ENTHALPY OF A CHEMICAL REACTION 31

Energy is involved in all chemical reactions. Chemical reactions are either exothermic or endothermic. The reaction

$$C(cr) + O_2(g) \rightarrow CO_2(g) + 393.5\ kJ/mol\ of\ product$$

is an example of an exothermic reaction since energy is released. The 393.5 kJ of energy is considered a product of the reaction and called the **enthalpy of reaction,** ΔH. The enthalpy of reaction is the energy released or absorbed in a chemical reaction. A reaction that absorbs energy as it proceeds, such as

$$\frac{1}{2}N_2(g) + \frac{1}{2}O_2(g) + 90.4\ kJ/mol \rightarrow NO(g)$$

is endothermic. In this situation the 90.4 kJ of energy is the enthalpy of reaction. Since the energy is absorbed the equation shows it as a reactant. The enthalpy of reaction for any chemical reaction is determined as follows.

$$\Delta H = (enthalpy\ of\ products) - (enthalpy\ of\ reactants)$$

For exothermic reactions, ΔH is a negative value, whereas ΔH is positive for endothermic reactions. A negative ΔH indicates the products are at a lower energy state than the reactants. A positive ΔH indicates the products are at a higher energy state than the reactants. In general, ΔH is expressed in kilojoules of energy for each mole of substance produced.

Example: $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$, $\Delta H = -242$ kJ (exothermic reaction)
$\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \rightarrow HI(g)$, $\Delta H = +25.9$ kJ (endothermic reaction)

Many substances can be formed using more than one technique. For example, carbon dioxide can be formed by burning carbon in oxygen.

$$C(cr) + O_2(g) \rightarrow CO_2(g),\ \Delta H = -393.5\ kJ$$

Another method of producing carbon dioxide involves a three-step process.

$$H_2O(g) + C(s) \rightarrow CO(g) + H_2(g),\ \Delta H = +131.0\ kJ$$
$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g),\ \Delta H = -242.0\ kJ$$
$$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g),\ \Delta H = -282.5\ kJ$$

To determine the total amount of energy released or absorbed using the three-step process, add the enthalpies of reaction for the three reactions.

$$\Delta H = (+131.0\ kJ) + (-242.0\ kJ) + (-282.5\ kJ) = -393.5\ kJ$$

The enthalpy of reaction for the multi-step process equals the enthalpy of reaction for the single-step process of making carbon dioxide. This equality of enthalpies was first proposed by Germain Hess in the mid 1800's. **Hess's law** of heat summation states that: *When a reaction can be expressed as the algebraic sum of two or more other reactions, the enthalpy of the reaction is the algebraic sum of the enthalpies of these reactions.*

Objectives

In this experiment, you will

- measure the enthalpy of solution for NaOH(cr),
- measure ΔH_f° for water from H_3O^+ and OH^-, and
- demonstrate that enthalpies of reaction are additive according to Hess's law.

EQUIPMENT

goggles and apron
plastic foam cup
glass stirring rod
graduated cylinder (50 or 100 cm^3)
Erlenmeyer flask (125 or 250 cm^3)
forceps
thermometer

PROCEDURE

A. Enthalpy of Solution

1. Prepare a data table as directed in the Analysis. Safety goggles and lab apron must be worn for this experiment. Measure and record the mass of a plastic foam cup.
2. Add approximately 1.00 g of NaOH pellets to the cup. **CAUTION:** *Do not handle the pellets, except with forceps.* **CAUTION:** *NaOH pellets and the NaOH solution you will prepare can cause burns; avoid skin and eye contact. Rinse spills with plenty of water.* Measure and record the total mass of cup and NaOH; calculate mass of NaOH.
3. Measure exactly 50.0 cm^3 of distilled water into a graduated cylinder. Measure and record the temperature of the water to the nearest 0.5°C. Add the water to the NaOH pellets in the cup. Stir the mixture with a glass stirring rod and record the highest temperature reached while the NaOH is dissolving. Save this solution for use in Part B.

B. Enthalpy of Neutralization

1. Place exactly 50.0 cm^3 of 0.50*M* HCl in an Erlenmeyer flask. **CAUTION:** *HCl causes burns; avoid skin and eye contact. Rinse spills with plenty of water.* Allow NaOH solution in the plastic foam cup and HCl in the flask to reach room temperature. To avoid contamination of the solutions, rinse the thermometer with distilled water after each use. When two solutions have reached the same temperature record this value in your table, T_1.
2. Now pour the HCl into the NaOH solution in the cup, and stir. Record the highest temperature reached before the solution begins to cool, T_2.
3. Rinse the solution down the drain with plenty of water. Rinse the containers with tap water, then distilled water in preparation for Part C.

C. Hess's Law

1. Place exactly 50.0 cm^3 of 0.50*M* HCl in an Erlenmeyer flask, and add exactly 50.0 cm^3 of distilled water. Record the temperature of the solution, T_1.
2. Place exactly the same mass of NaOH pellets as used in Part A in the plastic foam cup. Add the 100.0 cm^3 HCl solution to the NaOH pellets. Stir and record the highest temperature reached by the solution, T_2.
3. The solution may be rinsed down the drain with plenty of water.

ANALYSIS

1. Prepare a table for your data using Table 31-1 as a guide. To calculate the energy produced by a temperature change use the following equation.

$$\text{Energy} = \frac{\text{Mass of}}{\text{solution}} \times \frac{\text{Change in}}{\text{temperature}} \times \text{Specific heat}$$
$$(\text{J}) = (\text{g}) \times (\text{C}^\circ) \times (\text{J/g}\cdot\text{C}^\circ)$$

You should assume the following when making your calculations.

   a. the density of all solutions equals the density of water, 1.00 g/cm^3.
   b. the specific heat (C_p) of all solutions equals that of water, 4.184 J/g · C°.
   c. all substances react completely
   d. all energy evolved by a reaction is absorbed by the solution

Table 31-1

	A	B	C
1. mass of calorimeter		XXX	
2. mass of cup + NaOH(cr)		XXX	
3. mass of NaOH(cr)		XXX	
4. mass of H_2O		XXX	
5. mass of NaOH(aq)			
6. mass of HCl	XXX		
7. total mass of solutions	XXX		
8. original temperature of solutions, T_1			
9. highest temperature during reaction, T_2			
10. temperature change, $\Delta T = T_1 - T_2$			
11. energy produced (J)			
12. moles of product	(Na^+ + OH^-)	(H_2O)	(H_2O + Na^+)
13. energy evolved by 1 mole of product, H = kJ/mol			

2. Write a balanced equation for each reaction.

CONCLUSIONS

1. Show that the sum of the balanced equations in Parts A and B equals the equation in Part C.
2. What is the difference between the sum of the reaction enthalpies for Parts A and B and the enthalpy of reaction for Part C? What should the difference equal?
3. What were the main sources of error in this experiment?
4. Predict what would happen if the mass of NaOH(cr) in Part A were doubled but the amount of water remained constant. Explain your answer.