Activity 06-1

Thermochemistry and Calorimetry

Why?

Chemical reactions release or store energy, usually in the form of *thermal energy*. Thermal energy is the kinetic energy of motion of the atoms and molecules comprising an object. Heat is thermal energy that is transferred from one object to another. The amount of energy released or stored by a chemical reaction can be determined from the change in temperature. You need to know how much energy is either released or taken up and stored by a reaction in order to determine the utility of that reaction. This knowledge also allows you to identify the conditions essential for that reaction to occur efficiently and safely.

Learning Objectives

- Quantify the relationship between energy transferred and the change in temperature
- Understand the utility of the specific heat capacity
- Understand how to determine the heat of chemical reactions

Success Criteria

- Correctly use the specific heat capacity of substances in various situations to interrelate the amount of heat and the change in temperature
- Determine the energy transferred in a chemical reaction from the change in temperature

Prerequisites

- **Activity 04-1:** *Balanced Chemical Reaction Equations*
- **Activity 04-3:** *Introduction to Acid – Base Reactions*

Information

Energy is measured in units of Joules (J).

Thermal energy is transferred spontaneously from an object at a higher temperature to another object at a lower temperature. Thermal equilibrium is reached when the two objects are at the same temperature.

The temperature of an object increases when it absorbs energy; the temperature of an object decreases when it releases energy. This temperature change can be used to determine the amount of energy that was absorbed or released.

Model 1: Measuring Thermal Energy

In an experiment to determine the relationship between the temperature change of water and the amount of energy absorbed by the water, an electrical heater was used to increase the temperature of 1 g of water by 1 °C. The energy produced by an electrical heater over some period of time can be calculated very accurately: energy = electrical current × voltage × time. The results of this experiment are given below.

Mass of Water	Change in Temperature	Energy Used in Heating the Water
1.000 g	1.000 °C	4.184 J

Key Questions

1. How much energy was required to increase the temperature of 1.000 g of water by 1.000 °C?

2. How much energy would be required to increase the temperature of 100.0 g of water by 1.000 °C?

3. How much energy would be required to increase the temperature of 1.000 g of water by 50.0 °C?

4. The specific heat capacity of any substance is defined as the amount of energy needed to increase the temperature of 1 g of the substance by 1 °C. What is the specific heat capacity of water? Be sure to include the units of J/g °C.

5. Based on your answers to Key Questions 1-4, what is the equation that relates the amount of energy absorbed or released, by any substance, to the change in temperature of that substance? Write this equation using the following notation: q = heat, m = mass, ΔT = change in temperature, and c_s = specific heat capacity of the substance.

6. If you needed to experimentally determine the specific heat capacity of a new metal alloy that you developed, what would you need to measure, and how would you calculate the specific heat capacity from the measured values?

EXERCISES

1. Aluminum has a specific heat capacity of 0.902 J/g °C. How much energy is released when 1.0 kg of aluminum cools from 35 °C to 20 °C?

2. In preparing dinner you need a cup of very hot water, which you prepare on your electric stove. You use 80 kJ of electrical energy to heat 250 g of water starting at 20 °C. What is the final temperature of the water?

GOT IT!

1. At room temperature, equal masses of water and aluminum were each heated with 1 kJ of electrical energy. The aluminum became much hotter than the water. Explain why.

Model 2: Heat of a Chemical Reaction

Solutions of hydrochloric acid and sodium hydroxide are mixed in a beaker that is surrounded by Styrofoam insulation. The temperature of the solution and beaker increases from 24 °C to 38 °C. The volume of the resulting solution is 435 mL. Determine the amount of energy, ΔE_{total}, released by this reaction.

$\Delta E_{total} = \Delta E_{solution} + \Delta E_{beaker}$

ΔE_{total} = total energy released

$\Delta E_{solution}$ = energy used to heat the solution

$\Delta E_{solution} = c_s\, m\, \Delta T$

ΔE_{beaker} = energy used to heat the beaker, insulation, and thermometer

$\Delta E_{beaker} = (330\ \text{J/°C})\, \Delta T$

Assume that since the solution is dilute, the specific heat of the solution is the same as that of water. The beaker, insulation, and thermometer have a combined heat capacity of 330 J/°C. The *heat capacity* is the amount of energy required to change the temperature of some object by 1°C.

$$\Delta E_{total} = (4.184\ \text{J/g °C})(435\ \text{mL} \times 1.00\ \text{g/mL})(14\ \text{°C}) + (330\ \text{J/°C})(14\ \text{°C}) = 30.1\ \text{kJ}$$

Key Questions

7. In **Model 2**, what things become hotter due to the energy that is released in the reaction of hydrochloric acid and sodium hydroxide?

8. How is the energy calculated that is used in heating the solution in **Model 2**?

9. How is the energy calculated that is used in heating the other items in **Model 2**?

10. How is the total energy released in the chemical reaction in **Model 2** calculated?

11. What is the difference between the specific heat capacity and the heat capacity of a substance or object?

Problems

1. You mix 100. mL of 1.0 M HCl with 100 mL of 1.0 NaOH, both at 25 °C. The temperature of your calorimeter rises by 5.98 °C, and its heat capacity is 100 J/°C. How much energy is released per mol of $H_2O(l)$ formed?

2. An unknown piece of metal weighing 100. g is heated to 90.0 °C. It is dropped into 250 g of water at 20.0 °C. When equilibrium is reached, the temperature of both the water and piece of metal is 29.0 °C. Determine the specific heat of the metal using the fact that the energy lost by the metal must equal the energy absorbed by the water. Assume that the heat capacity of the container, a Styrofoam cup, is negligible.