Lesson Plan: Force

Background

Force is a push or a pull on an object. Pushing or pulling faster increases the force. For example, force is produced on a ball when you throw it into the air. The faster you throw it, the more its **acceleration**, or rate of change in velocity over time, increases, and the force produced on the ball increases. **Newton's Second Law of Motion**, $F = m\ a$, where m = *mass* (kg) and a = *acceleration* ($meter/sec^2$), accounts for many of the forces underlying actions in our everyday life. An important force that affects everyone on earth is gravity. The acceleration due to gravity (the a in $F = m\ a$) is essentially constant for all objects on Earth. This is true in the absence of **friction**, or drag force, which acts to oppose the motion.

The effects of gravitational force have confused humans since ancient times. The Greek philosopher, Aristotle, thought that gravity acting on two objects of different masses would cause them to fall a given distance to Earth at different speeds. According to legend, the great Italian scientist Galileo proved that this idea was wrong by dropping two cannon balls of different masses from the Leaning Tower of Pisa. The balls landed at the same time, leading Galileo to conclude that objects fall to Earth at the same velocity, contradicting Aristotle's teaching.

The finding that the time required for the two balls to fall to Earth is the same means that the velocity of the two balls is the same. This, in turn, implies that the acceleration due to gravity, or rate of change in velocity over time, $a=\Delta v/\Delta t$, is the same for the two balls. This is also true for other objects, disregarding drag force – all objects fall with the same velocity and land at the same time, since the acceleration due to gravity is essentially constant for all objects on Earth. For example, a teenager who weighs 100 lb (45.5 kg) should hit the water at the same time as a child of 50 lb (22.7 kg) when they free fall into a swimming pool. Including drag force, the times may vary slightly.

This laboratory provides a demonstration of Newton's Second Law, $F = m\ a$, by showing that two objects that differ in mass land at the same time when dropped from the same height. The objects land at the same time because their acceleration due to gravity, $a = 9.8\ m/s^2$, is the same.

Objectives & Grade Level

Demonstrate the relationship between falling time and velocity. Illustrate the effects of gravity on objects of the same or different mass. Appropriate for early to advanced high school science classes.

Materials & Equipment

- Two balls of the same size, but different masses (one is heavier than the other)
- Two balls of the same size and the same mass
- Two apples that are similar in size, but differ in mass (one is heavier than the other)
- Meter stick
- Plumb line
  A simple plumb line can be made from a string and a weight
- Camera (e.g., cell phone camera)
- Calculator

- Balance or scale to weigh balls and apples
  A postage scale or kitchen balance can be used
- Notebook and pencil for recording data and making calculations

Procedure

<u>Experiment 1: Two balls of the same size but different masses</u>

Objective: Demonstrate that the falling time is the same for two balls of different masses. The force of gravity acting on the two balls is the same, causing them to fall at the same velocity and land at the same time.

1. Weigh each of the balls on a balance to obtain their mass. Record the mass of each ball in the data table below.

Scientists use kilograms as the unit of mass. If your balance is calibrated in ounces, convert ounces to kilograms using the relationship 1 oz = 0.0283 kg. If your balance is calibrated in pounds, convert pounds to kilograms using the relationship 1 lb = 0.454 kg. Two balls of the same size but different masses are shown in ***Fig. 1****.*

2. Standing on a floor or level surface, measure a height of 1 *meter (m)* from the surface using a meter stick. Make sure the meter stick is straight and not tilted. Confirm this by holding a plumb line next to the meter stick (**Fig. 2**).

If you are using a yard stick instead of a meter stick, convert inches to meters using the relationship 12 in = 1 ft = 0.305 m. Note: A plumb line is used to find a line perpendicular to a surface using gravity. A plumb line can be made using a string and a small weight, such as a few washers.

Why does having a level surface and a plumb line matter?

3. Hold the two balls at a height of 1 *m*. Have a friend ready to record a video of each trial with a cell phone camera.

4. Drop both balls from the same 1-*meter* height and measure the time in *centiseconds* (*cs*, a *centisecond* is one hundredth of a *second*) that it takes for each ball to hit the ground. Record each trial using a cell phone camera. Be sure that you release the balls at the same time without force.

Try a few practice drops before starting the experiment to make sure that both balls are released at the same time from the same height. Look at the video recording, frame-by-frame, to make certain that the balls were released at the same time. If the balls were released at slightly different times, determine the time required for each ball to touch the ground separately, rather than using the same starting time for both balls.

5. Repeat Step 4 so that you have 3-5 trials in all, recording the times and filming each trial. Be sure that you confirm the starting and ending times from the time stamps on the individual frames in the movies. Record to the nearest hundredth of a *second* (the second decimal place, 0.00 *s*).

6. Find the average time for all the trials for each ball using a calculator. Use the Lesson Plan on Experimental Error to determine the experimental error for all the trlals for each ball, e.g., the *mean±sd (mean±standard deviation)*. Compare the *mean±2sd* for each ball to determine if the balls show differences in their falling times. If the

mean±2sd for the falling times of the two balls overlap, the differences are probably due to experimental error in the trials, e.g., releasing the balls at slightly different times or not identifying the correct time that the balls were released or hit the ground. If the *mean±2sd* for the two balls do not overlap, the differences are due to actual differences in the falling times of the two balls.

Why did we do the experiment at least three times and why do we need to take the average? Is the average time that the balls took to hit the ground the same or different? View the videos of the trials to confirm your answer.

7. Using the formula $v = a\ t$, calculate the velocity of each ball. Remember that the acceleration of the balls due to gravity is $a = 9.8\ m/s^2$. Again, calculate the experimental error for the velocity of each ball to see if any differences in your results are due to experimental error or actual differences in the velocities of the balls.

Is the velocity of the balls the same or different?

Experiment 2: Two balls of the same size and mass

Objective: This is a control to show that the acceleration due to gravity is the same for two balls of the same size and the same mass. The balls should land at the same time and with the same velocity.

1. Repeat Steps 1 - 6 from Experiment 1 and record the data. Use these data and what you have learned from Experiment 1 to predict the velocities of the two balls.

2. Using the formula $v = a\ t$, calculate the velocities of the balls.

   Did the balls fall with the same velocity?

Experiment 3: Two apples of similar size but different masses

Objective: Using what you learned from Experiments 1 and 2, predict the results; then perform the trials and calculate the velocity of each apple.

1. Repeat Steps 1 - 6 from Experiment 1 and record the data. Use these data and what you have learned from Experiments 1 and 2 to predict the velocities of the two apples.

2. Using the formula $v = a\ t$, calculate the velocities of the apples.

3. Compare your answers with those of your friends.

   Do your answers match those of your friends? Did the apples fall with the same velocity?

Data Tables

Experiment 1: Two balls of the same size but different masses

Mass (*kg*) Ball 1 __________ Ball 2 ___________		Time (*s*) Ball 1	Time (*s*) Ball 2
	Trial 1		
	Trial 2		
	Trial 3		
	Trial 4		
	Average Time (*s*)		
	Velocity, $v = a \cdot t$ (m/s)		

Experiment 2: Two balls of the same size and mass

Mass (*kg*) Ball 1 __________ Ball 2 ___________		Time (*s*) Ball 1	Time (*s*) Ball 2
	Trial 1		
	Trial 2		
	Trial 3		
	Trial 4		
	Average Time (*s*)		
	Velocity, $v = a \cdot t$ (m/s)		

Experiment 3: Two apples of similar size but different masses

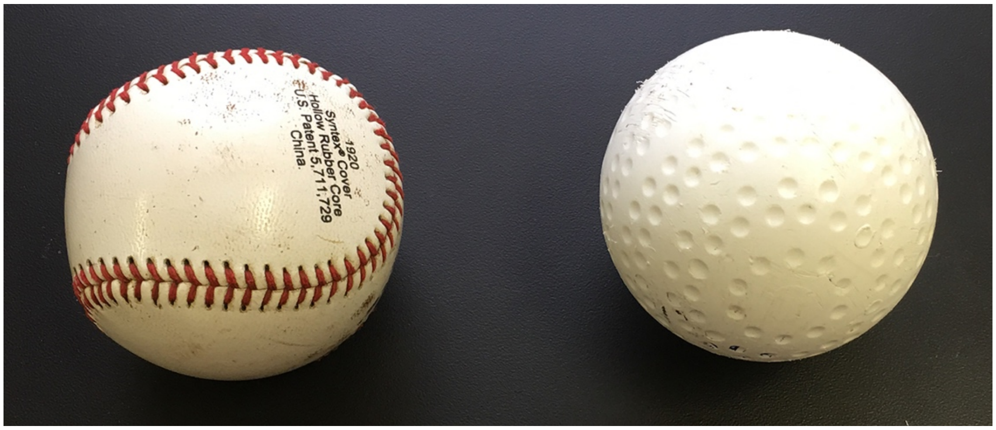
Mass (*kg*)		Time (*s*) Apple 1	Time (*s*) Apple 2
Apple 1 __________			
Apple 2 ___________	Trial 1		
	Trial 2		
	Trial 3		
	Trial 4		
	Average Time (*s*)		
	Velocity, $v = a \cdot t$ (m/s)		

Discussion Questions

1. _______________ (Height, Mass, Size) determines how fast an object hits the ground (i.e., determines the velocity).
2. Newton's Second Law of Motion states that the acceleration of objects due to gravity is ________ m/s^2.
3. Objects of different masses falling from the same height hit the ground at ___________ (the same, different) time(s).
4. The formula for the *velocity* of a free-falling object is _____________.

Figures

Fig. 1 Two balls of the same size but different masses



The two balls are the same size, but differ in mass. The mass of the hockey ball on the right (161.83 g) is ~1.65 times the mass of the baseball on the left (98.34 g).

Fig. 2 Plumb Line

A plumb line, made from a piece of string and a weight. One meter was measured from the floor using the plumb line so the measured distance was vertical to the floor.

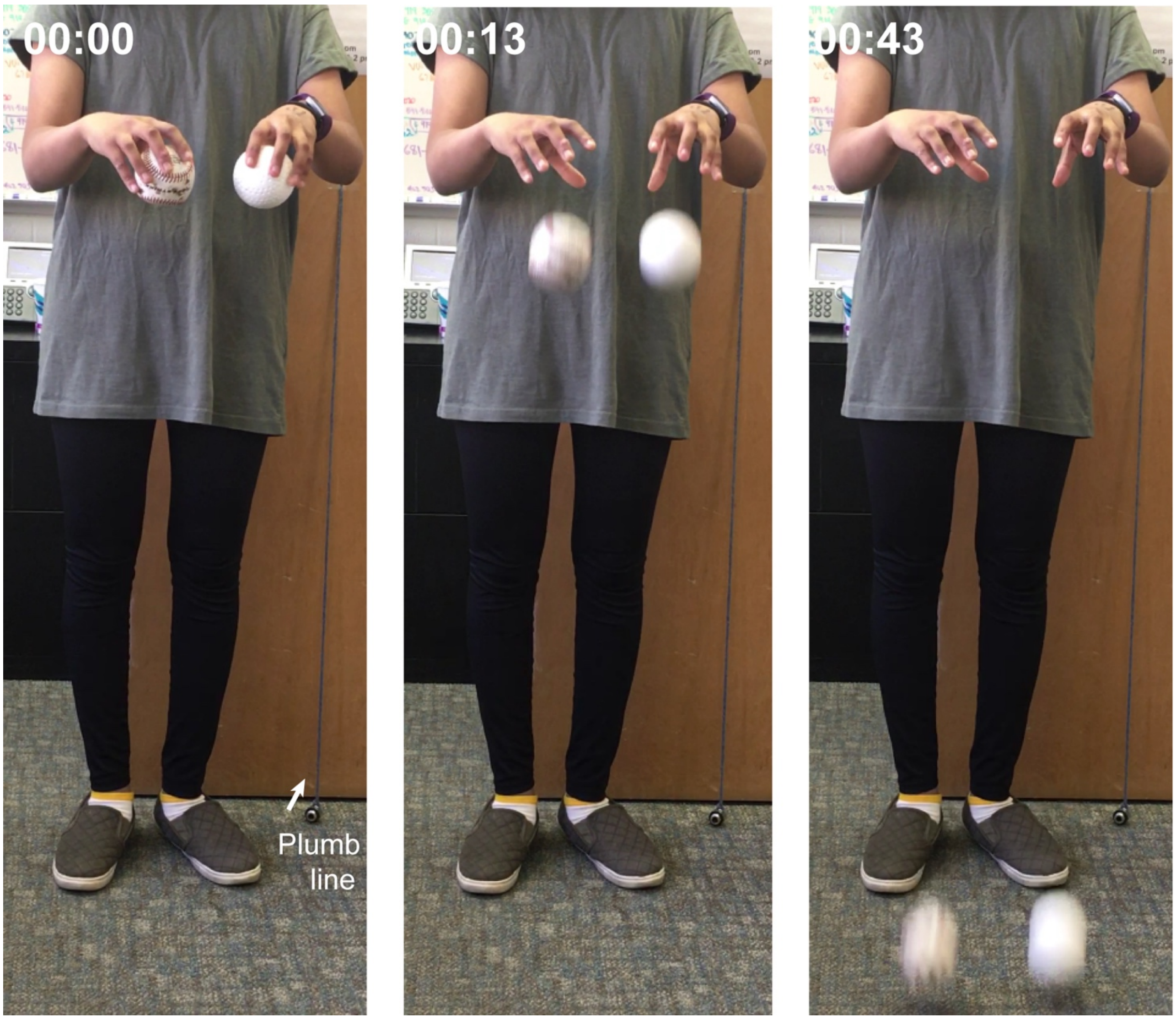


Fig. 3 Experiment 1: Two balls of the same size but different masses. The balls were dropped from a 1-*meter* height at the same time and recorded with a cell phone camera. The images are stills from the movie, which was recorded at 30 *frames/s*. The balls hit the floor at the same time, 0.43 *s* after they were released. Time is shown as 00:00 = *seconds*:*centiseconds*.

Experiment 1: Two balls of the same size but different masses

Mass (*kg*) Baseball 98.34 g = 0.09834 *kg* Hockey ball 161.83 g = 0.16183 *kg*		Time (*s*) Baseball	Time (*s*) Hockey ball
	Trial 1	0.43	0.43
	Trial 2	0.40	0.43
	Trial 3	0.40	0.42
	Trial 4	0.42	0.42
	Average Time (*mean*±*sd*, *s*)	0.41±0.02 *s*	0.425±0.006 *s*
	Velocity, $v = a \cdot t$ (*m/s*)	4.04±0.15 *m/s*	4.17±0.06 *m/s*

Methods: Experiment 1 was performed 4 times and each trial was recorded with a cell phone camera at 30 *frames/s*. The movies were opened in QuickTime Player 7 and the starting frame was found by dragging the cursor to the frame showing the release of the balls, then clicking on the time window (00:00:00) and selecting Frame Number to display the frame number. The ending frame when the balls hit the floor was found in the same way and the time (*s*) was determined by subtracting the starting frame from the ending frame, and dividing by 30 *frames/s*. The average time and *standard deviation* (*sd*) were determined using GraphPad at https://www.graphpad.com/quickcalcs/CImean1.cfm (see *BASICS: Lesson Plan on Experimental Error*).

Conclusions: The mean times, plus or minus twice the standard deviation (baseball, *mean*±*sd* = 0.41±0.02 s, *mean*±*2sd* = 0.37-0.45 *s*; hockey ball, *mean*±*sd* = 0.425±0.006 *s, mean*±*2sd* = 0.413-0.437 *s*), for each ball to fall to the floor overlap with each other, indicating that the measured times probably do not differ significantly from one another – the differences are most likely due instead to experimental error (e.g., errors in releasing the balls at the same time or determining the starting or ending time for the balls falling to the floor). This is also true of the overlapping *mean*±2*sd* for the velocities of the balls. The probable absence of significant differences for the falling time and velocity was confirmed using GraphPad unpaired statistical *t* tests, which showed no significant differences for the falling times or velocities of the two balls. This means that the two balls fall with the same time and velocity, despite the difference in their masses.

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