Exploring Energy Changes
Exothermic and Endothermic Reactions

Introduction

The story of chemistry is the story of change—physical change, chemical change, and energy change. Energy in the form of heat is exchanged in almost every chemical reaction or change in state. Some reactions require heat in order to proceed. Other reactions release heat as they take place. In this experiment, we will investigate several processes in order to get a feel for the amount of heat absorbed or released in physical and chemical reactions.

Concepts

- Thermochemistry
- Energy
- Heat
- Temperature
- Exothermic vs. endothermic
- System vs. surroundings

Background

Thermochemistry is the study of heat changes that take place in a change of state or a chemical reaction—heat energy is either absorbed or released. If a process releases energy in the form of heat, the process is called exothermic. A process that absorbs heat is called endothermic. How do we observe or measure the heat change that occurs in a physical or chemical change?

Heat is defined as the energy transferred from one object to another due to a difference in temperature. We do not observe or measure heat directly—we measure the temperature change that accompanies heat transfer. In a chemical reaction it is often not possible to measure the temperature of the reactants or products themselves. Instead, we measure the temperature change of their surroundings.

The difference between the system and the surroundings is a key concept in thermochemistry. The *system* consists of the reactants and products of the reaction. The solvent, the container, the atmosphere above the reaction (in other words, the rest of the universe) are considered the *surroundings*. Heat may be transferred from the system to the surroundings (the temperature of the surroundings will increase) or from the surroundings to the system (the temperature of the surroundings will decrease).

When a system releases heat to the surroundings during a reaction, the temperature of the surroundings increases and the reaction container feels warm to the touch. This is an *exothermic reaction*—the prefix *exo-* means "out of" and the root *thermic* means heat. Heat flows out of the sytem. An example of an exothermic reaction is the combustion of propane (C_3H_8) in a barbecue grill to produce carbon dioxide, water, and heat. *Equation 1* gives the chemical equation for this reaction; notice that heat appears on the product side in the equation for an exothermic reaction.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) + \text{heat} \qquad \textit{Equation 1}$$

When a system absorbs heat from the surroundings during a reaction, the temperature of the surroundings decreases and the reaction container feels cold to the touch. This is an *endothermic reaction,* where the prefix *endo-* means "into." Heat flows into the system. A familiar example of an endothermic process is the melting of ice. Solid water (ice) needs heat energy to break the forces holding the molecules together in the solid state. This physical change is represented by *Equation 2;* notice that heat appears on the reactant side in the equation for an endothermic reaction.

$$H_2O(s) + \text{heat} \rightarrow H_2O(l) \qquad \textit{Equation 2}$$

Experiment Overview

The purpose of this experiment is to examine the heat changes in physical and chemical processes and to classify them as exothermic or endothermic. In Part A, three reactions are carried out in heavy-duty, zipper-lock plastic bags. The bags make it easy to observe and feel the heat changes that occur. In Part B, the extent of heat transfer in one of these reactions will be investigated by measuring the resulting temperature change. The reaction will be carried out in an insulated foam cup and the temperature of the solution will be measured as a function of time.

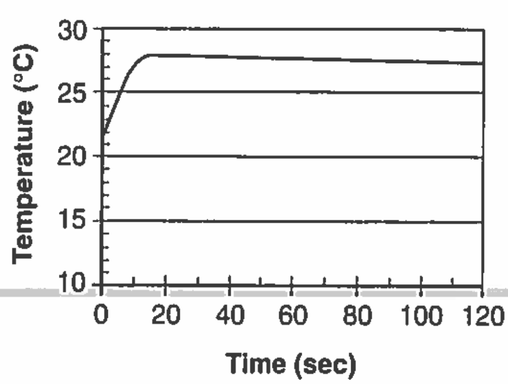
Pre-Lab Questions

1. Read the entire procedure and the recommended safety precautions. What hazards are associated with the use of hydrochloric acid in the lab? How can these hazards be reduced?
2. Classify each of the following processes as a physical change or a chemical change and as an exothermic or endothermic reaction.

   (a) Sugar is dissolved in water in a test tube and the test tube feels cold.

   (b) Gasoline is burned in a car engine.

   (c) Water is converted to steam according to the equation $H_2O(l) + \text{heat} \rightarrow H_2O(g)$.
3. Two solutions, hydrochloric acid and sodium hydroxide, were mixed and the temperature of the resulting solution was measured as a function of time. The following graph was recorded. Is the reaction between hydrochloric acid and sodium hydroxide exothermic or endothermic?



Materials

Ammonium chloride, NH_4Cl, 8–10 g
Calcium chloride, $CaCl_2$, 12–14 g
Hydrochloric acid solution, HCl, 1 M, 40 mL
Sodium bicarbonate, $NaHCO_3$, 3–5 g
Water, distilled or deionized
Temperature sensor or thermometer
Computer interface system (LabPro™)*
Computer or calculator for data collection*
Data collection software (LoggerPro™)*
*Optional

Balance, centigram (0.01 g precision)
Beaker, 400-mL
Graduated cylinders, 10- and 50-mL
Pen for labeling
Sealable, zipper-lock plastic bag, 1
Spatula
Insulated foam (Styrofoam®) cup, 6 oz, 1
Weighing dishes or small beakers, 4

Safety Precautions

Hydrochloric acid solution is toxic by ingestion or inhalation and is corrosive to eyes and skin. Avoid contact with eyes and skin. Notify the teacher and clean up all spills immediately with large amounts of water. Ammonium chloride and calcium chloride are slightly toxic by ingestion. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part A. Observing Heat Changes

1. Obtain 3 weighing dishes or small beakers and label them A–C.
2. Weigh out the appropriate amount of solid into each weighing dish, according to the following table. Record the exact mass of each solid in Data Table A.

Weighing Dish	A	B	C
Solid	Ammonium chloride	Calcium chloride	Sodium bicarbonate
Mass	2–3 g	3–4 g	1–2 g

3. Open a zipper-lock plastic bag and pour the solid from A into the bottom of the bag. Tilt the bag so all the solid falls into one corner of the bag, then lay the bag flat on the table.
4. Measure 10 mL of distilled water in a graduated cylinder and pour the water into the bag, trying to pool the water in the upper third of the bag.
5. Close the zipper-lock bag and gently squeeze the bag to mix the solid and liquid contents.
6. Feel the side of the bag where the reaction is occurring and record whether the bag feels hot or cold to the touch. Observe what happens as the contents mix. Record all observations in Data Table A.
7. Wash the contents of the bag down the drain with excess water. Rinse the inside of the bag with distilled water and dry it using a paper towel.
8. Repeat steps 3–6 using sample B and 10 mL of distilled water.
9. Wash the contents of the bag down the drain with excess water. Rinse the inside of the bag with distilled water and dry it using a paper towel.

10. Repeat steps 3–6 using sample C and 10 mL of 1 M hydrochloric acid solution.

11. Wash the contents of the bag down the drain with excess water. Dispose of the bag as instructed by your teacher.

Part B. Measuring Temperature vs. Time

Your teacher will assign you and your group one of the reactions from Part A to study in more detail. Record the identity of the reaction assigned to you in Data Table B. Use the following table to determine the required amount of solid and liquid for steps 13 and 14.

Reaction	Solid (g)	Liquid (mL)
A	Ammonium chloride (6–7 g)	Distilled water (30 mL)
B	Calcium chloride (9–10 g)	Distilled water (30 mL)
C	Sodium bicarbonate (2–3 g)	Hydrochloric acid, 1 M (30 mL)

12. Set an empty, dry Styrofoam cup into a 400-mL beaker so that the cup is stable and will not tip over.

13. Weigh out the required amount of solid in a weighing dish and record the identity and exact mass of the solid in Data Table B.

14. Measure 30.0 mL of the appropriate liquid in a graduated cylinder and pour the liquid into the Styrofoam cup. Record the identity and volume of the liquid in Data Table B.

15. Plug a temperature sensor into the interface system.

16. Open and format a graph in the data collection software so that the y-axis reads temperature in degrees Celsius. Set the minimum and maximum temperature values at 0 and 40 °C, respectively.

17. The x-axis should be set for time in seconds. Set the minimum and maximum time values at 0 and 240 sec, respectively.

18. Set the time interval to take a temperature reading every 10 seconds.

19. Place the temperature probe in the liquid in the Styrofoam cup.

20. Wait one minute (to allow the temperature sensor to become acclimated to the liquid temperature), then press start to begin collecting data. *Immediately add the solid from the weighing dish into the Styrofoam cup and gently mix the contents using a stirring rod.*

21. The system will automatically record data for the allotted time (240 sec), then stop.

22. Remove the sensor from the Styrofoam cup and rinse it with distilled or deionized water. Wash the contents of the cup down the drain with excess water.

23. If possible, obtain a printout of the data table and graph from the computer.

24. *Complete Data Table B:* Using the data from the computer table and graph of temperature vs. time, record the initial temperature of the solution (before adding solid) and the maximum or minimum temperature obtained after mixing.

Name: ______________________________

Class/Lab Period: ______________________

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Data Table A. *Observing Heat Changes*

Reaction	Solid + Liquid	Mass of Solid (g)	Observations
A	$NH_4Cl(s) + H_2O(l)$		
B	$CaCl_2(s) + H_2O(l)$		
C	$NaHCO_3(s) + HCl(aq)$		

Data Table B. *Measuring Temperature vs. Time*

Assigned Reaction	
Identity of Solid	
Mass of Solid (g)	
Identity of Liquid	
Volume of Liquid (mL)	
Initial Temperature (°C)	
Maximum or Minimum Temperature (°C)	

Post-Lab Questions

Attach the printout of the data table and graph for Part B to your lab report.

1. Complete the following Results Table to indicate whether each reaction in Part A represents a physical or chemical change and whether it is exothermic or endothermic.

Reaction	Physical or Chemical Change?	Exothermic or Endothermic?
A		
B		
C		

2. A chemical change involves a change in the composition of matter—the formation of a new chemical substance (product) with physical and chemical properties different from those of the reactants. Describe the evidence used to decide if any of the processes in Part A were chemical changes.
3. Did you observe any qualitative differences in the amount of heat generated in the reactions that were characterized as endothermic in Part A?
4. Consider Reaction A: Was energy released or absorbed by the reactants in this system? When you *touched* the reaction container (the plastic bag) was energy being released or absorbed by your *hand?*
5. Write a balanced equation for each of the processes in Part A. Remember to include heat on the reactant or product side, as appropriate.
6. In Part B, was the temperature that was measured a part of the system or the surroundings? How long did it take for the maximum or minimum temperature to be reached?
7. Describe in words the temperature versus time graph that was recorded in Part B. Be as specific as possible.
8. Complete the following sentence to summarize the observations and conclusions for the reaction in Part B: The reaction of ______________________________ with ______________________________ is an (exothermic/endothermic) process in which energy was (absorbed/released) by the system and the temperature of the surroundings (increased/decreased).