21. Varying Reaction Rates

How Fast Will it Fizz?

Objectives

In this activity, students investigate temperature—a factor that affects reaction rates. They also:

- Observe and compare the varying amounts of time it takes for the reaction to run its course under different conditions
- Measure the amount of time needed for a reaction to occur
- Observe that substances react chemically in characteristic ways with other substances to form new substances (compounds) with different properties

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the temperature of two different systems
- Measure the change in temperature over time during four trials of Alka-Seltzer® tablets as they react and produce bubbles in a container of water
- Using math skills to average temperature results

Time Requirement

- Introductory discussion and lab activity, Part 1 – Making predictions — 30 minutes
- Lab activity, Parts 2 and 3 — 30 minutes
- Analysis — 30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Alka-Seltzer® tablet
- ☐ Water, room temperature
- ☐ Clear plastic cup or beaker, 300 mL (10 oz)

For each student or group:

- ☐ Data collection system
- ☐ Temperature sensor, fast response
- ☐ Graduated cylinder, 100-mL
- ☐ Alka-Seltzer® tablets
- ☐ Stopwatch
- ☐ Clear plastic cups or beakers (3), 300-mL (10 oz)
- ☐ Spoon or stirring stick
- ☐ Warm water
- ☐ Ice water

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- How to use a graduated cylinder to measure liquid volume, as well as the meaning of the term *volume*
- How to define the terms *reactants* and *products* as well as have a basic understanding of the nature of a chemical change (reaction)
- How to set up and compute averages
- How to read and interpret a coordinate graph
- Be familiar with degrees Celsius, which is the SI unit of measure for temperature

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Evaporative Cooling
- Transfer of Energy in Chemical Reactions

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix 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)
- Connecting the temperature sensor �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Showing and hiding data runs in a graph �(7.1.7)

- Adjusting the scale of a graph �(7.1.2)

- Saving your experiment �(11.1)

Background

In an Alka-Seltzer tablet the sodium bicarbonate ($NaHCO_3$) and citric acid($H_3C_6H_5O_7$) are solids and so the H+ and CO_3^{-2} ions are not free to move, collide, and react. When dropped into water, the citric acid and sodium bicarbonate dissolve, freeing the ions to react by the following equation:

$H_3C_6H_5O_{7(aq)} + 3NaHCO_{3(aq)} \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_{7(aq)}$

The conditions under which a chemical reaction occurs have a great effect on the speed or rate at which the reaction occurs. These conditions are often termed the factors that affect a reaction rate. The following key factors affect the chemical reaction rate:

- *Temperature,* under which the reaction occurs, affects the rate of the reaction. For a chemical reaction to occur, the particles, atoms, or ions that are reactants must physically come into contact with one another. Anything that increases the frequency of these encounters increases the rate at which products are formed. A general rule of thumb for most (not all) chemical reactions is that the rate at which the reaction proceeds approximately doubles for each 10 degrees Celsius (10^oC) increase in temperature. At a higher temperature, a greater proportion of the colliding particles possess the necessary energy to effectively undergo a chemical reaction and form products.

- *Concentration* of reacting substances affects the rate of the reaction. The rate of a chemical reaction depends on the frequency of the collisions between the atoms or ions of the reactants. As the concentration of the reactants decreases the frequency of collisions decreases, and the rate of the reactions slows down.

- *Surface area* affects the rate of the reaction. The rate of a chemical reaction is affected by the physical size of the reactants. Decreasing the size of the particles that make up a given weight increases the number of particles represented by the same weight. Smaller particle size results in an increase in the rate of reaction because the surface area of the reactant has been increased.

- *Nature of the reactants* (state and type of reactants) affects the rate of the reaction. If any of the products or reactants involved in a chemical reaction are gases, the rate of reaction decreases as pressure on the system increases. Changing the pressure on a reaction that involves only solids or liquids has no effect on the rate.

- *Presence of catalysts* affects the rate of the reaction. A catalyst is a substance that speeds up a reaction, but is chemically unchanged at the end of the reaction. When the reaction has finished, there will be exactly the same mass of catalyst as there was at the beginning.

To increase the rate of a reaction you need to increase the number of successful collisions. One possible way of doing this is to provide an alternative way for the reaction to happen.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

- Drop an Alka-Seltzer tablet into a plastic cup filled with water at room temperature. Ask the students what they observe. Discuss how many different states of matter are present in the cup. Ask the students if a chemical reaction is occurring in the cup. They should be able to relate the formation of gas bubbles to the production of a new substance, and recognize this as evidence that a reaction is taking place. Explain to the students that the disappearance of the solid Alka-Seltzer tablet when placed in water is due to the reaction of sodium bicarbonate ($NaHCO_3$) and citric acid ($H_3C_6H_5O_7$). Write the chemical formulas for these reactants on the board. If the students are familiar with these chemical symbols—that is, if they know that *C* stands for carbon, *H* for hydrogen, and so on—ask the students which gas they think is released during the reaction (carbon dioxide, or CO_2).

- Direct the students to the "Thinking About the Question" section After a few minutes ask the groups to share some of their ideas with the class. After listening to the students' ideas, summarize by suggesting that conducting a reaction at a higher temperature puts more energy into the system and increases the reaction rate.

- Direct the students to the "Investigating the Question" section

Preparation and Tips

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

- Each lab group needs a total of four Alka-Seltzer tablets. To save money, you can purchase the "store" brand of effervescent tablets.

- Remind students to place the whole tablet into the water because breaking the tablet changes the variable of surface area.

- In order to save time in the ice water step (Part 3), you may choose to have ice water available to the student groups rather than having them make their own ice water.

- Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Handle glassware carefully.

- Do not use water hotter than 40 °C.

Driving Question

How do different temperatures affect the rate of a chemical reaction?

Thinking about the Question

If you have ever helped your family to prepare a meal or if you have ever baked, then you are familiar with changes in the rates of chemical reactions. There are many examples of changes in *reaction rates* in our daily lives, and some of the most easily observed changes happen in cooking. An egg cooks faster in a hotter pan. Bread dough rises more quickly in a warm place than in a cool one.

If you have had a glow-in-the-dark light stick before, such as the kind worn at concerts, you might have heard that putting the used light sticks in the freezer will help make them last longer. Such light sticks work by producing light through a chemical reaction. Placing a light stick into hot water makes it glow more intensely, showing that the reaction runs faster at a higher temperature. Placing it in the freezer slows down the rate of reaction.

The rate of a chemical reaction is the time required for a given quantity of *reactants* to be changed to *products*.

Can you think of other chemical reactions in which rates are affected by changes in temperature? Discuss with the members of your group a general rule that relates temperature to reaction rate.

> When substances or chemicals are warmer they seem to react faster. Chilling substances or chemicals can make them react more slowly. For example, the "Mentos® and Diet Coke" reaction produces a faster and bigger reaction when the soda is at least at room temperature and not right out of the refrigerator. Also, milk can spoil sooner if left out on the table, where it is warmer than in the refrigerator.

Sequencing Challenge

Note: This is an optional ancillary activity

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.

1	2	3	5	4
Make sure each lab group member is aware of safety rules and procedures for this lab.	Gather the necessary equipment and materials, or check to see that they have been provided to your group.	Fill a cup or beaker with 200 mL of warm tap water.	Drop the Alka-Seltzer tablet into the cup or beaker of water.	Begin recording the first run of temperature data.

Investigating the Question

Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1 – Making predictions

1. ☐ Predict what the reaction rate will be for a chemical reaction that occurs at room temperature.

   We predict that at room temperature there will be a faster reaction of the Alka-Seltzer.

2. ☐ Predict what the reaction rate will be for the same type of chemical reaction that occurs at a temperature close to freezing (ice-cold water).

   We predict that if the same kind of Alka-Seltzer is put into ice water, it will react more slowly than when put into the warm water.

Part 2 – What is the effect of warm temperature on reaction rate?

Trial 1

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

4. ☐ Fill a clear plastic cup or beaker with 200 mL of room temperature water.

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

6. ☐ Place the temperature sensor in the plastic cup or beaker.

7. ☐ Start recording the first run of temperature data. �(6.2)

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

9. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch. If you are not using a stopwatch, note on your graph the exact time that you dropped the Alka-Seltzer tablet in the water.

10. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording the first run of data. �(6.2)

11. ☐ Why do you think it is important to note the time as exactly as possible?

We are trying to find out how long it took the Alka-Seltzer to stop making fizz, so we do not want any time included for other things.

12. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

Trial 1 ___34.5___ seconds

13. ☐ Pour out the water and dissolved Alka-Seltzer tablet, according to your teacher's instructions.

14. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of room temperature water.

Trial 2

15. ☐ Start recording a second run of temperature data. �(7.1.3)

16. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch. If you are not using a stopwatch, note on the graph the exact time that you dropped the Alka-Seltzer tablet in the water.

17. ☐ Continue collecting data until the Alka-Seltzer tablet is completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph of data, and then stop recording the second run of data. �(6.2)

18. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

Trial 2 ___37___ seconds

19. ☐ What is the reason for repeating this trial and averaging the time? Why is this considered good experimental design?

Conducting more than one trial provides more data to average. More data makes for a better experiment. For example, if the second data run was considerably different from the first run, we might suspect that we made an error because we would have a basis for comparison. In our case, in the first trial (ice-cold water) the temperature was less cold because it had time to mix. In the second trial we used fresh water and ice because, in this particular experiment, the water used in the first trial was spilled.

Part 3 – What is the effect of ice-cold temperature on reaction rate?

Trial 1

20. ☐ Fill a clear plastic cup or beaker with 200 mL of water. Add five ice cubes to the cup, stir to mix, and wait one minute. Measure exactly 200 mL of the chilled water into another cup or beaker.

21. ☐ Place the temperature sensor in the plastic cup or beaker.

22. ☐ Using the same graph as in Part 2, start recording the first run of temperature data. �(6.2)
Note that this will be your third run of temperature data overall. You may choose to hide the previous runs of temperature data while you are conducting this part of the experiment. �(7.1.7)

23. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch, or note the exact time on the graph that you dropped the Alka-Seltzer tablet in the water.

24. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording data. �(6.2)

25. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

Trial 1 ____110____ seconds

Trial 2

26. ☐ Again fill the clear plastic cup or beaker with 200 mL of water. Add five ice cubes to the cup, stir to mix, and wait one minute.

27. ☐ Rinse and refill the clear plastic cup or beaker from the reaction with 200 mL of the chilled water.

28. ☐ Start recording the second run of temperature data �(6.2) for the ice water. Note that this will be your fourth run of data overall.

29. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch, or note the exact time on the graph that you dropped the Alka-Seltzer tablet in the water.

30. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording the second run of data. �(6.2)

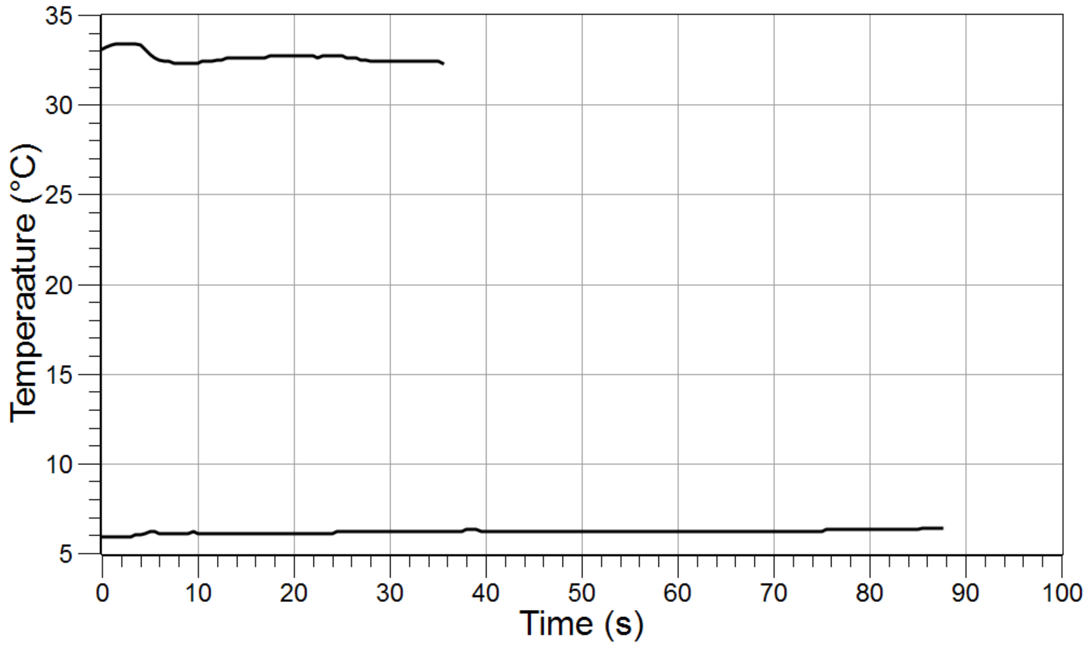
31. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

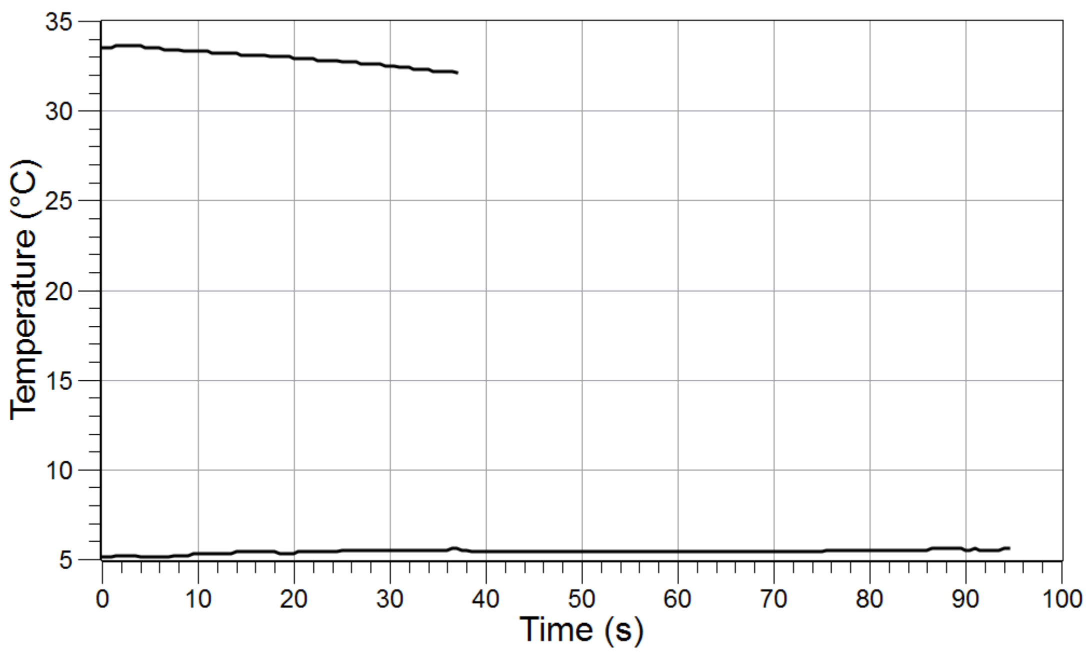
Trial 2 ____70____ seconds

32. ☐ Save your experiment. �(11.1)

Sample Data

The first graph below shows the first runs of warm water and ice-cold water. The second graph shows the second runs of warm water and ice-cold water.





Answering the Question

Analysis

1. Determine the average temperature for the experiment you performed with warm water in Part 2 of the Investigating the Question section.

   Average time to finish fizzing in warm water: 37.75 seconds

   Sample calculation:

   $$\frac{34.5 + 37}{2} = \frac{71.5}{2} = 37.75\text{s}$$

2. Determine the average temperature for the experiment you performed with ice-cold water in Part 3 of the Investigating the Question section.

   Average time to finish fizzing in ice-cold water: 90.75 seconds

   Sample calculation:

   $$\frac{87.5 + 92}{2} = \frac{181.5}{2} = 90.75\text{s}$$

3. Review the average time needed for the Alka-Seltzer tablet to finish fizzing in each part. Using room temperature water, how many times faster is the reaction rate than with the ice-cold water?

   We divided 90.75 by 37.75 to find this out, and we got 2.40 rounded to the nearest hundredth. This means that the reaction in the room temperature water was 2.40 times faster than the reaction in the ice-cold water.

   Sample calculation:

   $$\frac{90.75\text{s}}{37.75\text{s}} = 2.40 \text{ times faster}$$

4. How does temperature affect the rate of a chemical reaction?

   We found out that the chemical reaction of an Alka-Seltzer tablet was 2.40 times faster in room temperature water than in ice-cold water. We wanted to perform another trial at a medium temperature to see if it took a medium amount of time.

Multiple Choice

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

1. Rate of reaction:

   A. A measure of how fast a reaction occurs
   B. An equation showing the products and reactants of a chemical reaction
   C. A chemical reaction changes reactants into new products with new properties
   D. An element or compound that enters into a chemical reaction

2. Liquid:

   A. A state of matter that has no fixed shape but that has a definite volume
   B. The process where reactants change to form products
   C. Formulas and symbols are used to show what happens during a chemical reaction
   D. One of the original substances before a chemical reaction takes place

3. Product:

   A. Matter that has a definite shape and takes up a definite amount of space
   B. A substance that undergoes a chemical reaction, often by combining with another substance.
   C. An expression in which symbols, formulas, and numbers are used to represent a chemical reaction
   D. A substance formed by a chemical reaction

4. Solid:

   A. A state or phase of matter in which a substance has no definite shape or volume
   B. A process in which one or more substances are changed into others, including color or temperature changes or bubbles being formed
   C. A state of matter that has a definite shape and a definite volume
   D. Matter with no definite shape but with a definite volume

5. Reactant:

   A. The process where substances change to form products
   B. Element or compound that enters into a chemical reaction
   C. A measure of how fast a reaction occurs
   D. An equation showing the products and reactants of a chemical reaction

6. Reaction:

   A. Matter that has a definite shape and takes up a definite amount of space
   B. A chemical process changes reactants into new products with new properties
   C. An element or compound that enters into a chemical reaction
   D. A state of matter that has no fixed shape but that has a definite volume

7. Chemical equation:

   A. A substance formed by a chemical reaction
   B. A state of matter that has no fixed shape but that has a definite volume
   C. A chemical reaction changes reactants into new products with new properties
   D. Formulas and symbols are used to show what happens during a chemical reaction

8. Gas:

   A. A state or phase of matter in which a substance has a definite volume but no definite shape

   B. A description of a chemical reaction using chemical symbols and formulas to represent reactants and products

   C. A substance that undergoes a chemical reaction, often by combining with another substance

   D. A state or phase of matter in which a substance has no definite shape or volume

Key Term Challenge

Fill in the blanks from the randomly ordered words below.

gas	product	solid	reaction
liquid	a chemical reaction	reaction rate	reactant

1. Iron and oxygen change into iron oxide during a chemical ______reaction_______.

2. The rate of ____a chemical reaction______ is the time required for a given quantity of reactants to be changed to products.

3. Matter can be a _________solid_________, a liquid, or a gas.

4. Carbon dioxide is a _______product_________ of the chemical reaction between vinegar and baking soda.

5. The phase of matter that carbon dioxide is usually found as is a _________gas__________.

6. A _______liquid________ takes on the shape of its container.

Further Investigations

Investigate the reaction rate when there is more surface area (smaller particle size) available to react, by breaking up the Alka-Seltzer tablet before recording the time required to completely finish fizzing at warm and cold temperatures.

Investigate the reaction rate for a wider range of temperatures. Can you predict the reaction rate for specific temperatures?

Design an experiment that makes use of the pressure sensor to measure the amount of gas produced by an Alka-Seltzer tablet fizzing in warm and cold water.

If you predicted that the gas produced in this experiment is actually carbon dioxide (CO_2), design an experiment to test your prediction.

Design an experiment to test the reaction rate of Mentos® candy dropped into Diet Coke® or other carbonated cola. Which temperature results in the highest “fountain,” room-temperature or ice-cold? What does this have to do with rate of reaction?

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.