LESSON 17: Balloon Rockets

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

• DESCRIPTION

Apply the concepts of pressure and Newton's laws of motion to build simple rockets.

• OBJECTIVE

This lesson demonstrates the basic principles of rocketry by applying the concept of pressure and Newton's Second and Third Laws of Motion. Students use a balloon to explore these concepts. The lesson can be extended to introduce the concepts of drag and power.

• CONTENT TOPICS

Scientific inquiry, measurement; force (pressure)

It is best to use long, thin balloons for this experiment.

• MATERIALS

- ❑ Balloons
- ❑ Straws
- ❑ String
- ❑ Permanent marker
- ❑ Cargo (paper clips, bottle caps, candy, etc.)
- ❑ Cereal boxes, construction paper, or any other material to make lightweight cargo containers
- ❑ Tape, glue, scissors, and any other materials needed for construction

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 212 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:

- PS2.A: Forces and Motion
- PS2.C: Stability and Instability in Physical Systems
- PS3.C: Relationship Between Energy and Forces
- ETS1.A: Definiting and Delimiting an Engineering Problem (see ***Analysis & Conclusion***)
- ETS1.B: Developing Possible Solutions (see ***Analysis & Conclusion***)
- ETS1.C: Optimizing the Design Solution (see ***Analysis & Conclusion***)
- ETS2.A: Interdependence of Science, Engineering, and Technology (see ***Analysis & Conclusion***)

OBSERVATION & RESEARCH

BACKGROUND

Rocketry has existed for hundreds of years. Although the technology has greatly improved and there are numerous methods for propelling a rocket, the simple science behind rockets has always been the same. To propel a rocket, some kind of force must be expelled from the rocket in order to push it forward. A force is the amount of push or pull on an object. The mechanical force that pushes a rocket or aircraft through the air is known as thrust.

Two of Newton's laws of motion relate to force, and therefore, relate to thrust. Newton's Second Law of Motion states that the relationship between an object's mass (m), its acceleration (a), and the applied force (F) is **F = ma**. For example, the force of a basketball pushed toward the ground is equal to the mass of the ball multiplied by the acceleration of the ball toward the ground. Newton's Third Law of Motion states that for every action there is an equal and opposite reaction. For example, when a basketball is pushed toward the ground, the force with which the basketball hits the ground is oppositely and equally applied back to the ball by the ground. As a result, the ball bounces back upward.

In this experiment, the rocket is propelled by pressure. Pressure is the amount of force exerted on an area. When you blow up the balloon, you are filling the balloon with gas particles (mainly oxygen). The gas particles move freely within the balloon and may collide with one another. As more gas is added to the balloon, the number of gas particles in the balloon increases, as well as the number of collisions. While the force of a single gas particle collision is too small to notice, the total force created by all of the gas particle collisions within the balloon is significant. As the number of collisions within the balloon increases, so does the pressure within the balloon.

In addition, the pressure of the gas inside the balloon becomes greater than the air pressure outside of the balloon. The pressure inside the balloon serves as the fuel for the rocket. When you release the opening of the balloon, gas quickly escapes to equalize the pressure inside with the air pressure outside of the balloon. As the air escapes from the balloon, it exerts a force on the ground and the air outside of the balloon. According to Newton's Third Law of Motion, as the gas is released from the balloon and pushes against the outside air, the outside air pushes back. As a result, the rocket is propelled forward by the opposing force. This opposing force is thrust.

FORMULAS & EQUATIONS

Newton's laws of motion have played a key role in humans' understanding of the universe.

- **Newton's First Law of Motion (the Law of Inertia) states:** Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.
- **Newton's Second Law of Motions states:** The acceleration (a) of an object as produced by a net force is directly proportional to the magnitude of the net force (F), in the same direction as the net force, and inversely proportional to the mass (m) of the object. This relationship is described by the equation: **F = ma**.
- **Newton's Third Law of Motion states:** For every action, there is an equal and opposite reaction.

Pressure is the amount of force exerted on an area.

This relationship is described by the following equation: **p = F/A**.

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 scientific laws can be found in the Science—A Way of Thinking section of CEF's *Passport to Science Exploration: The Core of Chemistry*.
- Additional information on types of measurements, including force and pressure, can be found in the Measurement section of CEF's *Passport to Science Exploration: The Core of Chemistry*.
- Additional information on states of matter can be found in the in Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.

HYPOTHESIS

▶A simple rocket made with a balloon will be propelled down a string according to Newton's laws of motion, because of thrust generated by pressure.

LESSON 17: Balloon Rockets

DIFFERENTIATION IN THE CLASSROOM

LOWER GRADE LEVELS/BEGINNERS

Conduct the experiment as described on page 212 (or perform the experiment as a demonstration), and focus on gases and pressure. How do they know the pressure is increasing in the balloon? Use the amount of people in the room as an example. If more people were crammed into the room and moving around, would they feel more pressure on their bodies as they bumped into one another? Likewise, if you have marbles or similar objects available, you can instruct students to hold one marble closed in between both hands. When they shake their hands with the marble inside, they will feel the marble move around and collide with the inside of their hands. If they hold three marbles closed within both hands and shake them, do they notice a difference?

HIGHER GRADE LEVELS/ADVANCED STUDENTS

DESCRIPTION

Build simple rockets by applying the concepts of pressure and Newton's laws of motion.

OBJECTIVE

This lesson demonstrates the basic principles of rocketry, addressing Newton's laws of motion and the concepts of force, pressure, drag, and power.

OBSERVATION & RESEARCH

The development of flight and rocketry has led to major advances for humans, and these inventions rely on similar principles. To propel an aircraft or rocket, some kind of force must be expelled from the vehicle in order to push it forward. A **force** is the amount of push or pull on an object.

The mechanical force that pushes a rocket or aircraft through the air is known as **thrust**. On the contrary, **drag** is a mechanical force that opposes an aircraft's motion through the air. It is generated by the difference in velocity between a solid object and a **fluid** (liquid or gas). Without the presence of a fluid or without motion, there is no drag.

In this experiment, the rocket is propelled by pressure. **Pressure** is the amount of force exerted on an area. When you blow up the balloon, you are filling the balloon with gas particles (mainly oxygen). The gas particles move freely within the balloon and may collide with one another. As more gas is added to the balloon, the number of gas particles in the balloon increases, as well as the number of collisions. While the force of a single gas particle collision is too small to notice, the total force created by all of the gas particle collisions within the balloon is significant. As the number of collisions within the balloon increases, so does the pressure within the balloon.

In addition, the pressure of the gas inside the balloon becomes greater than the air pressure outside of the balloon. The pressure inside the balloon serves as the fuel for the rocket. When you release the opening of the balloon, gas quickly escapes to equalize the pressure inside with the air pressure outside of the balloon. As the gases escape from the balloon, the gas particles exert a force on the ground and the air outside of the balloon. According to Newton's Third Law of Motion, every action has an equal and opposite reaction. Therefore, as the gas is released from the balloon, it pushes against the outside air, and the outside air pushes back. As a result, the rocket is propelled forward by the opposing force. This opposing force is thrust.

In an aircraft or rocket, the engine provides power to the propeller, which produces the thrust. **Power** is the rate at which energy is converted or work is performed. In general, an engine with more power produces more thrust. In addition, the thrust must be greater than drag in order for an aircraft or rocket to accelerate forward for takeoff and to increase its speed during flight. If an aircraft is flying at a constant speed, the amount of thrust will equal drag.

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.

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- Additional information on types of measurements, including force and pressure, can be found in the Measurement section of CEF's *Passport to Science Exploration: The Core of Chemistry.*
- Additional information on states of matter can be found in the in Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry.*

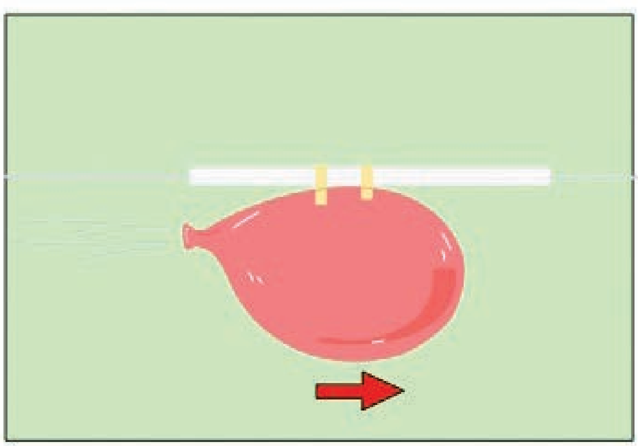
LESSON 17: Balloon Rockets

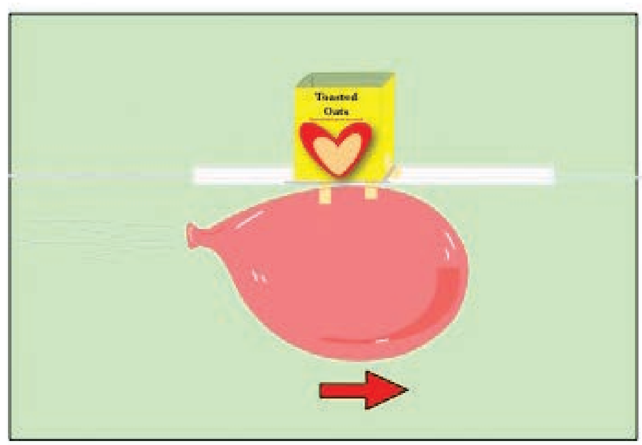
EXPERIMENTATION

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: As the amount of gas in the balloon changes, does the distance the rocket travels change?) Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss variables.

EXPERIMENTAL PROCEDURE

1. Tie one end of a string to a chair, doorknob, or other support.
2. Put the other end of the string through a straw. Then pull the string tight, and tie it to another support in the room.
3. Blow up the balloon, and pinch the end of the balloon to keep the air inside. Do not tie the balloon.
4. Tape the balloon to the straw so that the opening of the balloon is horizontal with the ground. You may need two students for this: one to keep the air pinched inside the balloon and the other to tape the balloon to the straw.
5. Have one student pull the balloon all the way back to the end of the string (the starting line), so the balloon opening is against one support. That student should hold the balloon opening closed. Have another student use the marker to draw a finish line near the other end of the string.
6. Let go of the balloon and watch it move along the string!
7. Then, have students test different methods to transport "cargo" across the string to the finish line.





DATA COLLECTION

Have students record data in their science notebooks or on the following activity sheet. What happened when the opening of the balloon was released and the gas was allowed to escape? If they timed the process, how long did it take for a rocket to cross the finish line? Have students answer the questions on the activity sheet (or similar ones of your own) to guide the process.

LESSON 17: Balloon Rockets

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.
- Describe force, pressure, and thrust.
- Define and provide examples of Newton's Second and Third Laws of Motion.
- Explain the general science behind rocketry.
- Describe drag and power (see ***Differentiation in the Classroom***).
- Differentiate between thrust and drag (see ***Differentiation in the Classroom***).

Fun Fact

Fireworks, developed by the Chinese, are considered the earliest form of rockets.

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.

- Tell your students that they need to devise a way to transport cargo across a string using only the materials you provide them. Have the students work in groups or individually to test methods. Discuss how they may accomplish this task and offer hints as needed.
- Use the lesson to practice measurement and apply calculations. Measure the distance from the start to the finish line on the string. Measure the mass of the inflated balloon. (They can use a clip to keep the balloon opening closed and then subtract the mass of the clip.) Then, time how long it takes for the balloon to move across the finish line. Students can then use these measures to calculate the rocket's force.

REAL-WORLD APPLICATIONS

- Jet engines work by igniting fuel, combined with compressed oxygen, inside the engine. As a result of the reaction, large amounts of gas are released quickly out of the rear of the aircraft. The extremely high acceleration of the mass of gas creates a large force. Then, as indicated by Newton's Third Law of Motion, an equal and opposite force (thrust) is created in the opposite direction of the released gas, propelling the jet forward.

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 17 ACTIVITY SHEET: Balloon Rockets

OBSERVE & RESEARCH

1. Write down the materials you observe. ______________________________

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2. Predict how these materials may be used. ______________________________

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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)
Force		
Thrust		
Newton's Second Law of Motion		
Newton's Third Law of Motion		
Pressure		

4. Consider how a balloon can be propelled down a string and how/why that would work.

▶**Write your hypothesis.** ______________________________

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LESSON 17 ACTIVITY SHEET: Balloon Rockets

PERFORM YOUR EXPERIMENT

1. Tie one end of a string to a chair, doorknob, or other support.
2. Put the other end of the string through a straw. Then pull the string tight, and tie it to another support in the room.
3. Blow up the balloon, and pinch the end of the balloon to keep the air inside. Do not tie the balloon.
4. Have a partner tape the balloon to the straw so that the opening of the balloon is horizontal with the ground, while you keep the air pinched inside the balloon.
5. Have your partner use the marker to draw a finish line near the end of the string. Then, let go of the balloon and observe!
6. Test different methods to transport "cargo" across the string to the finish line. See your teacher for materials.

ANALYZE & CONCLUDE

1. Once you have the balloon set, what happens when you let go of it? What causes this to happen? ________________

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2. What do you think will make the balloon move faster? ________________________________

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3. What happens when you add cargo to the balloon rocket? ________________________________

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

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LESSON 17 ACTIVITY SHEET: Balloon Rockets

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)
Fluid		
Drag		
Power		

2. How are modern rockets propelled? ____

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3. If a pilot wants to fly at a constant speed, what must occur? What if the pilot wants the aircraft to accelerate?

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4. What is Newton's First Law of Motion? ____

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LESSON 17 ACTIVITY SHEET: Balloon Rockets

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

OBSERVE & RESEARCH

1. Write down the materials you observe. Balloons, straws, string, permanent marker, paper clips, cereal boxes, tape, scissors …

2. Predict how these materials may be used. The balloons may be used as decorations. Straws may be used to drink a liquid. String may be used to tie things together. Permanent markers may be used to draw or write on something. These materials may be combined to create and test a transport system.

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)
Force	A push or pull acting on an object, which sometimes causes a change in position or motion.	
Thrust	The mechanical force that pushes a rocket or aircraft through the air.	
Newton's Second Law of Motion	Sir Isaac Newton's Second Law of Motion states that the relationship between an object's mass (m), its acceleration (a), and the applied force (F) is described by the formula $F = ma$.	
Newton's Third Law of Motion	Sir Isaac Newton's Third Law of Motion states that for every action, there exists an equal and opposite reaction.	
Pressure	The amount of force exerted on an area.	

4. Consider how a balloon can be propelled down a string and how/why that would work.

▶ **Write your hypothesis.** A simple rocket made with a balloon will be propelled down a string because of pressure and opposing forces.

LESSON 17 ACTIVITY SHEET: Balloon Rockets

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

PERFORM YOUR EXPERIMENT

1. Tie one end of a string to a chair, doorknob, or other support.
2. Put the other end of the string through a straw. Then pull the string tight, and tie it to another support in the room.
3. Blow up the balloon, and pinch the end of the balloon to keep the air inside. Do not tie the balloon.
4. Have a partner tape the balloon to the straw so that the opening of the balloon is horizontal with the ground, while you keep the air pinched inside the balloon.
5. Have your partner use the marker to draw a finish line near the end of the string. Then, let go of the balloon and observe!
6. Test different methods to transport "cargo" across the string to the finish line. See your teacher for materials.

ANALYZE & CONCLUDE

1. Once you have the balloon set, what happens when you let go of it? What causes this to happen? The balloon travels along the string "track." Pressure from the gases inside the balloon pushes those gases out of the balloon when it is released. As the gases escape from the balloon, they exert a force on the outside air, which in turn exerts an opposing force and pushes the balloon forward.

2. What do you think will make the balloon move faster? Increasing the pressure of the gas inside the balloon will make the balloon move faster along the track.

3. What happens when you add cargo to the balloon rocket? The increased weight from the cargo slows down the balloon rocket.

4. 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 17 ACTIVITY SHEET: Balloon Rockets

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)
Fluid	Any substance made up of particles that flow or move freely, such as a liquid or gas.	
Drag	The resistance of motion through a fluid; a mechanical force that opposes an aircraft's motion through the air.	
Power	The rate at which energy is converted or work is performed.	

2. How are modern rockets propelled? Modern rockets are propelled using Newton's Third Law of Motion. The engines on the rocket emit a force that pushes against the ground, which sends the rocket into the air. The force exerted on the ground is equal and opposite to the force exerted on the rocket.

3. If a pilot wants to fly at a constant speed, what must occur? What if the pilot wants the aircraft to accelerate?

If a pilot wants to fly at a constant speed, the amount of thrust must equal the amount of drag. If the pilot wants to accelerate the aircraft, the aircraft needs more power to produce more thrust. The aircraft will go faster when the amount of thrust is greater than the amount of drag.

4. What is Newton's First Law of Motion? Newton's First Law of Motion states that an object at rest stays at rest, and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.