Name: _____ Date: _____

Gizmo Activity: Evaluating Theories of Free Fall

[Note: This activity requires you to use the Free Fall Tower *Gizmo™.]*

Learning goals
After completing this activity, you will be able to …

- Use a controlled experiment to evaluate two competing theories of free fall.
- Analyze data to determine which theory is correct.
- Explain how gravity, air resistance, and mass affect the acceleration of falling bodies.

Vocabulary: air resistance, controlled experiment, free fall, manipulated variable, vacuum, variable

Warm-up questions (Do these BEFORE using the Gizmo.)

1. What would happen if you dropped a feather and rock at the same time from a second-story bedroom window? _____

2. Suppose you did the experiment and the rock hit the ground first. Why do you think this happened? _____

Competing scientific theories
Before the time of Galileo Galilei (1564–1642), science was dominated by the theories of an ancient Greek philosopher named Artistotle. Aristotle stated that Earth was at the center of the solar system and that there were five elements: earth, water, air, fire, and aether. Aristotle also believed that the speed of an object was in proportion to the force acting on the object. For falling objects, this force was equal to the object's weight, so therefore heavier objects should fall faster.

Galileo, an Italian physicist and astronomer, argued that without friction, all bodies would fall at the same rate. But how could he do an experiment without friction? If Galileo dropped balls through air, the air would push against the objects. This force is called **air resistance**. You have felt air resistance if you have ever tried to walk or bicycle into a strong wind. Air resistance can really slow you down! Galileo needed to do experiments in a way that air resistance was not a factor.

1. How did Galileo's theory of falling objects differ from Aristotle's theory? _____

_____

_____

2. Suppose you observed a feather and a rock falling. The feather is falling much more slowly than the rock.

   A. How would Aristotle explain why the rock falls faster than the feather? _____

   _____

   B. How would Galileo explain why the rock falls faster than the feather? _____

   _____

3. Suppose you were about to drop a large rock and a small rock.

   A. What would Aristotle predict? Explain. _____

   _____

   B. What would Galileo predict? Explain. _____

   _____

   _____

4. Suppose you were about to drop two rocks. One rock is attached to a parachute. The total mass of the first rock is equal to the mass of the second rock plus its parachute.

   A. What would Aristotle predict? Explain. _____

   _____

   _____

   B. What would Galileo predict? Explain. _____

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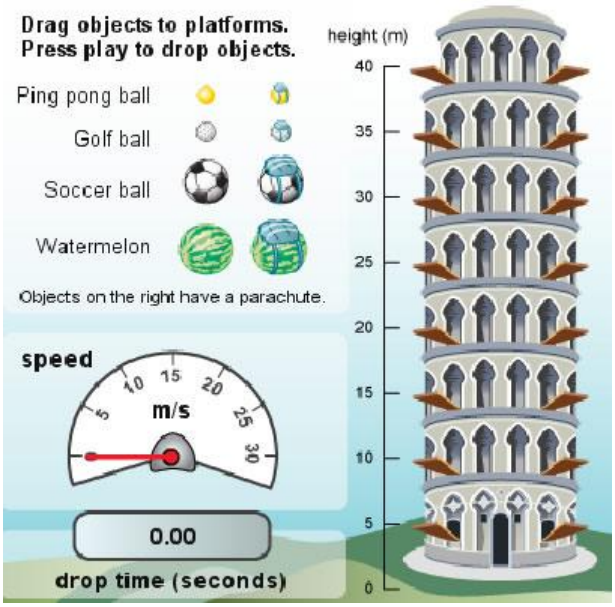
Activity A: Free fall in air

Free fall is any motion caused by gravity. According to legend, Galileo first demonstrated his theory of free fall by dropping cannonballs from the Tower of Pisa. You can model these experiments using the *Free Fall Tower* Gizmo.

When you open the Gizmo, you will see an image of the Tower of Pisa and several objects that you can drop. Before you begin, check that under **Choose atmosphere** you have selected **Air**.

For your first experiment, drag the **Ping pong ball** and the **Golf ball** to the diving boards at the top of the tower. The two balls are about the same size, but the golf ball has much more mass than the ping pong ball.



1. Predict: What do you think will happen when the objects are dropped? _____

   _____

   _____

2. Observe: Click **Play** ( ). What happens? _____

   _____

3. Predict: Click **Reset** ( ). Drag the **Watermelon** and the **Soccer ball** to the two top diving boards. A watermelon is much heavier than a soccer ball.

   What do you think will happen when these objects are dropped? _____

   _____

4. Observe: Click **Play**. What happens? _____

   _____

5. Predict: Click **Reset**. Drag the **Golf ball** to the diving platform currently occupied by the **Watermelon**. There should now be a golf ball on one platform and a soccer ball on the other. A soccer ball has a mass of 450 grams. A golf ball has a mass of 45 grams.

   According to Aristotle's theory, which ball should fall more quickly? _____

6. Test: Click **Play**. What do you observe? _____

_____

Does this result support Aristotle's theory? Explain why or why not. _____

_____

_____

7. Analyze: Think about the results of these experiments. Which results support Aristotle's theory of free fall? Explain. _____

_____

_____

_____

8. Analyze: Which results support Galileo's theory of free fall? Explain. _____

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9. Draw conclusions: So far, which theory do you think is better supported by evidence? Explain your answer. _____

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10. Think and discuss: From the results so far, were you able to prove Galileo's theory that, without air resistance, all objects fall at the same rate? Explain why or why not.

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Activity B: Parachutes

About 100 years before Galileo did his experiments, Leonardo da Vinci sketched an idea for a parachute. A parachute is designed to be lightweight and catch air. A parachute will not add much mass to a falling object. (In the *Free Fall Tower* Gizmo, the parachute adds no weight at all.) Although da Vinci never built or tested his parachute idea, a parachute based on his design was successfully used in 2000 by Adrian Nicholas of the United Kingdom.

da Vinci's parachute

Drop each object from 40 meters in air, with and without a parachute. Record the **drop time** for each object and estimate the **speed** at impact. (This is the speed of the object when it hits the ground.) When objects have a parachute, click **Open parachute(s)** as soon as possible after clicking **Play**.

Object	Drop time	Final speed	Object	Drop time	Final speed
Ping pong ball (3 g)			Ping pong ball with opened parachute (3 g)		
Golf ball (45 g)			Golf ball with opened parachute (45 g)		
Soccer ball (450 g)			Soccer ball with opened parachute (450 g)		
Watermelon (6,000 g)			Watermelon with opened parachute (6,000 g)		

1. Analyze: How did the parachute affect objects falling through air? _____

_____

2. Analyze: Which object was slowed the most by the parachute? Why do you think this was?

_____

_____

3. Draw conclusions: Does the data with parachutes support Aristotle's theory of free fall or Galileo's theory of free fall? Explain your reasoning.

_____

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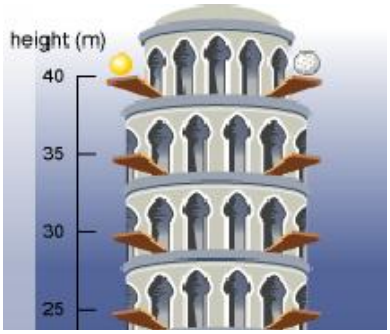
Activity C: Free fall in a vacuum



Galileo did not have the ability to drop objects with no friction at all. This can happen if objects are dropped in a **vacuum**, which is a place with no air. There is no air resistance in a vacuum because there is no air to push back on a falling object.

You can model this situation with the *Free Fall Tower* Gizmo. Under **Choose atmosphere**, click **Vacuum (no air)**. Drag the **Ping pong ball** and the **Golf ball** to the 40-meter platforms.

1. Predict: What do you think will happen when the objects are dropped? Explain your thinking.

2. Observe: Click **Play**. What happens? _____

3. Experiment: Try any combination of objects. Each time, drop the objects from the 40-m platforms. In some of your experiments, use objects with open parachutes.

   What do you observe? _____

4. Draw conclusions: Do these results support Aristotle's theory of free fall or Galileo's theory of free fall? Explain why. _____

Activity D: Controlled experiments

In any experiment, a **variable** is a factor that can be changed. There are several variables that might affect how long it takes an object to fall: the height it falls from, the strength of gravity, the presence of air, the object's mass, the object's size, and the object's shape.

In science, the goal is often to determine the effect of a single variable. For example, Arisotle's theory states that an object's mass determines how quickly it falls. Galileo thought that air resistance affected how quickly an object fell. To see which theory is correct, you did an experiment in which all variables were the same except for the mass of the object.

An experiment in which all variables are the same except for one variable is called a **controlled experiment**. The one variable that changes in a controlled experiment is called the **manipulated variable**.

1. Analyze: Henry designs an experiment in which he drops a watermelon and a ping pong ball from a 40-meter height. He does this in air. When the watermelon hits the ground first he concludes that heavy objects fall faster than light objects.

   A. Is this a controlled experiment? Why or why not? _____

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   B. How could you change Henry's experiment so that it is a controlled experiment that tests the effect of an object's mass? _____

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   C. Would you accept Henry's conclusion that heavier objects fall faster than light objects? Explain why or why not. _____

   _____

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   _____

2. Analyze: Jane designs an experiment in which she drops two balls from a 10-meter height. The balls are the same size and shape. The first ball has a mass of 4 grams and the second ball has a mass of 347 grams. She does the experiment inside a vacuum chamber so there is no air.

   A. Is this a controlled experiment? Why or why not? _____

   _____

   _____

   B. What is the manipulated variable in Jane's experiment? _____

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   C. Suppose the two balls hit the floor at the same time. Jane concludes that, without air resistance, mass does not affect how quickly objects fall. Would you accept her conclusion? Explain why or why not.

   _____

   _____

   _____

3. Analyze: Roberto does an experiment in air. He uses two identical soccer balls. Each ball has a parachute. He releases the balls from the same height. For one ball, he opens the parachute and for the other ball the parachute is closed.

   A. Is this a controlled experiment? Why or why not? _____

   _____

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   B. What is the manipulated variable in Roberto's experiment? _____

   _____

   C. Suppose the soccer ball with the open parachute falls more slowly. Roberto concludes that if two objects have the same mass, the object with more air resistance will fall more slowly. Do you agree with his conclusion? Explain.

   _____

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4. Summarize: Explain how you used controlled experiments to test two theories of free fall: Aristotle's theory that heavier objects fall faster than light objects, and Galileo's theory that, without friction, all objects fall at the same rate.