10. Conservation of Matter

Objectives

In this investigation, students test the law of conservation of matter for both physical and chemical changes.

Procedural Overview

Students conduct the following procedures:

- Find the mass of the reactants before the chemicals are reacted and the mass of the products after the reaction has occurred (in a chemical reaction where a precipitate forms)
- Measure the mass of a solute and a solvent separately and the mass of the solution after combining the two
- Determine the mass of gas produced during a chemical reaction by calculating the difference between the mass of the initial reactants and the mass of the final products (the final products do not include the escaped gas)

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Balance
- Test tube (2), 15-mm x 100-mm
- Beaker, 250-mL
- Plastic soda bottle (with cap), 500-mL
- Sodium nitrate ($NaNO_3$), 5 g
- 0.1 M Sodium sulfate (Na_2SO_4), 5 mL[1]
- 0.1 M Strontium chloride ($SrCl_2$), 5 mL[2]
- Sodium bicarbonate ($NaHCO_3$), 8 g[3]
- 5% Acetic acid ($HC_2H_3O_2$), 30 mL[4]
- Distilled (deionized) water, 10 mL

[1]To formulate using solid sodium sulfate (Na_2SO_4), refer to the Lab Preparation section.
[2]To formulate using solid strontium chloride ($SrCl_2$), refer to the Lab Preparation section.
[3]Sodium bicarbonate ($NaHCO_3$) is household baking soda.
[4]Household vinegar can be used for the 5% acetic acid ($HC_2H_3O_2$).

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Mass
- ♦ Chemical and physical changes
- ♦ Evidence of a chemical reaction

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Evidence of a Chemical Reaction

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.

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

Background

The law of conservation of matter states that matter cannot be created or destroyed by a physical or chemical change. In both cases, the number of atoms remains the same before and after the change. The law of conservation of matter does not apply to nuclear reactions, where matter may be changed to energy.

In a physical change, the substances before and after the change remain chemically the same, although the arrangement of the *molecules* and average motion of the particles may be different. During a chemical reaction, chemical changes occur and the *atoms* of one or more substances undergo rearrangements. The result of these rearrangements is the formation of new and different substances. The substances are made of the same atoms but are put together in a new way. All of the original atoms are still present.

Because of the law of conservation of matter we are able to write balanced chemical equations. Such equations make it possible to predict the masses of individual reactants and products that are involved in a chemical reaction.

In the first part of this experiment, sodium sulfate (Na_2SO_4) chemically reacts with strontium chloride ($SrCl_2$) to form dissolved sodium chloride (NaCl) and strontium sulfate ($SrSO_4$). Strontium sulfate is a white, solid precipitate. The balanced chemical equation for this reaction is:

$$Na_2SO_4(aq) + SrCl_2(aq) \rightarrow 2NaCl(aq) + SrSO_4(s)$$

In the second part of this experiment, a solution is made by physically dissolving sodium nitrate in water to form a solution. This becomes cold to the touch and is an example of an endothermic process.

$$NaNO_3(s) \rightarrow NaNO_3(aq)$$

In the third and fourth parts of this experiment, sodium bicarbonate ($NaHCO_3$) chemically reacts with vinegar (acetic acid, $HC_2H_3O_2$). This reaction produces sodium acetate ($NaC_2H_3O_2$), water (H_2O), and carbon dioxide gas (CO_2).

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$$

First, the reaction is performed in an open system. Then it is performed again in a closed system. In the open system, the carbon dioxide gas is allowed to escape to the atmosphere. A loss of mass between the reactants and products occurs, but is not a violation of the law of conservation of matter. This is proven when the reaction is repeated in a closed system, in which the carbon dioxide gas is retained.

Pre-Lab Discussion and Activity

Physical and Chemical Changes

Place a small beaker containing an ice cube on a balance. As the ice cube melts, record its mass periodically while engaging the students in a discussion about change. Review the differences between physical and chemical changes. Discuss whether particular properties of the substance change when the substance undergoes a physical or chemical change. Discuss the effects of chemical and physical changes on the total mass of the system.

1. What is a physical change? Give several examples.

A physical change is one in which the physical appearance of a substance changes, but the chemical structure of the substance remains the same. Water (H_2O) is an example. Melting ice, boiling water, and condensing steam are all examples of physical changes in which a specific chemical substance is in different physical forms.

2. When an ice cube melts, what remains the same? What changes?

Ice is made of H_2O molecules as is liquid water. Therefore, the chemical substance stays the same. The number of water molecules present also does not change, which means that the mass of the ice cube is the same as the mass of the liquid water.

The physical appearance of the water changes. This is because the speed of the water molecules and the distance between the water molecules changes.

3. Does the mass before and after a physical change always stay the same?

Yes, during the physical change, the number of molecules before and after the change remains constant. Therefore, the mass does not change. This aligns with the law of the conservation of matter. It states that matter can neither be created nor destroyed, only changed.

4. What is a chemical change (or chemical reaction)? What evidence suggests a chemical change has occurred? Give several examples.

A chemical change is one in which a completely new substance is formed. The formation of a solid product from dissolved reactants (precipitate), the evolution of gas, a significant color change, and a change in temperature all indicate that a chemical change has occurred. For example burning paper, rusting, and reacting an acid with a base are all examples of chemical changes.

5. Does mass stay the same during a chemical change?

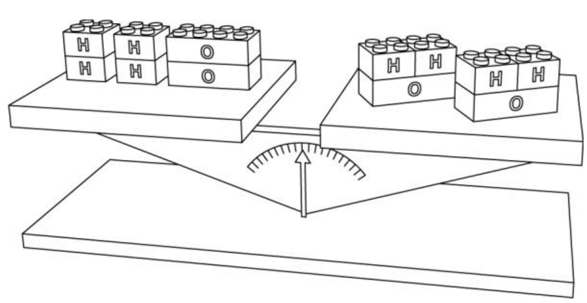
Yes, the atoms of reacting substances can rearrange and form new molecules. New substances form, even though the number of atoms of the total system remains unchanged. Often this is not obvious. For example, when burning paper, the mass of the paper seems to decrease, however the missing mass is simply changed into the gases that are released during burning. This aligns with the law of the conservation of matter which states that matter can neither be created nor destroyed.

Law of Conservation of Matter

Write the law of conservation of matter on the board: "Matter cannot be created or destroyed, only changed in form." Write the equation for the composition of water, $2H_2 + O_2 \rightarrow 2H_2O$, on the board. Ask the students what each of the numbers mean. As they are telling you, build each model using a model kit. Use an elementary school, double-pan balance and place the models on the pans. Place the reactants on one side and the products on the other. Most elementary school balances are not very precise and the students should see the reactants and products balance (even if there are minor variations in the mass of the individual components making up the models).

Teacher Tip: If you do not have a double-pan balance, you can simply measure the mass of the models on an electronic balance or single-pan balance and record the results. A less precise scale is preferred.

Teacher Tip: If you do not own a model kit, models of compounds can be built using large plastic preschool building blocks. Write the symbols for common elements on the different colored blocks.



$2H_2 \quad + \quad O_2 \quad \rightarrow \quad 2H_2O$

6. The law of conservation of matter states that matter cannot be created or destroyed. What does this mean in your own words?

Everything must be accounted for. Atoms cannot disappear or appear from nowhere. They can only be rearranged.

7. For the reaction of hydrogen with oxygen to produce water, what does each number in the equation mean? How can we build models of the molecules involved in this reaction?

The subscripts refer to the number of atoms of that type in each molecule. The subscript "2" in O_2 means there are two oxygen atoms in one molecule of oxygen. The coefficient (the number in front of the molecular formula) refers to the number of molecules. The "2" in front of the hydrogen molecule ($2H_2$) means there are two hydrogen molecules.

8. A different chemical reaction involves the decomposition of hydrogen peroxide to form water and oxygen gas. Beginning with two molecules of hydrogen peroxide (H_2O_2), how many water and oxygen molecules are produced to balance the pans?

The balanced chemical reaction is: $2H_2O_2 \rightarrow 2H_2O + O_2$. Two molecules of hydrogen peroxide decompose into two molecules of water and one molecule of oxygen. Notice on the reactant side, that there are a total of four hydrogen atoms and four oxygen atoms making up two hydrogen peroxide molecules. On the product side, the law of conservation of matter is obeyed. Although the four hydrogen atoms and four oxygen atoms are rearranged into different molecules, they exist on the product side as well.

Teacher Tip: Build two hydrogen peroxide molecules. Then allow the students to use the same number of each type of block to build the product molecules. Place their products on the balance and compare with the original reactant molecules.

Lab Preparation

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

1. Prepare 100 mL of 0.1 M sodium sulfate (Na_2SO_4). This is enough for 20 lab groups.

Dissolve 1.4 g of anhydrous Na_2SO_4 in 100 mL of distilled water.

Alternatively, dissolve 3.2 g of sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$) in 100 mL of distilled water.

2. Prepare 100 mL of 0.1 M strontium chloride ($SrCl_2$). This is enough for 20 lab groups.

Dissolve 1.6 g of anhydrous $SrCl_2$ in 100 mL of distilled water.

Alternatively, dissolve 2.7 g of strontium chloride hexahydrate ($SrCl_2 \cdot 6H_2O$) in 100 mL of distilled water.

3. Sodium bicarbonate ($NaHCO_3$) is household baking soda.

4. The 5% acetic acid ($HC_2H_3O_2$) may be replaced with household vinegar.

Safety

Follow all standard laboratory procedures.

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.

2	1	5	3	4
Determine the total mass of the starting substances and the glassware they are contained within.	Measure the starting substances and place in them into a 250-mL beaker.	Compare the mass and of the starting substances and the ending substances.	Mix the starting substances and record any observations.	Measure the mass all of the final substances and glassware.

Procedure with Inquiry

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

Collect Data

Part 1 – Sodium Sulfate Solution and Strontium Chloride Solution

1. ☐ Place 5.0 mL of sodium sulfate solution (Na_2SO_4) into a test tube, and place the test tube in a 250-mL beaker.

2. ☐ Place 5.0 mL of strontium chloride solution ($SrCl_2$) into another test tube, and place it in the 250-mL beaker with the other test tube containing Na_2SO_4.

3. ☐ Determine the total mass of the solutions, test tubes, and beaker by placing them on a balance. Record this initial mass below.

Initial mass of Na_2SO_4, $SrCl_2$, and glassware (g): 135.10 g

4. ☐ Predict the amount of product that is produced from these reactants.

There should be the same mass of products as there are reactants.

5. ☐ Carefully pour the strontium chloride solution and the sodium sulfate solution into the beaker. Observe the chemical reaction and record your observations below.

A white solid forms (a precipitate) making the solution look cloudy.

6. ☐ How do you know a chemical reaction took place?

When mixed, the reactants formed a precipitate. The mixed solution appears milky. The bottom of the beaker may have become slightly cooler.

7. ☐ Place *both* test tubes back inside the beaker and measure the mass of the test tubes, beaker, and solution again. Record the final mass below.

Final mass of Na_2SO_4, $SrCl_2$, and glassware (g): __________135.08 g ________

8. ☐ Why is it important to measure the mass of all the glassware together after the reaction occurs?

The initial mass also includes the mass of all the glassware. If the test tubes are removed and not measured after the reaction, the final mass is missing the mass of the original test tubes. This distorts the comparison.

9. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the next part of this investigation.

Part 2 – Dissolving of Sodium Nitrate

10. ☐ Place approximately 5 g of solid sodium nitrate ($NaNO_3$) into a 250-mL beaker.

11. ☐ Place 10 mL of distilled water into a test tube, and place the test tube inside the 250-mL beaker containing the 5 g of $NaNO_3$(s).

12. ☐ Determine the total mass of the water, test tube, $NaNO_3$(s), and beaker by placing them on the balance. Record this initial mass below.

Initial mass of $NaNO_3$, H_2O, and glassware (g): __________133.71 g ________

13. ☐ Predict the amount of product that is produced from these reactants.

Again, there should be the same mass of products as there are reactants.

14. ☐ Pour the water into the beaker with the solid and swirl the mixture until all of the solid dissolves. Record your observations below.

The solid dissolves and it feels cold.

15. ☐ Does a chemical reaction take place? Explain your reasoning.

No chemical reaction happens because no new substance is formed. The heat absorbed is used to break the lattice structure, but no new substance forms.

16. ☐ Place the test tube back inside the beaker and measure the mass of the test tube, beaker, and solution again. Record the final mass below.

Final mass of $NaNO_3$, H_2O, and glassware (g): _______133.70 g ________

17. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the next part of this investigation.

Part 3 – Sodium Bicarbonate and Acetic Acid (Open System)

18. ☐ Place approximately 5 g of solid sodium bicarbonate ($NaHCO_3$) into a 250-mL beaker.

19. ☐ Pour 10 mL of 5% acetic acid ($HC_2H_3O_2$) into one test tube and an additional 10 mL into a second test tube. Place both test tubes inside the 250-mL beaker containing the $NaHCO_3$(s).

20. ☐ Determine the total mass of the $HC_2H_3O_2$, test tubes, $NaHCO_3$(s), and beaker by placing them on the balance. Record this initial mass below.

Initial mass of $NaHCO_3$, $HC_2H_3O_2$, and glassware (g): 153.23 g

21. ☐ Predict the amount of product that is produced from these reactants.

The mass of the products will appear to be less than expected. This is because the reaction takes place in an open system. One of the products of the reaction is a gas. The gas escapes to the atmosphere and therefore is not measured. This is not a violation of the law of conservation of mass. Instead, it is an example of not measuring all of the components together. (This is similar to neglecting to add the test tubes when measuring the mass of the products.)

22. ☐ Pour the acetic acid from one of the test tubes into the beaker with the solid and swirl the mixture until the reaction subsides.

23. ☐ Pour the acetic acid from the second test tube and swirl the mixture until the reaction stops. Record your observations below.

Bubbles form.

24. ☐ Does a chemical reaction occur? Explain.

Yes, a chemical reaction occurs. The presence of bubbles indicates that a new substance (a gas) is produced.

25. ☐ Place the test tubes back inside the beaker and measure the mass of the test tubes, beaker, and solution again. Record the final mass below.

Final mass of $NaHCO_3$, $HC_2H_3O_2$, and glassware (g): 152.50 g

26. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the final part of the experiment.

Part 4 – Sodium Bicarbonate and Acetic Acid (Closed System)

27. ☐ Place approximately 3 g of solid sodium bicarbonate ($NaHCO_3$) in a clean 500-mL plastic soda bottle.

28. ☐ Pour 10 mL of 5% acetic acid ($HC_2H_3O_2$) into a test tube.

29. ☐ Carefully slide the test tube inside the plastic bottle containing the $NaHCO_3$(s), making sure not to spill any of the acetic acid.

30. ☐ Screw on the cap of the plastic bottle tightly.

31. ☐ While still being careful not to spill the acetic acid, place the bottle and its contents on a balance. Record this initial mass below.

Initial mass of the soda bottle and its contents (g): __________46.48 g________

32. ☐ Why must you be careful not to spill the acetic acid at this point in the experiment?

The point of this experiment is to compare the mass of the system before and after a chemical change occurs. If even a small amount of acetic acid and sodium bicarbonate mix, they partially react.

33. ☐ Gently tip the bottle until the test tube inside spills the acetic acid into the sodium bicarbonate. Record your observations below.

Bubbles form and the pressure within the bottle increases.

34. ☐ Once the reaction is complete, and without unscrewing the cap, measure the mass of the bottle and its contents. Record the mass below.

Final mass of the closed soda bottle and its contents (g): _______46.45 g _______

35. ☐ Remove the cap from the bottle and allow the gas to escape.

36. ☐ Why did the pressure inside the bottle increase?

One of the products of the reaction between sodium bicarbonate and acetic acid is a gas (carbon dioxide). Because the gas is unable to escape, it remains trapped inside the bottle, causing the pressure to increase.

37. ☐ Compared with the mass of the bottle and its contents before unscrewing the cap, do you expect the mass to be greater, less, or the same after the gas escapes?

Carbon dioxide gas is matter. It has mass and occupies space. Opening the bottle allows the carbon dioxide to escape. This causes the mass of the system to be less than when the carbon dioxide is trapped inside the bottle.

38. ☐ Screw on the cap and measure the mass of the bottle and its contents. Record the final mass below.

Final mass of the open soda bottle and its contents (g): _______46.17 g _______

39. ☐ Dispose of the solutions and clean up according to your teacher's instructions.

Data Analysis

1. ☐ Determine the change in mass for each process. Record the results in Table 1 below.

Table 1: Initial mass, final mass, and change in mass

Experiment	Initial Mass (g)	Final Mass (g)	Change in Mass (g)
Part 1: $Na_2SO_4 + SrCl_2$	135.10	135.08	0.02
Part 2: Dissolving $NaNO_3$	133.71	133.70	0.01
Part 3: $NaHCO_3 + HC_2H_3O_2$ (open system)	153.23	152.50	0.73
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system before opening the bottle)	46.48	46.45	0.03
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system after opening the bottle)	46.48	46.17	0.31

2. ☐ How many grams of gas (CO_2) were formed in part 3 and part 4 of this investigation? How do you know?

In part 3 of this experiment, 0.73 g of CO_2 gas were formed. In part 4 of this experiment, 0.31 g of gas were formed. The amount of gas released is equal to the difference between the mass of the reactants and the products.

3. ☐ Calculate the percent change in mass for each part of the experiment and record them in Table 2.

$$\text{percent change} = \left|\frac{\text{change in mass}}{\text{initial mass}}\right| \times 100$$

Table 2: Percent change in mass

Experiment	Show Your Work Here	Percent Change in Mass
Part 1: $Na_2SO_4 + SrCl_2$	$\left\lvert\frac{0.02\text{ g}}{135.10\text{ g}}\right\rvert \times 100 = 0.007\%$	0.01%
Part 2: Dissolving $NaNO_3$	$\left\lvert\frac{0.01\text{ g}}{133.71\text{ g}}\right\rvert \times 100 = 0.007\%$	0.007%
Part 3: $NaHCO_3 + HC_2H_3O_2$ (open system)	$\left\lvert\frac{0.73\text{ g}}{153.23\text{ g}}\right\rvert \times 100 = 0.48\%$	0.48%
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system before opening the bottle)	$\left\lvert\frac{0.03\text{ g}}{46.48\text{ g}}\right\rvert \times 100 = 0.06\%$	0.06%
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system after opening the bottle)	$\left\lvert\frac{0.31\text{ g}}{46.48\text{ g}}\right\rvert \times 100 = 0.67\%$	0.67%

Analysis Questions

1. Why is the percent change in mass not always exactly 0%?

Balances are very sensitive pieces of equipment. Slight variations in the environment of the balance as well as unavoidable losses or gains in mass during the experimental procedure can change the final, displayed results.

2. What happens to the mass in part 3 and the second part of 4? Is this a case where the law of conservation of matter is untrue? Explain.

In both part 3 and the second part of 4, the reaction is open to the atmosphere. The gaseous products are allowed to escape from the container. The mass of the escaped gas could not be measured. Accounting for the mass of any gas in the reaction helps support the law, not refute it.

3. Do your results confirm the law of conservation of matter? Why or why not?

Yes, the results confirm the law of conservation of matter. In parts 1, 2, and the first part of 4, the masses before and after the change are essentially the same (different by less than 0.1%). In part 3 and the second part of 4, the final mass is less than the beginning mass, but these differences are due to the gas that escaped.

4. Does the law of conservation of matter apply to both physical and chemical changes?

Yes. In this experiment, part 1 is a chemical change and part 2 is a physical change. In both cases matter is conserved.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In the process of electrolysis, electricity is used to convert water into its gaseous elements, hydrogen (H_2) and oxygen (O_2): $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$. If electrolysis is performed using 30 grams of water, how many grams of gas are produced?

After all of the water reacts, 30 grams of gas are produced. The law of conservation of matter states that you cannot gain or lose any mass during the reaction.

2. Pyrite is a shiny yellow mineral also known as "fool's gold". It is composed of iron and sulfur. If a 36.4 gram sample of pyrite is broken down into its elemental components and 17.3 grams of iron are produced, how many grams of sulfur are produced?

There are 19.1 grams of sulfur produced. That is the difference between the pyrite (36.4 g of combined iron + sulfur) and the iron (17.3 g).The law of conservation of matter states that you cannot gain or lose any mass during the reaction.

3. When a log burns, the resulting ash has less mass than the log. Why does this loss of mass not violate the law of conservation of matter?

When a log burns, gases (mainly carbon dioxide and water vapor) are formed and escape into the atmosphere. The ash (carbon) that remains after burning has less mass than the original log.

$$Log(s) + O_2(g) \rightarrow CO_2(g) + H_2O(g) + C(s)$$

Multiple Choice Questions

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

1. In a chemical reaction how does the mass of the products compare with the mass of the reactants?

- **A.** Greater than
- **B.** Less than
- **C.** **Equal to**
- **D.** Depends on if the reaction is endothermic or exothermic

2. **If 7 grams of sodium (Na) reacts with 12 g of chlorine (Cl_2), how much table salt (sodium chloride, NaCl) is produced?**

- **A.** 5 grams
- **B.** 13 grams
- **C.** **19 grams**
- **D.** 26 grams

3. **What is the mass of the resulting gas when 3 grams of dry ice (solid carbon dioxide, CO_2) sublimes to gaseous CO_2?**

- **A.** 0 grams
- **B.** 2 grams
- **C.** **3 grams**
- **D.** 5 grams

4. **During a chemical reaction how does the total number of atoms of the reactants compare with the total number of atoms of the products?**

- **A.** **Equal to**
- **B.** Greater than
- **C.** Less than
- **D.** Depends on the type of reaction

5. **Which of the following states that matter cannot be created or destroyed?**

- **A.** Kinetic molecular theory
- **B.** Collision theory
- **C.** Atomic theory
- **D.** **Law of conservation of matter**

Key Term Challenge

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

1. The l**aw of conservation of matter** states that **matter** cannot be created or destroyed, only changed in form. This means that any atoms present at the beginning of a reaction must also be present at the end of the reaction. The **number** of atoms can be counted in the laboratory by using a **balance** and measuring the **mass** of the reactants and the products. The mass before a change and after a change is **the same**.

2. During **physical** changes atoms do not rearrange to form new substances even though the **appearance** of the substance changes. An example is ice melting into liquid water. During **chemical** changes the atoms do rearrange to form new substances. If any of these new substances are gaseous, they may escape from a reaction. This occurs in **open** systems. C**losed** systems seal reactions from their surroundings so that gaseous products can be trapped and measured.

Extended Inquiry Suggestions

Perform an experiment in which either oxygen or carbon dioxide gas is one of the products. Use either a carbon dioxide gas sensor or an oxygen gas sensor to measure the ppm (parts per million) being produced. Calculate the mass of the gas along with the other products to determine if the mass of the reactants is the same as the mass of the products.

Determine the effect of melting or freezing on the mass of a substance.

Determine the effect of melting and freezing multiple times on the mass of a substance.

11. Varying Reaction Rates

Objectives

Students recognize temperature is a factor that affects chemical reaction rates.

Procedural Overview

Students gain experience conducting the following procedures:

- Observing and comparing the time it takes for a reaction to run its course under different temperature conditions
- Measuring the time needed for a reaction to occur based on a graphical representation
- Using math skills to average temperature results

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
- Graduated cylinder, 100-mL
- Clear plastic cups or beakers (3), 300-mL (10 oz)
- Alka-Seltzer® tablets (6)
- Room temperature water, 400 mL
- Warm water, maintained at a constant temperature, 400 mL
- Ice-cold water, 400 mL

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- How to use a graduated cylinder to measure liquid volume, as well as the meaning of the term volume
- The terms reactants and products as well as an understanding of the nature of a chemical change (reaction)
- How to set up and compute averages
- How to read and interpret a coordinate graph

Related Labs in This Guide

Labs conceptually related to this one include:

- Water—The Universal Solvent
- Evidence of a Chemical Reaction

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)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sampling rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Finding the coordinate of a point in a graph �(9.1)
- 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, 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 to form carbon dioxide, water, and trisodium citrate:

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_7(aq)$$

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. 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 °C) 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. 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*. 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). 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 reaction rate.

- *Presence of catalysts*. 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, the number of successful collisions must increase. The rate of the Alka-Seltzer reaction is dependent on both the rate at which the solids dissolve and the rate at which they react once in solution.

This activity focuses on the chemical reaction for this experiment. You may wish to clarify for students that dissolving the Alka-Seltzer tablet is a physical change, rather than a chemical change. The chemical reaction occurs once the reactants are in solution. This may help deter confusion.

Pre-Lab Discussion and Activity

Engage students in the following activity and discussion:

Drop an Alka-Seltzer tablet into a plastic cup filled with water at room temperature and ask the following questions.

1. What do you observe?

When the tablet enters the water it begins to bubble vigorously.

Discuss how many different states of matter are present in the cup (gas, liquid, and solid).

2. Is a chemical reaction is occurring in the cup?

The formation of gas bubbles indicates the production of a new substance, and this is evidence that a chemical reaction is taking place.

3. What gas do you think is released during the reaction?

The gas is carbon dioxide

Note: The presence of CO_2 can be demonstrated with a CO_2 gas sensor.

Explain to students that the evolution of the CO_2 gas is directly related to the disappearance of the solid Alka-Seltzer tablet. When dissolved in water, the sodium bicarbonate ($NaHCO_3$) and citric acid ($H_3C_6H_5O_7$) react to form CO_2.

If the students are familiar with these chemical symbols ("C" stands for carbon, "H" for hydrogen, and so on; "aq" stands for aqueous, or dissolved in water, "g" for gas, "l" for liquid), write the equation for the chemical reaction so they can see it:

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_7(aq)$$

or simply write the formulas for the two reactants, citric acid, $H_3C_6H_5O_7$, and sodium bicarbonate, $NaHCO_3$.

Lab Preparation

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

- Each lab group needs six Alka-Seltzer tablets (the "store" brand of effervescent tablets with the same ingredients can be used).
- Remind students to place the whole tablet into the water because breaking the tablet changes the variable of surface area.
- The ice-cold water should always have ice cubes in it to maintain the temperature.
- The warm water should be kept at a constant temperature.
- Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Handle glassware carefully.
- ♦ Handle hot water with care to avoid burns.

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.

2	1	5	3	4
Start recording temperature and drop the Alka-Seltzer tablet into a cup with room temperature water at the same time.	Connect the temperature sensor to the data collection system	Compare the average time to complete the reaction at different temperatures.	Use the graph of Temperature versus time to find how long it took to complete the reaction	Average the time it took to complete two trials at the same 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 – Room temperature reaction

Set Up

1. ☐ How long do you think it will take for the tablet to dissolve completely?

Answers will vary. At room temperature the tablet dissolves in 40 to 60 seconds.

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

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

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

5. ☐ Change the sampling rate to 10 Hz, or 10 samples per second. �(5.1)

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

7. ☐ Why do you think it is important to use a clear cup or beaker?

In order to find out how long it takes for the Alka-Seltzer to stop fizzing (producing gas), students need to be able to watch the process.

8. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so it is not touching the sides of the container.

Collect Data

9. ☐ Drop the Alka-Seltzer tablet into the water and at the same time, start recording temperature data. �(6.2)

10. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. When it has stopped fizzing, stop recording the first run of data. �(6.2)

Analyze Data

11. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

12. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

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.

15. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

16. ☐ What is the reason for doing a second trial at the same temperature?

Conducting more than one trial provides data to average. An average of multiple trials can give a better indication of overall behavior and provide information about the precision and accuracy of the measurements.

17. ☐ Sketch the room-temperature runs on the graph provided in the Data Analysis section, leaving room for data runs for the other trials (using warm and ice-cold water) on the same graph.

Part 2 – Warm temperature reaction

Set Up

18. ☐ How do you think the time to dissolve the tablet in warm water will compare to the time it took to dissolve in room temperature water?

The tablet will dissolve faster in warm water because the additional molecular motion of the warm water will increase the rate at which molecules interact.

19. ☐ Fill a clear plastic cup or beaker with 200 mL of warm water.

20. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container.

Collect Data

21. ☐ Drop the Alka-Seltzer tablet into the water and start recording temperature data at the same time. �(6.2)

22. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. When it has stopped fizzing, stop recording the first run of data. �(6.2)

Analyze Data

23. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

24. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

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

26. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of warm water.

27. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

28. ☐ Sketch the warm-temperature runs on the graph provided in the Data Analysis section.

Part 3 – Cold temperature reaction

Set Up

29. ☐ How do you think the time to dissolve the tablet in cold water will compare to the time it took to dissolve in room temperature water?

The tablet will dissolve slower in cold water because slower molecular motion of the cold water will decrease the rate at which molecules interact.

30. ☐ Fill a clear plastic cup or beaker with 200 mL of ice-cold water.

Note: Obtain only the water. There should be no ice cubes in the cup.

31. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container.

Collect Data

32. ☐ Drop the Alka-Seltzer tablet into the water and start recording temperature data at the same time. �(6.2)

33. ☐ Continue collecting data until the Alka-Seltzer tablet has stopped fizzing, and then stop recording the first run of data. �(6.2)

Analyze Data

34. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

35. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

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

37. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of ice-cold water.

38. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

39. ☐ Sketch the ice-cold temperature runs on the graph provided in the Data Analysis section.

40. ☐ Save your experiment and clean up according to your teacher’s instructions. �(11.1)

Data Analysis

Reaction time at different temperatures

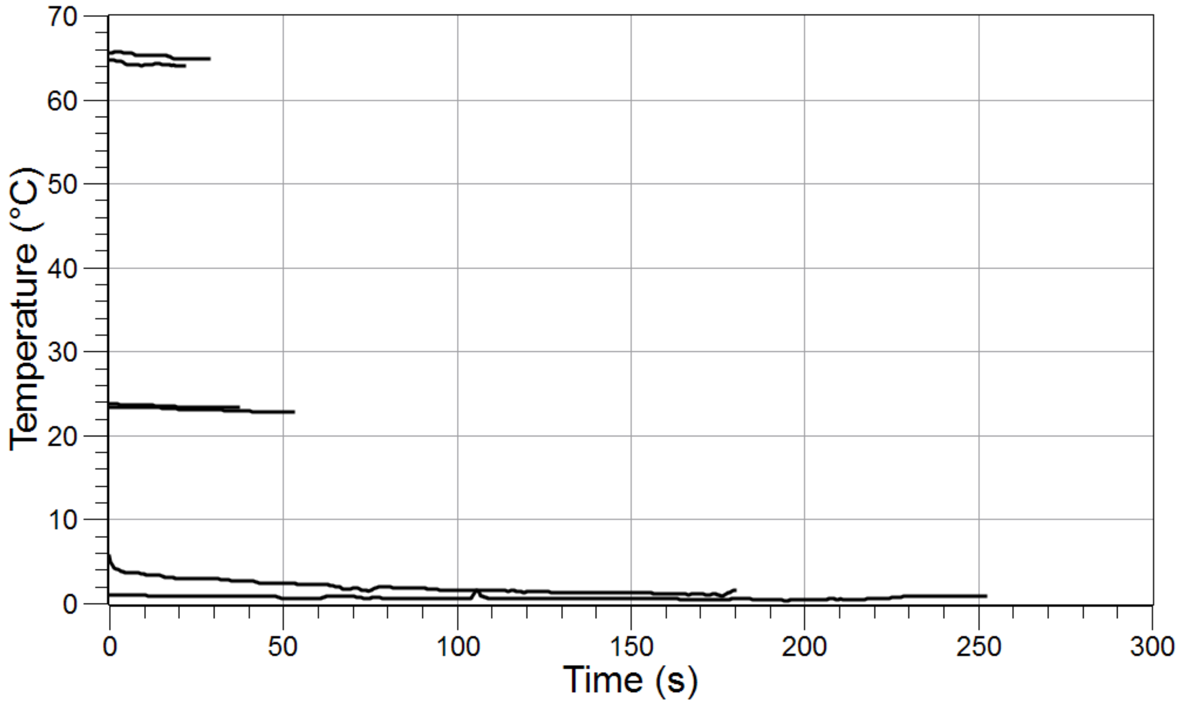


Table 1: Reaction time of Alka-Seltzer in water

Reaction Condition	Trial	Temperature (°C)	Reaction Time (s)
Room temperature water	1	23.9	37.0
	2	23.9	53.0
Warm water	1	65.0	28.5
	2	65.5	21.5
Cold water	1	2.0	180.0
	2	1.1	252.0

Analysis Questions

Table 2: Average reaction time of Alka-Seltzer in water

Reaction Condition	Average Reaction Time (s)
Warm water	25.0
Room temperature water	45.0
Ice cold water	216.0

1. Determine the average reaction time for the trials performed with room temperature water. Record this time in Table 2.

$$\frac{37.0\text{ s} + 53.0\text{ s}}{2} = \frac{90.0\text{ s}}{2} = 45.0\text{ s}$$

2. Determine the average reaction time for the trials performed with warm water. Record this time in Table 2.

$$\frac{28.5\text{ s} + 21.5\text{ s}}{2} = \frac{50.0\text{ s}}{2} = 25.0\text{ s}$$

3. Determine the average reaction time for the trials performed with cold water. Record this time in Table 2.

$$\frac{180.0\text{ s} + 252.0\text{ s}}{2} = \frac{432.0\text{ s}}{2} = 216.0\text{ s}$$

4. Review the average time needed for the Alka-Seltzer tablet to finish fizzing in each part. How many times faster is the reaction rate using warm water than using ice-cold water?

The reaction in the warm water was 8.6 times faster than the reaction in the ice-cold water:

$$\frac{\text{Ice-cold: } 216.0\text{ s}}{\text{Warm: } 25.0\text{ s}} = 8.6\text{ times faster}$$

5. How does temperature affect the rate of this chemical reaction?

In this example, the chemical reaction of an Alka-Seltzer tablet was 8.6 times faster in warm water than in ice-cold water. The higher the temperature, the faster the reaction.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In this experiment, you collected data until the water "stopped fizzing." What is another, more generic, way of stating what caused the reaction to stop?

The reaction continued until at least one of the reactants was consumed completely.

2. Two identical pieces of iron are sealed in identical containers. One container is placed in a room held at 25 °C, and the other is placed outside on a hot day (35 °C). Which piece of iron do you think will rust the most?

The piece of iron placed outside would likely rust the most because the hotter air would cause a higher number of collisions between oxygen molecules and iron atoms.

Multiple Choice Questions

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

1. The rate of reaction is

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

2. A liquid is

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

3. A product is

- **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. A solid is

- **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. A reactant is

- **A.** The process where substances change to form products
- **B. An 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. A reaction is

- **A.** Matter that has a definite shape and takes up a definite amount of space
- **B. A chemical process that 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 has a definite volume

7. A chemical equation is

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

8. A gas is

- **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 list of randomly ordered words in the Key Term Challenge Word Bank.

1. Iron and oxygen change into iron oxide during the **chemical** reaction we know as rusting. Carbon dioxide is a **product** of the chemical reaction between vinegar and baking soda. Matter can be a **solid**, a liquid, or a gas, and chemical reactions can happen in each **phase**. The rate of a chemical **reaction** is the time required for a given quantity of **reactants** to be changed to products.

Extended Inquiry Suggestions

Investigate the reaction rate when there is more surface area (many particles of smaller 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?