LESSON 30: Balloon in a Bottle

ESTIMATED TIME **Setup:** 5–10 minutes | **Procedure:** 10–15 minutes

- **DESCRIPTION**

  Place a balloon over a Pyrex® glass bottle or flask to observe the behavior of the balloon in response to changes in temperature.

- **OBJECTIVE**

  This lesson uses a balloon and a Pyrex® glass bottle to demonstrate the relationship between temperature and volume of a gas. Students place a balloon over the opening of a Pyrex® glass bottle or flask and observe the reaction of the balloon to differences in temperature. The lesson can be extended to address the relationship between energy and temperature.

- **CONTENT TOPICS**

  Scientific inquiry; measurement (temperature); states of matter; properties of matter (gas laws); energy

- **MATERIALS**

  - ❑ Pyrex® glass vessel (bottle or flask)
  - ❑ Balloon
  - ❑ Water
  - ❑ Hot plate (a coffee hot plate will work as well)

Always remember to use the appropriate safety equipment when conducting your experiment. Refer to the ***Safety First*** section in the ***Resource Guide*** on pages 421–423 for more detailed information about safety in the classroom.

Jump ahead to page 371 to view the Experimental Procedure.

NATIONAL SCIENCE EDUCATION STANDARDS SUBJECT MATTER

This lesson applies both *Dimension 1: Scientific and Engineering Practices* and *Dimension 2: Crosscutting Concepts* from "A Framework for K–12 Science Education," established as a guide for the updated National Science Education Standards. In addition, this lesson covers the following Disciplinary Core Ideas from that framework:

- PS1.A: Structure and Properties of Matter
- ETS2.A: Interdependence of Science, Engineering, and Technology (see ***Analysis & Conclusion***)

OBSERVATION & RESEARCH

BACKGROUND

Matter is defined as anything that has mass and takes up space. It is everything around us! People characterize and classify matter by its properties. Two basic properties of matter are mass and volume. **Mass** is a measure of the amount of matter in a substance. The mass of an object can be measured with a balance. To determine the mass of an object, the object is compared to another object with a mass that is known. The unit of measurement that scientists use to measure mass is the kilogram (kg) or gram (g). **Volume** is a measure of the amount of space an object occupies and can be measured in a number of different ways. Volume is measured in liters or cubic units, such as cubic centimeters.

Matter exists primarily as a solid, liquid, or gas on the earth. **Solids** have a definite volume and a definite shape. Examples of solids are chairs, glasses, and trees. **Liquids** have a definite volume but no definite shape. Examples of liquids are water and oil. **Gases** have no definite shape and no definite volume. The volume and shape of a gas are determined by the vessel that contains it. Examples of gases include oxygen, nitrogen, and argon, which along with other gases, make up the air around you.

Likewise, different forms of energy can be identified by different properties as well. **Energy** is a measure of the ability to do work or generate heat. Energy is found in many forms and can change from one form to another. Some forms of energy include kinetic energy, chemical energy, thermal energy, and light.

Temperature is a measure of the average kinetic energy (energy of motion) of particles in a substance. It is a measure of how fast the particles are moving around.

LESSON 30: Balloon in a Bottle

The temperature of a substance is measured using a thermometer.

Gases are defined by a set of laws known as the gas laws, which describe the relationships between volume, temperature, and pressure. One of those laws, **Charles' Law**, explains the relationship between temperature and volume. Charles' Law states that the volume and temperature of a gas are directly proportional. As the temperature of a gas increases, the volume of the gas increases at a proportional rate. (Proportional means that they change at a constant rate. For example, $^1/_2$ is proportional to $^2/_4$ and $^3/_6$.)

In this lesson, a balloon is placed over the opening of a glass vessel. As the air inside the glass vessel is heated, it expands, causing the balloon to inflate. When the hot air is cooled, the volume of the gas decreases and tries to pull more air in from the outside. As this occurs, the balloon is pulled inside the vessel.

CONNECT TO THE *YOU BE THE CHEMIST* CHALLENGE

For additional background information, please review CEF's Challenge study materials online at http://www.chemed.org/ybtc/challenge/study.aspx.

- Additional information on measurement can be found in the Measurement section of CEF's *Passport to Science Exploration: The Core of Chemistry*.
- Additional information on states and properties of matter can be found in the Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.

HYPOTHESIS

▶A balloon placed over the opening of a glass vessel will inflate as the vessel is heated because of the relationship between the temperature and volume of a gas. Likewise, when the heated vessel is cooled, the balloon will be pulled into the bottle because of the decrease in temperature and volume.

FORMULAS & EQUATIONS

Charles' Law: The volume and temperature of a gas are directly proportional. Therefore, the proportion of volume to the temperature of a gas equals a constant.

$\mathbf{V/T = K}$, *where* V *is volume,* T *is temperature, and* K *is a constant.*

Because the formula is equal to a constant, it is possible to solve for a change in volume or temperature using the following proportion:

$\mathbf{V_1/T_1 = V_2/T_2}$

The other gas laws include the following:

Boyle's Law: At a constant temperature, the product of the pressure and the volume of an ideal gas is constant.

$\mathbf{PV = K}$, *where* P *is pressure,* V *is volume, and* K *is a constant.*

Boyle's law can also be used to solve for a change in pressure or volume using the following equation:

$\mathbf{P_1V_1 = P_2V_2}$

Gay-Lussac's Law: The pressure exerted on a container by a gas is directly proportional to the temperature of the gas.

$\mathbf{P/T = K}$, *where* P *is pressure,* T *is temperature, and* K *is a constant.*

Again, Gay-Lussac's Law can be used to calculate changes in pressure or temperature using the following proportion:

$\mathbf{P_1/T_1 = P_2/T_2}$

Avogadro's Law: Equal volumes of gases at the same temperature and pressure contain the same number of molecules (n) regardless of their chemical nature and physical properties. This number (Avogadro's number) is 6.022×10^{23}.

$\mathbf{V/n = K}$, *where* V *is volume,* n *is the number of molecules, and* K *is a constant.*

Finally, the **ideal gas law** is a combination of these laws that relates temperature, pressure, and volume.

$\mathbf{PV = nRT}$, *where* P *is pressure,* V *is volume,* T *is temperature,* n *is the number of molecules, and* R *is the ideal gas constant.*

The equation is called "ideal" because it is based on a hypothetical ideal gas. However, this law serves as a useful approximation for most gases under most conditions.

LESSON 30: Balloon in a Bottle

DIFFERENTIATION IN THE CLASSROOM

LOWER GRADE LEVELS/BEGINNERS

Perform the experiment as described on page 371, but spend more time on the different states of matter and their properties. Name items in the classroom, and ask the students to say whether they are solids, liquids, or gases. In which state is the glass bottle? Solid! It has a definite shape and volume. In which state is the water? Liquid! It has a definite volume but no definite shape. Pour the water into different containers to illustrate how the shape changes but not the volume. In which state is the substance inside the balloon? Gas! It has no definite shape or volume. Discuss with the class how they know certain gases exist if they can't see them.

HIGHER GRADE LEVELS/ADVANCED STUDENTS

DESCRIPTION

Place a balloon over a Pyrex® glass bottle or flask to observe the behavior of the balloon in response to changes in temperature.

OBJECTIVE

This lesson uses a balloon and a Pyrex® glass vessel to demonstrate the relationship between the temperature and volume of a gas. It also addresses the relationship between energy and temperature.

OBSERVATION & RESEARCH

Energy is defined as the capacity to do work or produce heat. Energy can take many different forms, including light, sound, electricity, chemical bonds, mechanical motion, and thermal energy. The **law of conservation of energy** (first law of thermodynamics) states that while energy can change from one form to another, it can neither be created nor destroyed. When matter changes, whether through a physical or chemical change, the amount of energy in the system is the same before and after the changes, but the energy may be in a different form or forms.

Temperature is a measure of the average kinetic energy (energy of motion) of particles in a substance. It is a measure of how fast the particles are moving around. The temperature of a substance is measured using a thermometer. Temperature, thermal energy, and heat are related, but they are not the same thing.

Thermal energy is the total energy of particles in a substance. The transfer of thermal energy from an object at a higher temperature to an object at a lower temperature is known as **heat**. Heat is commonly transferred (moved from one substance to another) in one of three ways—conduction, convection, or radiation.

Conduction is the transfer of energy by collisions between nearby atoms. Conduction is the most common means of heat transfer in solid matter. For example, on a hot summer day, if you grab the handle of a car door, the heat will move from the door handle to your hand. If you touch that hand to your face, you will notice that your hand will feel warmer than usual because of the energy transfer.

Convection is the transfer of energy by the bulk molecular motion within a liquid or gas. Convection occurs because of temperature differences within the fluid or between the fluid and its container. You may notice the results of convection in homes or buildings that are a few stories high. If there are not special temperature controls on each floor, the upper floors will often be warmer than the bottom floor because the hot air will rise and the cooler air will fall.

Radiation is the transfer of energy (as electromagnetic waves) through an empty space or clear material without heating the empty space or clear material. The most common form of radiation is solar radiation. In solar radiation, the rays from the sun heat up the earth.

In this experiment, when the Pyrex® glass vessel is heated, conduction causes the heat from the hot plate to transfer through the bottle and to the water and gas inside.

CONNECT TO THE *YOU BE THE CHEMIST* CHALLENGE

For additional background information, please review CEF's Challenge study materials online at http://www.chemed.org/ybtc/challenge/study.aspx.

- Additional information on types of measurements can be found in the Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.
- Additional information on energy changes can be found in the Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.
- Additional information on energy and heat can be found in the Energy section of CEF's *Passport to Science Exploration: Chemistry Concepts in Action.*

LESSON 30: Balloon in a Bottle

DIFFERENTIATION IN THE CLASSROOM

The liquid inside begins to vaporize as it becomes warmer. In addition, the liquid and gases inside the vessel transfer the heat through convection, causing the hot air to rise. The heated gas also expands according to Charles' Law, causing the balloon to inflate. When the hot air is cooled, the volume of the gas decreases and tries to pull more air in

EXPERIMENTATION

As the students perform the experiment, challenge them to identify the independent, dependent, and controlled variables, as well as whether there is a control setup for the experiment. (Hint: If you change the temperature of the gas, does the volume of the gas change?) Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss variables.

EXPERIMENTAL PROCEDURE

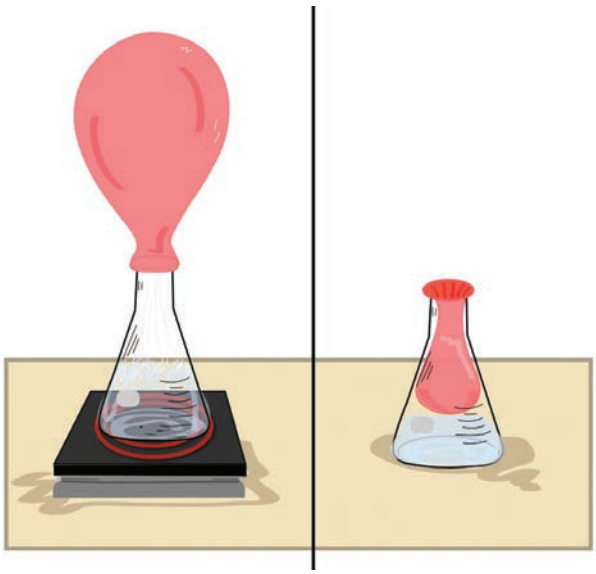
Part One

1. Fill the Pyrex® glass vessel with no more than a half cup of cold tap water.
2. Place a balloon over the opening of the vessel.
3. Place the vessel on a hot plate and heat it.
4. Watch as the balloon inflates. Note that the expansion of the balloon is mainly a result of the expansion of the air inside. However, some of the expansion results from the water vapor that is released from the heated water.
5. Remove the vessel from the heat, and allow it to cool for a few minutes.

Be careful while handling hot items. If a hot plate is not available, microwaving the water for a few minutes will also work.

Part Two

1. Fill the Pyrex® glass vessel with no more than a half cup of hot tap water, and place it on a hot plate. Heat the vessel until the water begins to boil.
2. Take the vessel off of the hot plate and allow the boiling water to sit for about 10 seconds.
3. Place a balloon over the opening of the vessel.
4. Let the solution cool, and observe the balloon as it is sucked into the vessel. (Freeze or refrigerate the vessel to speed up this process.)



DATA COLLECTION

Have students record data in their science notebooks or on the following activity sheet. What is inside the glass container? What occurs when the container is heated? What happens when the container is cooled? Have students answer the questions on the activity sheet (or similar ones of your own) to guide the process.

Fun Fact

Pyrex® is a brand name for a type of glassware made from borosilicate glass (primarily made of silica and boron oxide). Borosilicate glass is less dense and more resistant to thermal shock than regular glass.

LESSON 30: Balloon in a Bottle

ANALYSIS & CONCLUSION

Use the questions from the activity sheet or your own questions to discuss the experimental data. Ask students to determine whether they should accept or reject their hypotheses. Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss valid and invalid hypotheses.

ASSESSMENT/GOALS

Upon completion of this lesson, students should be able to …

- Apply a scientific inquiry process and perform an experiment.
- Define and identify different types of measurements, such as mass, volume, and temperature.
- Differentiate between the different states of matter.
- Describe the relationship between the temperature and volume of a gas and understand that this relationship is known as Charles' Law.
- Describe the relationships between temperature, pressure, volume, and amount of gas.
- Define energy and explain the law of conservation of energy (see ***Differentiation in the Classroom***).
- Compare and contrast the different types of heat transfer (see ***Differentiation in the Classroom***).

MODIFICATIONS/EXTENSIONS

Modifications and extensions provide alternative methods for performing the lesson or similar lessons. They also introduce ways to expand on the content topics presented and think beyond those topics. Use the following examples, or have a discussion to generate other ideas as a class.

- Before the lesson begins, tell the students you can inflate a balloon without blowing into it. Ask them if they know how this is possible.
- If it is not possible to use a Pyrex® glass vessel and a hot plate, the volume and temperature relationship can still be demonstrated using empty 2-liter plastic soda pop bottles. Run the bottle with the cap off under hot water for a minute or two. Immediately place the cap on, and place the bottle in a refrigerator, freezer, or ice bath for 10 minutes. Upon removing the bottle, it should look like someone squeezed it. The reduction of temperature has caused a reduction of volume within the bottle. Run the bottle under hot water again, with the cap still on, and the bottle should return to its original shape.
- Give the students balloons, and tell them to ask their parents if they can try an experiment at home. Instruct them to partially (not completely) blow up the balloon, tie it tight, and then put it in their freezer. They should then check the balloon 10 minutes later. The balloon should be smaller.

REAL-WORLD APPLICATIONS

- Charles' Law is used to explain the operation of a hot-air balloon. An object will float when it weighs less than the fluid it displaces. **Displacement** is the act of moving something out of its original position or of one substance taking the place of another. When a gas is heated, it expands. Since density is defined as the amount of matter per unit of volume, as the volume of the air increases, its density decreases. Therefore, hot air is less dense than cold air and will rise above the cold air. Once the air in a balloon gets hot enough, the combined weight of the balloon plus this hot air is less than the weight of an equal volume of cold air outside that it is displacing. As a result, the balloon starts to rise. The balloon will return to the ground when the gas in the balloon is allowed to cool.
- The air pressure in a car tire (not the actual rubber) is primarily responsible for supporting the weight of a car. People who live in areas where temperature changes significantly with the seasons should check the air pressure in their tires often. The changes in temperature will change the pressure within the tire.

COMMUNICATION

Discuss the results as a class and review the activity sheet. Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss the importance of communication to scientific progress.

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

OBSERVE & RESEARCH

1. Write down the materials you observe. _____

_____

_____

2. Predict how these materials may be used. _____

_____

_____

3. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Matter		
Mass		
Volume		
Solid		
Liquid		
Gas		
Energy		
Temperature		

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

4. Consider what will happen when a balloon attached to the opening of a glass vessel is heated and then cooled and why.

▶**Write your hypothesis.** _____

_____

_____

PERFORM YOUR EXPERIMENT

Part One

1. Fill the Pyrex® glass vessel with no more than a half cup of cold tap water.
2. Place a balloon over the opening of the vessel.
3. Have your teacher place the vessel on a hot plate and heat it. Observe the balloon.
4. Once your teacher removes the vessel from the hot plate, allow it to cool for a few minutes.

Part Two

1. Fill the Pyrex® glass vessel with no more than a half cup of hot tap water. Have your teacher heat the vessel on a hot plate until the water begins to boil.
2. Have your teacher take the vessel off the hot plate, and allow the boiling water to sit for about 10 seconds.
3. Place a balloon over the opening of the vessel.
4. Let the solution cool and observe the balloon. You can also freeze or refrigerate the vessel to speed up the process.

ANALYZE & CONCLUDE

1. In Part One, what happens to the balloon when it is placed on top of the vessel filled with cold tap water, and the vessel is heated? _____

_____

_____

2. In Part Two, what happens to the balloon when it is placed on top of the vessel filled with heated tap water and then allowed to cool? _____

_____

_____

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

3. What is Charles' Law, and how does it relate to this experiment? _____

_____

_____

4. What is Boyle's Law? _____

_____

_____

5. What is Gay-Lussac's Law? _____

_____

_____

6. What is the ideal gas law? _____

_____

_____

7. Is your hypothesis valid? Why or why not? If not, what would be your next steps? _____

_____

_____

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

EXPAND YOUR KNOWLEDGE—ADVANCED

1. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Law of conservation of energy		
Thermal energy		
Heat		
Conduction		
Convection		
Radiation		

2. What relationships are described by the gas laws? _____

_____

_____

3. How is the energy transferred in this experiment? Explain. _____

_____

_____

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

OBSERVE & RESEARCH

1. Write down the materials you observe. A Pyrex® glass vessel, balloons, water, hot plate …

2. Predict how these materials may be used. A Pyrex® glass vessel may be used in the lab to heat a substance. Balloons may be used as decorations. Water may be used to drink or boil food. A hot plate may be used to heat a substance. These materials may be used to demonstrate the physical properties of water and air.

3. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Matter	Any substance that has mass and takes up space; matter is generally found as a solid, liquid, or gas on the earth.	
Mass	A measure of the amount of matter in a substance.	
Volume	A physical property that measures the amount of space a substance occupies.	
Solid	A state of matter characterized by a definite volume and definite shape.	
Liquid	A state of matter that has a definite volume but no definite shape; a liquid will take the shape of the container that holds it, filling the bottom first.	
Gas	A state of matter that has no definite volume or shape; a gas will take the shape of the container that holds it, filling the entire container.	
Energy	The ability to do work or produce heat.	
Temperature	A measure of the average kinetic energy of particles in a substance, generally identified by sensations of hot and cold.	

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

4. Consider what will happen when a balloon attached to the opening of a glass vessel is heated and then cooled and why.

▶**Write your hypothesis.** A balloon placed over the opening of a glass vessel containing cold water will inflate as the vessel is heated because of the relationship between the temperature and the volume of a gas. Likewise, when the heated vessel is cooled, the balloon will be pulled into the bottle because of the decrease in temperature and volume.

PERFORM YOUR EXPERIMENT

Part One

1. Fill the Pyrex® glass vessel with no more than a half cup of cold tap water.
2. Place a balloon over the opening of the vessel.
3. Have your teacher place the vessel on a hot plate and heat it. Observe the balloon.
4. Once your teacher removes the vessel from the hot plate, allow it to cool for a few minutes.

Part Two

1. Fill the Pyrex® glass vessel with no more than a half cup of hot tap water. Have your teacher heat the vessel on a hot plate until the water begins to boil.
2. Have your teacher take the vessel off the hot plate, and allow the boiling water to sit for about 10 seconds.
3. Place a balloon over the opening of the vessel.
4. Let the solution cool, and observe the balloon. You can also freeze or refrigerate the vessel to speed up the process.

ANALYZE & CONCLUDE

1. In Part One, what happens to the balloon when it is placed on top of the vessel filled with cold tap water, and the vessel is heated? The balloon increases in size when the vessel and the air inside is heated.

2. In Part Two, what happens to the balloon when it is placed on top of the vessel filled with heated tap water and then allowed to cool? The balloon is pulled inside the vessel.

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

3. What is Charles' Law, and how does it relate to this experiment? Charles' Law states that the volume and temperature of a gas are directly proportional. As the temperature of a gas increases, the volume of the gas increases at a proportional rate. In this experiment, as the gas in the vessel is heated, the volume of the gas increases, causing the balloon to expand.

4. What is Boyle's Law? Boyle's Law states that at at constant temperature, the product of the pressure and the volume of an ideal gas is always constant.

5. What is Gay-Lussac's Law? Gay-Lussac's Law states that the pressure exerted on a container by a gas is directly proportional to the temperature of the gas.

6. What is the ideal gas law? The ideal gas law is a combination of the gas laws that relate temperature, pressure, and volume. It is represented by the equation PV = nRT.

7. Is your hypothesis valid? Why or why not? If not, what would be your next steps?

Answer 1: Valid because the data support my hypothesis.

Answer 2: Invalid because the data do not support my hypothesis. I would reject my hypothesis and could form a new one, such as

LESSON 30 ACTIVITY SHEET: Balloon in a Bottle

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

EXPAND YOUR KNOWLEDGE—ADVANCED

Have students complete this section if you used the advanced differentiation information, or challenge them to find the answers to these questions at home and discuss how these terms relate to the experiment in class the next day.

1. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Law of conservation of energy	A scientific law stating that while energy can change form, it cannot be created or destroyed; also known as the first law of thermodynamics.	
Thermal energy	The total energy of particles in a substance.	
Heat	The flow of thermal energy from one substance to another because of differences in temperature.	
Conduction	The transfer of energy by collisions between nearby atoms.	
Convection	The transfer of energy by the bulk molecular motion within a liquid or gas.	
Radiation	The transfer of energy (as electromagnetic waves) through an empty space or clear material without heating the empty space or clear material.	

2. What relationships are described by the gas laws? The relationships described by the gas laws include those between pressure and volume, volume and temperature, pressure and temperature, and volume and the amount of moles.

3. How is the energy transferred in this experiment? Explain. Heat is transferred from the hot plate to the glass vessel and the water inside by conduction. The heat is then transferred between the water and air in the bottle through convection.