very rapidly and forms a very corrosive liquid.
4. Place the solid sodium hydroxide into the water in the cups. Stir gently with the glass stirring rod until the solid is completely dissolved and record the highest temperature reached.
5. Discard the solution safely and rinse the cup thoroughly with water.

**Part Two:** *The Reaction of Solid Sodium Hydroxide with Hydrochloric Acid*

6. Repeat steps 2-4, but replace the 200 mL of water with 200 mL of 0.25 M hydrochloric acid.
7. Discard the solution and again rinse the cup thoroughly before proceeding to Part Three.

**Part Three:** *The Reaction of Sodium Hydroxide Solution with Hydrochloric Acid*

8. Accurately measure 100 mL of 0.50 M hydrochloric acid solution into your calorimeter and 100 mL of 0.50 M sodium hydroxide into a 250 mL beaker. Both solutions should be at or near room temperature.
9. Record the temperatures and volumes of each solution.
10. Add the sodium hydroxide solution to the acid solution in the Styrofoam cup. Stir the mixture with the glass stirring rod and record the highest temperature reached.
11. Discard the solution as directed.

**Data Analysis:**

1. From your data, calculate the following for **each part** of the experiment.
   a. The temperature change of the liquid.
   b. The heat absorbed by the solution. (Assume that the solution has a the same density and specific heat of water)
   c. The number of moles of sodium hydroxide present.
   d. The amount of heat evolved per mole of sodium hydroxide used. This final value is the heat of reaction ($\Delta H$).
2. Compare the experimental $\Delta H$ value with the accepted value (prelab question 1) and calculate the experimental error.

**Discussion Questions:**

1. Add the ionic equations given in the introductions for Parts One and Three. Compare the result with the ionic equation for Part Two.
2. Compare the sum of the heats of reaction for Parts One and Three with that obtained for Part Two. In the light of your answer to Question 1, explain your results here.
3. Discuss Hess's law in terms of the law of conservation of energy and in terms of the three parts of this experiment.
4. Suppose you had used 8 g of sodium hydroxide in Part One.
   a) How would this have affected the change in temperature?
   b) What quantity of heat would have been evolved in your reaction?
   c) What effect would this have had on your calculation of the heat of reaction for Part One?

Heat of Reaction - Hess's Law
Data Table

| **Part 1** | |
|---|---|
| Mass of Styrofoam cups | |
| Mass of cups and $H_2O$ | |
| Initial temperature | |
| Final temperature | |
| Mass of NaOH(s) | |

| **Part 2** | |
|---|---|
| Mass of Styrofoam cups | |
| Mass of cup and 0.25M HCl | |
| Initial temperature | |
| Final temperature | |
| Mass of NaOH(s) | |

| **Part 3** | |
|---|---|
| Volume of 0.50 M HCl | |
| Volume of 0.50 M NaOH | |
| Initial temperature of HCl | |
| Initial temperature of NaOH | |
| Highest final temperature of mixture | |