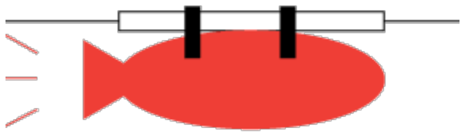


Balloon Rockets

Having Fun with Newton's Laws of Motion

Newton's Third Law (for every action there is a reaction) provides a basic explanation for how a rocket engine works. The air trapped inside the balloon pushes out the open end, providing an "action". The balloon's resulting motion is the "reaction".

In this experiment you will measure and analyze the relationships between the volume of air in a balloon and the distance, speed and average acceleration of its travels.

Objectives:

- Describe and explain the nature of the forces acting on and within an inflated balloon held closed.
- Describe and explain the nature of the forces acting on and within an inflated balloon when it released and free to move.
- Distinguish between independent and dependent variables in an experiment.
- Graphically represent relationships between the volume of air in a balloon and its displacement when it is released.

Materials needed:

Balloons; smaller (7"-9"); larger (12")
Balloon pump
String (fishing line) about 15 m long (35-40 feet)
Small S hook
Bag clip
Drinking straw
Cloth measuring tape
4 small washers (e.g., 1/8 x 3/4)
Scissors
Masking (painter's) tape
Sharpie marker
Meter stick (or long measuring tape)
Stopwatch
Graph paper (or electronic spreadsheet)
Electronic balance (optional)

Watch the Balloon Rockets video on YouTube to get started: https://bit.ly/2PbQSeS

Experiment 1 – Distance of Motion

In the first experiment, you will blow up the balloon to different volumes and release it on a string. In each trial, you will measure the distance the balloon travels, and make a graph of the amount of air in the balloon versus distance traveled.

Work in groups of 3 or 4 for best results.

1. Find an area where you can stretch out a string to a length of 10-15 meters. Hook one end of the string around a solid support. A member of your team will hold the other end tight when you are ready to launch your balloon.
2. Partially inflate the balloon and tape a short piece of string from the nozzle to the center spot on the bottom side (figure 1). Draw a straight line following the string.
3. Find the largest circumference and mark a line perpendicular to the central axis line. This will be the center point of the surface of the balloon.

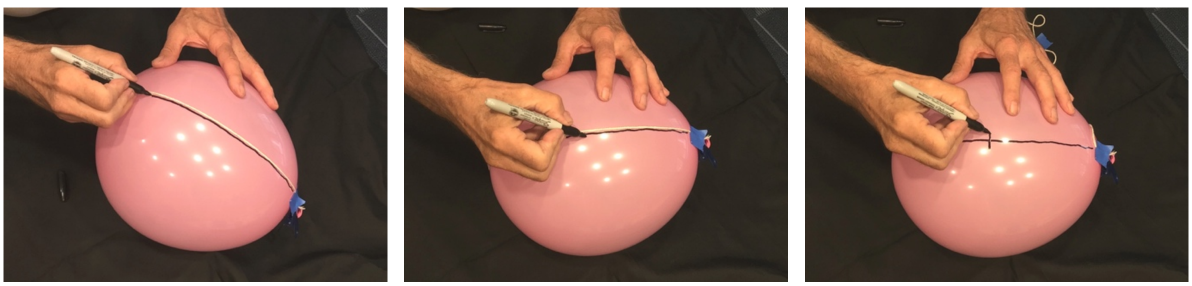


Figure 1. Finding the center point of the surface of the balloon

4. Cut the straw in half and pull the loose end of the string through it.
5. Mark a starting point with a piece of tape, close to the end of the string from which you will launch your balloon rocket.
6. Decide which lab partner(s) who will
    a. Pump and count the number of strokes to inflate the balloon.
    b. Hold the lose end of the string tight and level
    c. Locate and measure the distance traveled by the balloon when it stops
    d. Tape the balloon to the straw and then release it.
7. When you are ready to conduct your flight, pump up the balloon to the desired volume (or number of pump strokes) and clamp the nozzle with a bag clip.
8. Measure the circumference at the widest part of the balloon with a measuring tape and record in Table 1.

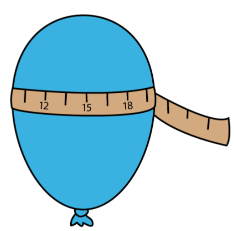


Image: https://www.education.com

9. Attach the balloon to the drinking straw with tape, following the guide marks you drew before. The balloon should **hang below** the string.
10. When you are ready, count down and launch your balloon.

11. Locate the stopping point; measure and record the total distance traveled in Table 1.
12. Repeat steps 5 through 12 with different amounts of air in the balloon (i.e., different circumferences) and record each trial in the first three columns of **Table 1**.

Table 1. Balloon flight data for different volumes.

Trial number	Number of pump strokes	Circumference (cm) (amount of air)	Distance traveled (m)	Diameter (cm)	Volume of balloon (cm^3)
1					
2					
3					
4					
5					

Calculations

1. Complete **Table 1** by calculating the diameter of the balloon for each of your trial, and then the volume, using the equations below.
2. Calculate the diameter from the measured circumference,

$$d = \frac{circumference}{\pi}$$

3. Once you have the diameter, you can calculate the volume of the balloon for each of your trials; enter your results to complete **Table 1**.

$$V = \frac{1}{6}\pi d^3$$

Summary

Rockets work by very rapidly pushing gases out of their nozzles or engines in one direction. This violent explosion of gasses pushes the rest of the rocket toward the opposite direction. This is an example of Newton's Third Law, "For every action there is an equal and opposite reaction." The word "equal" means that both the acting force and the resulting force are equal in magnitude or amount. In other words, when you push on something, it pushes back on you just as hard.

1. Describe the forces and actions when you throw a tennis ball as hard as you can, using the principles of Newton's Third Law.

2. Apply the same principles to describe what happens when you rapidly push against a wall as hard as you can.

3. Graph your results with amount of air (circumference, volume or number of pump strokes) as the independent variable and distance traveled as the dependent variable.

Experiment 2 – Speed of Motion

The first rockets were invented by the Chinese, thousands of years ago, in the form of fireworks. The same laws of physics put rockets to work carrying cargo.

In this experiment you will use a **stopwatch** to **measure the time** it takes for a balloon to travel a fixed distance, based on its cargo (steel washers), and then calculate the balloon's average velocity. In each trial will use the **same distance** and the **same amount of air** in the balloon. Your teacher will tell you **what distance** at which you will make your time measurements.

Your goal will be to graph your results comparing the **mass of the cargo** carried by the balloon (independent variable) **versus average velocity** how fast it travels)**.**

1. Set up and repeat the procedure you used previously, but use a new balloon. Use the same string.
2. Place a piece of tape on the string to mark the starting and stopping points for each trial.
3. Decide which lab partners who will
    a. Hold the lose end of the string tight and level
    b. Use the stopwatch to time the time of flight.
    c. Pump up the balloon.
    d. Tape the balloon and **extra mass** (cargo) to the straw and release it.
4. Counting the number of pump strokes, inflate your balloon to about 1/2 of its total volume and enter the pump strokes in **Table 2**. If required, measure the circumference.
5. Tape the balloon to the straw and prepare to launch.
6. Set the **stopwatch** to zero, place the balloon at the starting point on the string.
7. Count down and release your first balloon.

8. **Record the time**, the balloon hits the stopping point. Remember, you will use the same distance for the remainder of your trials.
9. Repeat steps 3 through 8, taping one additional metal washer for each trial under the straw before you attach the balloon. Record each trial in **Table 2**.
10. Under **Calculations**, calculate the average velocity for each of the trials and enter these values in **Table 2**.

Table 2. Balloon flight data for different masses.

Trial number	Number of pump strokes	Number of washers)	Mass of the cargo (washers)	Distance (same for all trials)	Time (seconds)	Average velocity
1		0				
2		1				
3		2				
4		3				
5		4				
6		5				

Calculations

1. Complete Table 2 by calculating the average **velocity** for each of your trials,

$$velocity = \frac{distance\ traveled\ by\ the\ balloon}{time\ of\ flight}$$

Trial number	Average velocity (cm/s)	Show your calculations
1	________________	
2	________________	

3 ________________

4 ________________

5 ________________

6 ________________

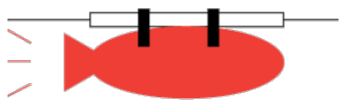
2. Enter your answers in Table 2.
3. Construct a graph, on either graph paper or the computer, to compare the **mass of the cargo** (the washers) of the balloon rocket (x axis) and the **average velocity** of the balloon (y-axis).

Analysis

1. What conclusions could you make from your graph?

2. Write a sentence or two to summarize your findings of your experiment in terms of Newton's Third Law, in your own words.

Teacher Page



Balloon Rockets

Having Fun with Newton's Third Law of Motion

The purpose of this investigation is to allow students to design an experiment, selecting their own independent variables (amounts of air in the balloon) to determine the relationship between fuel (air) and distance traveled. From these data, student will be able to calculate average velocity (speed), final velocity, and (if desired) average acceleration.

Depending on the algebraic skills of your students, they could calculate the volume of the balloon and then different percentages of the volume (e.g., 85%, 70%, 65%, 50%, etc.) from which they could calculate proportional circumferences (yes, it's a little tedious). You could do this beforehand and provide your own suggestions. Alternatively, students could choose their own circumferences, starting with 95 cm for a 30 cm balloon fully inflated (e.g., 95 cm, 85 cm, 75, cm, 60 cm, etc.), for as many trials as you would like to have them make.

The most practical and efficient way to quantify the amount of air in the balloon is to count the number of pump strokes. The graphs will look identical, whether students use pump stroked, circumference, or volume. It comes down to how much math you want them to do.

Experiment 1

We prefer using a smaller (7-9 inch diameter) balloon for Experiment 1. Twelve inch balloons have more air resistance at larger volumes, but feel free to experiment.

The following table provides examples of starting points, whether you choose to suggest volumes, circumferences or diameters. Percent of initial volumes are merely provided as a practical teacher reference. A quick and practical way to quantify the amount of air in the balloon is to use the number of strokes of a balloon pump.

Table 1. Suggested amounts of air for a 7 inch balloon (values rounded)

Pump strokes	Circumference (cm)	Diameter (cm)	Volume cm^3	Distance (feet)	% of full volume
11	58	30	3298	18.5	100
9	54	28	2662	15.5	80
7	50	27	2113	14	65
6	49	26	1989	12	65
4	42	24	1252	10.5	55
3	37	21	856	8	25

The diameter of the balloon can be approximated from the measured circumference,

$$d = \frac{circumference}{\pi}$$

The volume of the balloon can be approximated from diameter,

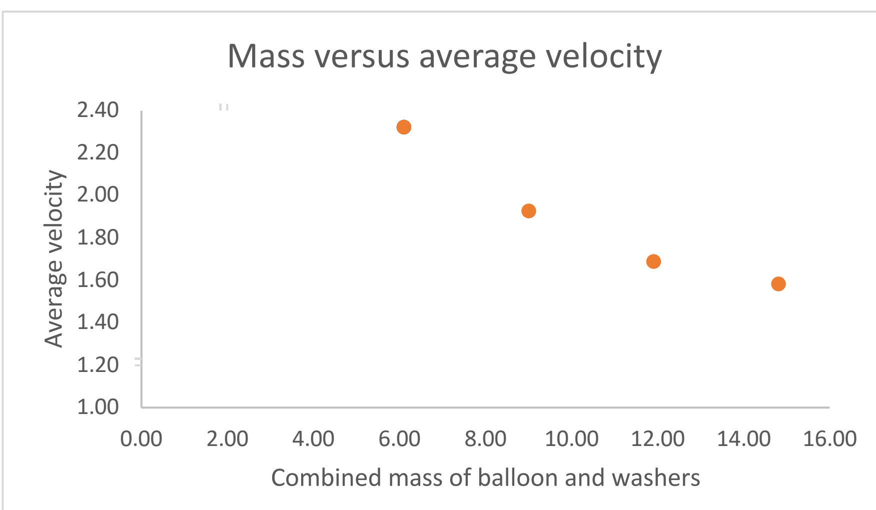
$$V = \frac{1}{6}\pi\, d^3$$

<u>Experiment 2</u>

We conducted Experiment with a 12” balloon inflated to 20 pump strokes (about 50% capacity). A convenient mass increment is about 3 g. We have used small fender washers (a thin wide flat washer) with an average mass of 2.9 g, although a common penny works well too.

Table 2. Balloon flight data for different masses.

Trial number	Number of pump strokes	Number of washers)	Total mass (balloon + masses)	Distance (feet)	Time (seconds)	Average velocity (feet/s)
1	20	0	6.10	16	2.1	2.32
2	20	1	9.00	16	2.53	1.93
3	20	2	11.90	16	2.89	1.69
4	20	3	14.80	16	3.08	1.58



A Word about Acceleration

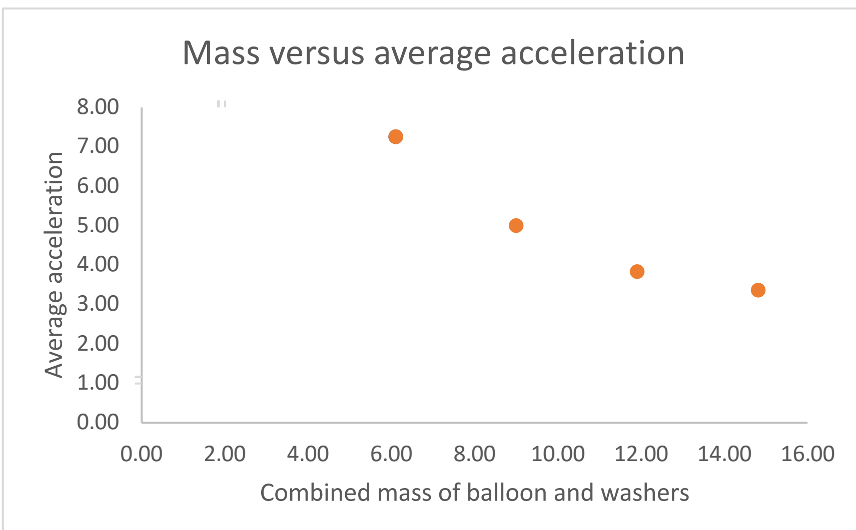
If you choose, you can have students try to calculate the average acceleration for each trial. Interestingly, you might expect that the more a balloon is inflated, the greater the acceleration. Actually this is not the case. The more air, the further it will go, but the thrust of the air leaving the nozzle is the same. In fact the acceleration will appear to decrease with more air, one reason due to air resistance.

In **Experiment 2**, however, acceleration can be calculated, since the only variable changing is the mass of the cargo. Although the acceleration throughout the flight is not constant, we can still measure the average acceleration, using the distance (s) and time, $s = ½ a t^2$. Rearranging, the average acceleration will be $2s/t^2$.

The average acceleration for the these four trials is shown in **Table 3**.

Table 3. Average acceleration versus mass of balloon and cargo

Average velocity (feet/s)	Average acceleration (feet/s/s)
2.32	7.26
1.93	5.00
1.69	3.83
1.58	3.37



Pedagogical suggestions:

- If time is an issue, student groups could be assigned different circumferences or volumes of air (pump strokes), rather than each group doing all five trials, and then class data combined and graphed collectively.
- Have students practice each experiment with 1 or 2 runs before they begin to collect data, to get the feel for what they will do and what to expect.

- Students should work in groups of at least three, two pairs of hands just are not enough. Eight hands is best; six can make do.
- Balloon pumps are required, not only for hygiene, but also for convenience. In fact the amount of air in the balloon can be based on the number of full strokes on the pump, rather than having to measure circumference and calculating volume, if algebra is a problem.
- Have students remove the balloon from the pump as soon as possible once it is inflated to the desired volume to avoid losing any air. A bag clip will serve to seal the end until launch.
- When ready to launch, have students hold the nozzle of the balloon, remove the bag clip, and the release the balloon from their fingers. Just pulling off the bag clip will not provide reliable or consistent results.
- If you chose, students can measure the circumference with a tape, to a certain volume, one student pumps, another measures. This may be cumbersome, so another idea would be for the teacher to figure out in advance the number of pump strokes as a guide and then have students measure the circumference once the balloon are pumped up.
- In Experiment 1, students will be measuring the distance traveled in each of the trials. It may be useful to have them mark off 1 m (or, for example 5 foot) increments on the floor with tape to not have to measure from zero distance every time. The tape markers could also be used for successive classes.
- Have students mark starting point on the string with a piece of tape. In Experiment 2, they will require instruction where to mark the (same) stopping point for each trial. A piece of painter's tape is sufficient.
- Experiment 2 requires a pre-determined stopping point. You can experiment to find what works best for your situation. We used 12" balloons with 20 pump strokes (about 50% capacity), with a stopping distance of 16 feet. This should be determined by the distance the balloon with 5 masses (washers) attached. Longer distances will provide longer times, which are easier for students to measure, but the larger volumes may introduce a little more air resistance, although it will not be a problem for the main point of the experiment.
- The washer masses we use for Experiment 2 are 1/8" x ¾ inch fender washer with a mass of about 2.9 g on average. Have student tape one additional washer for each successive trial on the underside of the straw, before taping the straw to the balloon. That will keep the balloon from flipping over in flight.
- In Experiment 2, students can use a phone stopwatch, although they can be a little tricky to make sure the start and stop are pressed at the right instant. A mechanical stopwatch has a button that is easier to feel in the hand without having to look.
- We recommend using new balloons for each class, and even between Experiments 1 and 2. They tend to lose their stretch after being repeatedly inflated.