12. Endothermic or Exothermic Chemical Reactions

Objectives

Students recognize that chemical reactions require or release energy. They also:

- Recognize that heat—the transfer of energy—can be evidence of a chemical reactions
- Classify reactions as endothermic (energy is absorbed) or exothermic (energy is released)

Procedural Overview

Students investigate endothermic and exothermic reactions while they:

- Measure the temperature change to the surroundings as energy is transferred by different chemical reactions.
- Interpret information about the thermal energy generated during chemical reactions by exploring a temperature versus time graph
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent and analyze data
- Interpret information about the reactant (oxygen) in the exothermic chemical reaction by exploring a pressure versus time graph

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Fast response temperature sensor
- Absolute pressure sensor
- Erlenmeyer flask, 250-mL
- Graduated cylinder, 100-mL
- Quick-release connector[1]
- Barbed Tubing connector[1]
- Tubing, 20 to 30 cm[1]
- Stopper, 1-hole, for Erlenmeyer flask
- Beaker or clear plastic cup, 250-mL
- Instant hot-pack (disposable type)
- Alka-Seltzer® tablets (2)
- Distilled water, 100 mL

[1]Included with PASPORT Absolute Pressure Sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Temperature measurement and temperature measurement scales
- Use of a graduated cylinder to measure liquid volume, as well as the meaning of the term volume
- The terms reactants and products as well as a basic understanding of the nature of a chemical change (reaction)
- The indicators of a chemical change or reaction
- How to read and interpret a coordinate graph

Related Labs in This Guide

Labs conceptually related to this one include:

- Evidence of a Chemical Reaction
- Percent Oxygen in Air
- Phase Change
- Temperature versus Heat

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connect a sensor to the data collection system �(2.1)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Recording a run of data �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Measuring the difference between two points in a graph �(9.2)

- Displaying multiple graphs �(7.1.11)

- Saving your experiment �(11.1)

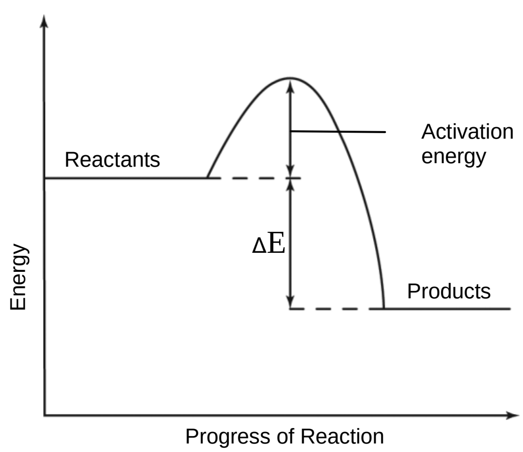
Background

Qualitative observations are a crucial means of determining whether a chemical reaction is occurring. Several different types of evidence can serve as indicators of a chemical reaction. This evidence includes formation of a gas or of a solid (known as a precipitate), a color change, the disappearance of a solid, and the release or absorption of heat.

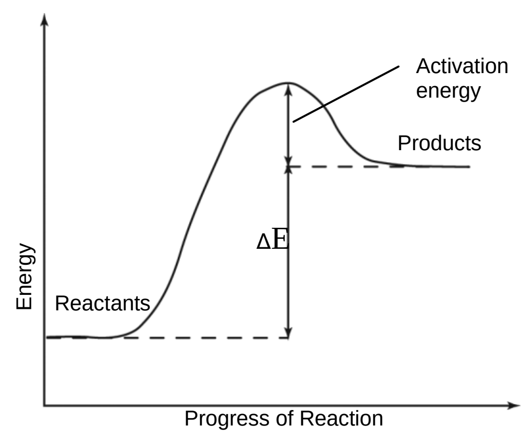
While the formation or disappearance of a substance, or a change in color, are relatively easy for students to observe, a change in thermal energy is apparent only if students are able to handle the vessel in which the reaction is occurring—and if the change is significant enough to be perceived. However, a temperature sensor can be used to measure any change in temperature and provides an excellent means of obtaining evidence for students to make quantitative observations as well as qualitative observations.

The change in temperature is used to determine the energy of reaction, which is the energy released or absorbed during a chemical reaction. In a chemical reaction, the amount of energy stored in the reacting molecules is rarely the same as the amount of energy stored in the product molecules. Depending on which is the greater, energy is either released to or absorbed from the surroundings.

Exothermic Chemical Reaction



Endothermic Chemical Reaction



Chemical reactions that release thermal energy to the surroundings are called exothermic; those that absorb thermal energy are called endothermic. Heat is the transfer or “flow” of thermal energy. Exothermic reactions will heat the surroundings because they release energy. In an exothermic reaction, the surrounding temperatures may get warmer. Endothermic reactions will cool the surroundings because they absorb energy. In an endothermic reaction, the surrounding temperatures get cooler.

However, activation energy must be added to the system to start the reaction. For example, mixing propane gas into the air does not usually cause a reaction, but if a spark is added to provide the activation energy, the combustion reaction occurs and will continue until one of the reactants is used up.

Most disposable (one-use) chemical hot-packs contain chemicals that react with air. The reactants include iron, salt (a catalyst), water, and oxygen. The oxygen is obtained from the air, and is required for the iron to oxidize, or produce iron oxide (commonly referred to as rust.

This oxidation reaction is exothermic. The salt is a catalyst for the reaction, speeding it up in much the same way it does on the undersides of cars where winter roads are salted. Hot-packs have other ingredients as well, including carbon (often in the form of charcoal) to disperse the flow of thermal energy, and a substance called vermiculite, which serves as an insulator to help retain the heat.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

1. What are the indications that a chemical reaction has taken place?

Gas production, formation of a precipitate, a color change that is permanent, and a change in thermal energy (absorption of thermal energy – endothermic or release of thermal energy – exothermic)

2. Have students identify different chemical reactions that they observe in a typical day.

Answers will vary; collect and discuss all answers at the front of the room. Add the associated indication to each reaction that you discuss. For example, for the reaction rusting, the indication would be a change of color.

Discuss the ingredients of Alka-Seltzer® and the uses of the product (read to the students the directions or indications on the package). What is an Alka-Seltzer tablet made of? It contains aspirin, heat-treated sodium bicarbonate (baking soda), and citric acid. When the tablets are dropped into water, the sodium bicarbonate and citric acid react to produce sodium citrate plus gas (bubbles).

Ask the groups to share some of their ideas about observable indicators with the class. List their ideas on the board. If necessary suggest any indicators of chemical reactions the students have missed. Ask students to describe the methods or senses they would use to qualitatively observe a change in thermal energy.

Students' identification of typical daily chemical reactions will vary. If they have difficulty in coming up with chemical reactions, prompt them with a suggestion of fireworks (which give off energy in the form of heat and light) and include other prompts of combustion reactions if necessary. For endothermic reactions, suggest chemical cold-packs used for first aid. Make sure to use the terms endothermic and exothermic as you guide students' contribution to the discussion. If necessary, help them create a mnemonic device to remember which term means "gets colder" and which means "gets warmer."

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Lab Preparation

These are the materials and equipment to set up prior to the lab:

1. Each lab group will need two Alka-Seltzer tablets. To save on cost, you may choose to purchase a generic brand of effervescent tablets. The distilled water in which the tablets are to be dissolved should be at room temperature.

2. Any brand of disposable (one-use) chemical hot-pack will work. Do not use the gel-type packs with the metal disc. Allow at least ten minutes for the chemical hot-pack to warm up in the air. Students should shake the hot-packs several times to enable the contents to mix adequately with the air. If time is critical, you may want to activate the hot-packs yourself before the students arrive. You may also wish to provide students with an activity to work on, or a topic for discussion during Part 2, while they wait for the hot-pack reaction to occur in the closed flask.

3. Temperature sensor options

   Fast response temperature sensor: If you use the rapid response temperature sensors, their thin wire will easily be sealed between the rubber stopper and the wall of the flask.

   Stainless steel temperature sensor: If you prefer to use stainless steel temperature sensors, you will need to modify the rubber stoppers in the following way: provide two holes; one for the tubing of the pressure sensor, and one for the temperature sensor. The hole to accommodate the temperature sensor may be larger in diameter than the probe part of the sensor, in which case you will need to put an additional “collar” around the probe (this plastic collar is included with the stainless steel temperature sensor).

   If these modifications are necessary, you can either make them ahead of time or show the students how to make them. If time permits, allow the students to work out the solution for the modifications themselves.

4. Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.

- Handle glassware carefully.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

3	1	2	4
Place two Alka-Seltzer tablets into a beaker of distilled water.	Measure 100 mL of distilled water to be added to a beaker.	Begin recording temperature data	Find the difference between the initial and final temperature.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Is the reaction of Alka-Seltzer and water endothermic or exothermic?

Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect a temperature sensor to the data collection system. �(2.1)

3. ☐ Display Temperature on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

4. ☐ Measure 100 mL of distilled water and pour it into the 250-mL beaker.

5. ☐ Place the temperature sensor in the water in the beaker.

6. ☐ Predict whether the reaction of Alka-Seltzer and water is exothermic (energy released, temperature increases) or endothermic (energy absorbed, temperature decreases).

Answers will vary; however, the reaction is endothermic.

Collect Data

7. ☐ Begin data recording. �(6.2)

8. ☐ Drop two Alka-Seltzer tablets into the water.

9. ☐ Continue recording data until the Alka-Seltzer tablets are completely dissolved and the temperature data is no longer changing.

10. ☐ Stop data recording. �(6.2)

Analyze Data

11. ☐ Observe your graph of temperature data. You may need to adjust the scale of the graph to view all of your data. �(7.1.2)

12. ☐ What did you observe on the graph?

The temperature decreases during this reaction.

13. ☐ Measure the difference between the initial and final temperature on your graph. �(9.2)

14. ☐ Record the difference between the initial and final temperature in Table 1 in the Data Analysis section, and identify the reaction as endothermic or exothermic.

15. ☐ Save your experiment. �(11.1)

Part 2 – What happens when a hot-pack reacts with the air?

Set Up

16. ☐ Predict whether the reaction of the disposable hot-pack is exothermic (energy released) or endothermic (energy absorbed).

Students are likely to predict correctly that this reaction will be exothermic because they know it will get hot.

17. ☐ Predict what will happen to the air pressure in a flask when the reaction of the disposable hot-pack is placed in a flask and sealed.

Answers will vary. As the iron oxidizes, the oxygen is consumed and the absolute pressure decreases.

18. ☐ Open the hot-pack and shake it gently to expose the chemicals within its pouch to the surrounding air.

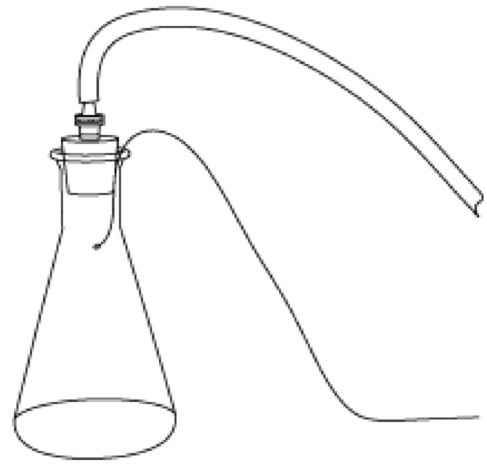
   Note: You will need to let the hot-pack's chemicals react with the air for several minutes.

19. ☐ While you are waiting for the hot-pack to begin reacting, prepare the stopper for use with the Erlenmeyer flask:

a. Insert the tubing of the pressure sensor into the hole in the stopper.

b. Connect the tubing to the pressure sensor using the quick-release connector.

c. Position the temperature sensor in the flask so that it will be sealed tightly between the mouth of the flask and the stopper.



20. ☐ Start a new experiment on the data collection system. �(1.2)

21. ☐ Connect the pressure sensor and the temperature sensor to the data collection system. �(2.2)

22. ☐ Display two graphs simultaneously �(7.1.11) —on one graph, display Temperature on the *y*-axis with Time on the *x*-axis. On the second graph, display Pressure on the *y*-axis with Time on the *x*-axis.

23. ☐ Change the sampling rate to take a measurement every 2 seconds. �(5.1)

24. ☐ Use your sense of touch to monitor the temperature of the hot-pack as its chemicals react with the air. You may need to shake the hot-pack a few times as it is reacting in order to mix air into the chemicals.

25. ☐ Why do you think it is important to shake the hot-pack?

Answers may vary, but the chemical reaction that makes the hot-pack hot requires oxygen. Shaking the hot-pack allows more oxygen to come in contact with the chemicals in the hot-pack.

26. ☐ Gently place the hot-pack into the flask.

27. ☐ Arrange the temperature sensor in the flask so it is touching the hot-pack.

28. ☐ How would the results differ if the temperature sensor was not touching the hot-pack?

If the temperature sensor does not touch the hot-pack, students would be measuring the temperature of the air above the hot-pack instead of the actual temperature of the hot-pack itself.

Collect Data

29. ☐ Begin data recording. �(6.2)

30. ☐ Observe the temperature graph for 2 to 3 minutes before closing the flask.

31. ☐ Place the stopper, with the pressure sensor tube, into the mouth of the flask, sealing it tightly and holding the temperature sensor in place.

32. ☐ Why is it important to make sure the stopper tightly seals the temperature sensor in the flask?

If the Erlenmeyer flask is not sealed, the air will leak in or out and the pressure data will not be correct.

33. ☐ Continue recording temperature and pressure data until there are no further changes.

34. ☐ Stop data recording. �(6.2)

Analyze Data

35. ☐ What do you observe on your graphs of temperature versus time and pressure versus time?

The temperature increases and then stabilized at about 36 °C. The pressure decreased, but stopped decreasing when the temperature stabilized, possibly indicating the oxygen in the flask had been used up.

36. ☐ Measure the difference between the initial and final temperature on your graph. �(9.2)

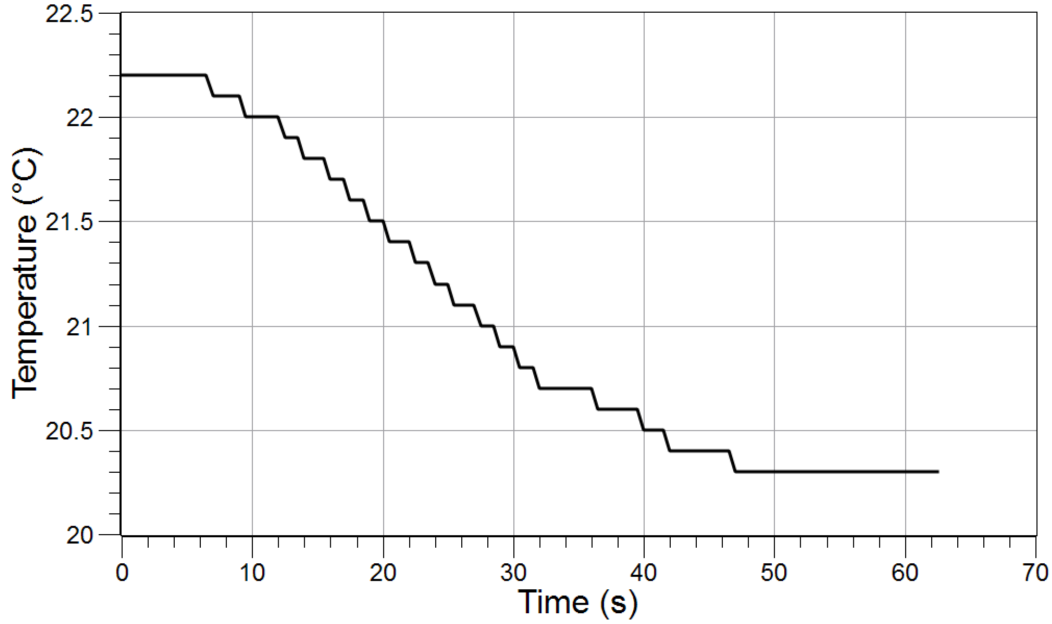
37. ☐ Record the difference between the initial and final temperature in Table 1 in the Data Analysis section, and identify the reaction as endothermic or exothermic.

38. ☐ Save your experiment and clean up your lab station according to your teacher's instructions. �(11.1)

Data Analysis

Part 1 – Is the reaction of Alka-Seltzer and water endothermic or exothermic?

Alka-Seltzer data



Part 2 – What happens when a hot-pack reacts with the air?

Hot-pack data

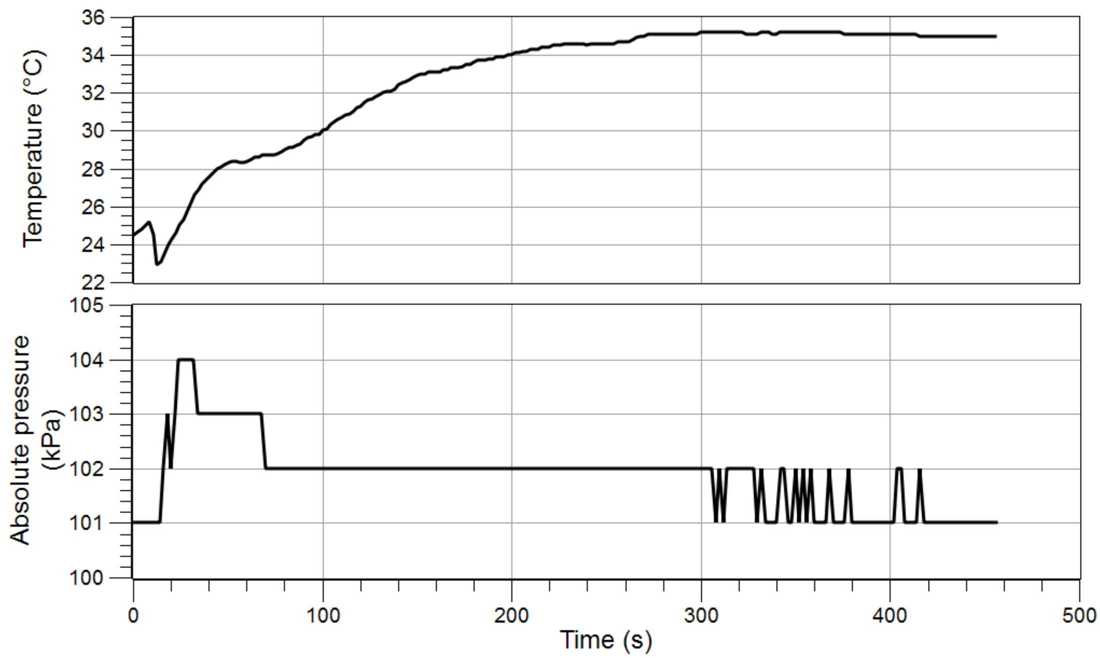


Table 1: Temperature change

Reaction	Temperature Difference (°C)	Type of Reaction
Alka-Seltzer	–1.9	Endothermic
Hot pack	10.5	Exothermic

Analysis Questions

1. How did your predictions of the "type of reaction" compare to your results in Part 1 and Part 2?

Answers will vary, as they are predictions. The Alka-Seltzer reaction is endothermic and the hot-pack reaction is exothermic.

2. How did your prediction of the air pressure change compare to your results in Part 2?

Answers will vary. Students may have predicted that the pressure in the flask would increase due to the increase in temperature, but as the oxygen is consumed, the air pressure decreases.

3. The chemical reaction between the hot-pack and the air required oxygen. What evidence do you see in your data that oxygen from the air in the flask was used for the reaction?

The air pressure decreased, providing evidence that the hot-pack used the oxygen in the flask (in the "Percent of Oxygen in Air" activity, students determine that about 20% of air is oxygen). After that, it could not react any more and the temperature of the hot-pack stopped increasing.

Synthesis Questions

Use available resources to help you answer the following questions.

1. When an automobile engine starts up, is this an endothermic or exothermic reaction? How can you tell?

The spark plug provides the activation energy that ignites the gasoline. This burning of gasoline is an exothermic reaction, which we know because the engine (the container of the reaction) gets warm.

2. Write a general statement about how to classify chemical reactions according to whether they give off energy in the form of heat or absorb heat energy from their surroundings.

When a chemical reaction causes its surroundings to get warmer it is giving off energy as heat and is called an exothermic reaction. When a chemical reaction causes its surroundings to get colder it is taking in energy by absorbing heat, and is called an endothermic reaction.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. A new chemical substance formed as a result of a chemical reaction is a:

- **A.** Reactant
- **B.** Solid
- **C.** **Product**

2. The term used in science to describe a reaction that absorbs energy in the form of heat is:

- **A.** Exothermic
- **B.** **Endothermic**
- **C.** Reactant

3. A reaction that gives off heat is classified as:

- **A.** An endothermic reaction
- **B.** A phase change
- **C.** **An exothermic reaction**

4. Pressure is measured in SI units known as:

- **A.** Newtons
- **B.** **Pascals**
- **C.** Joules

5. Suppose you mix two colorless and odorless liquids together while measuring the temperature of this mixture. You observe that the initial temperature is 23 °C, and that 5 minutes later the temperature has changed by 11.6 °C and the liquid is now light pink in color. Which of the following could be true?

- **A.** **If the final temperature represents an increase, an exothermic reaction has occurred.**
- **B.** Because of the color change, no chemical reaction could have occurred.
- **C.** If the color changed, then the temperature should have stayed the same.

6. Consider the scenario in the previous question. Under what condition could you say that an endothermic reaction had possibly occurred?

- **A.** If there had been no color change instead of a change from clear to light pink.
- **B.** If the final temperature represents an increase compared to the initial temperature.
- **C.** **If the final temperature represents a decrease compared to the initial temperature.**

7. Consider the scenario in Question 5 again. If the reaction is exothermic, what is the final temperature of the liquid?

- **A.** 11.4 °C
- **B.** **34.6 °C**
- **C.** 266.8 °C

8. Which of the following best describes a chemical reaction that is *either* endothermic or exothermic?

- **A.** A chemical reaction which requires thermal energy to be added to it.
- **B.** A chemical reaction that involves the changing of reactants into products.
- **C.** **A chemical reaction in which thermal energy is absorbed or released.**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Chemical reactions may be accompanied by changes in **energy**, often in the form of **heat**. Chemical processes that absorb heat from their surroundings are **endothermic**, while those that release heat into their surroundings are **exothermic**. The heat released or absorbed by chemical reactions usually results in a change in temperature.

Extended Inquiry Suggestion

Students may find it interesting to measure and compare their results from Part 2 of this activity with a graph of the temperature change of the hot-pack without limiting the air supply.

How could this experiment be changed or modified to illustrate Charles' law?

Investigate the temperature change of chemical reaction of ammonium nitrate and water.*

Investigate the temperature change of chemical reaction of hydrochloric acid and magnesium ribbon.*

*For these investigations, use the stainless steel temperature sensor.