Mass vs. Weight
Accelerating Mass

Objective

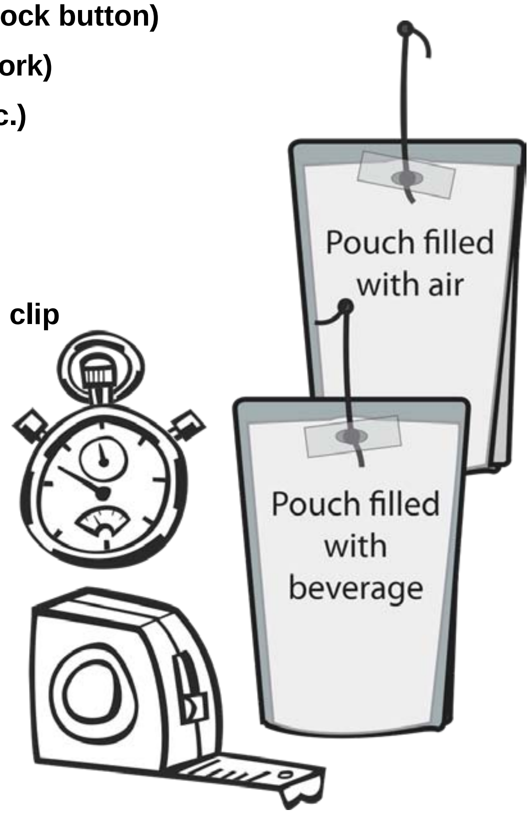
To compare how the mass of objects affects acceleration in the normal 1g (gravity) environment of Earth vs. the microgravity environment of space.

Description

Students explore Newton's Second Law of Motion by attaching an empty (air-filled) foil drink pouch to a tape measure and determining how long it takes the tape measure to retract, and then repeating with a full (liquid-filled) pouch. Which drink pouch accelerates the fastest, the full one with the greatest mass or the empty pouch with the least mass? Once this experiment is completed, students will discuss their data and compare it to the video results of a similar experiment done in microgravity on the International Space Station (ISS).

Materials

- **Empty (air-filled) foil drink pouch**
- **Full (liquid-filled) foil drink pouch**
- **Tape measure (12' with spring release and lock button)**
- **Cellophane tape (any classroom tape will work)**
- **Stop watch (measures to nearest 1/100th sec.)**
- **Scale or beam balance**
- **Safety goggles**
- **Copies of the Student Data Sheets**
- ***Mass vs. Weight* "Accelerating Mass" video clip**



MASS VS WEIGHT

Background

For background information, refer to the *Newton's Laws of Motion Introduction* brief that follows this activity.

Procedure

1. Measure the mass of both an empty (air-filled) and full (liquid-filled) drink pouch and record each mass on the Student Data Sheet. (To inflate the empty pouch, insert the drink straw and blow into it. Remove the straw and cover the hole with a piece of tape.)
2. Tape one end of the air-filled drink pouch to the end of the tape measure. The pouch should not be placed on the tape measure, but be taped on the end and pulled behind it. ***Wear safety goggles*** during this experiment.
3. Extend the tape measure 2 meters (79 inches) and lock the tape in its extended position. Set the tape measure and pouch upside down on a smooth surface to provide as little friction as possible when the tape is retracted. Turning the tape measure upside down will reduce drag.
4. Predict what will happen to the air-filled drink pouch when the tape measure lock is released. Make another prediction for the liquid-filled drink pouch. Record your predictions on the Student Data Sheet.
5. Have one student hold the tape measure down so that it can't move. Count down from 5 and release the lock. Have the second student time how long it takes the tape measure to move the bag two meters. Time the movement to the nearest hundredth of a second. Allow a practice trial.
6. Measure the movement of the bag three times; record the data, and calculate the average.
7. Repeat steps 2 – 6 using a liquid-filled drink pouch.
8. Predict how the same experiment would work in the microgravity environment on-board the International Space Station.
9. View the *Mass vs. Weight* "Accelerating Mass video clip to discuss and compare the 1g and microgravity outcomes of this experiment.

Assessment

1. Review the Accelerating Mass Student Data Sheet. Compare and discuss the results from each student group.
2. Have students write an explanation of how Newton's Laws of Motion helps explain the activity results.

Extensions

1. Use the mass car template from the *Mass vs. Weight* "Mass Car" activity to hold pennies (2.5 g each) instead of drink pouches on the tape measure. This will allow for more precise Accelerating Mass measurement trials and data. Create a graph to plot the data.
2. Have students develop a way to measure mass in space. A normal Earth scale does not work in a microgravity environment. It is critical that scientists take accurate measurements. How can they accomplish this? Students can reference the "Inertial Balance" activity in the NASA curriculum guide, *Microgravity: A Teacher's Guide With Activities in Science, Mathematics and Technology*.
3. Assume that you are conducting this experiment with a very long retractable tape measure, and your drink pouch accelerates uniformly (at a constant rate). Use the kinematic equations below to compute the acceleration and distance traveled when a drink pouch is accelerated from distance *x*.

Standards

National Science Education Standards

Unifying Concept and Processes
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Motions and Forces

History and Nature of Science
- Science as a human endeavor

Principles and Standards for School Mathematics

(refer to *Mass vs. Weight* "Introduction" for complete standards)

Number and Operations
- Understand numbers
- Understand meanings
- Compute fluently

Measurement
- Understand measureable attributes
- Apply appropriate techniques

Data Analysis and Probability
- Formulate questions
- Select and use methods
- Develop and evaluate inferences
- Understand and apply

Process Standards
- Problem Solving
- Communication
- Connections
- Representation

Below is an example if the drink pouch is accelerated 0.0 m/s to 4.1 m/s in 3.7 seconds.

$a = v_f - v_i\ / t$
(acceleration = final speed – initial speed / time)

$d = v_i \bullet t + ½ \bullet a \bullet t^2$
(distance = initial speed • time + one-half • acceleration • time squared)

a = 4.1 m/s – 0 m/s **/** 3.7 s
a = 1.1 m/s^2

d = 0 m/s • 3.7 s + ½ • 1.1 m/s^2 • $(3.7s)^2$
d = 0 m + ½ • 1.1 m/s^2 • $(13.7s)^2$
d = ½ • 1.1m/s^2 • $(13.7s)^2$
d = 7.5 m

4. Have students set up the tape measure with each drink bag. For each, release the lock but do not hold the tape measure. Which moves more, the pouch or the tape measure? Both will move but the one with less mass will move the most. If both pouch and tape measure have the same mass, they should meet in the middle. Discuss the results.

5. There are several types of motion sensors available to science classes. Use one of these sensors to gather data. Compare the data from the sensors to the data gathered as described in this activity. Is it more precise and easier to use?

Name: ______________________________________

MASS VS WEIGHT

Accelerating Mass
Student Data Sheet

PROCEDURE

1. Measure the mass of both an empty (air-filled) and full (liquid-filled) drink pouch. Record data in chart.
2. Extend a tape measure 2 meters (79 inches). Lock it in place; release lock, and measure how long (to the nearest 0.00 of a second) it takes the tape measure to retract completely. Repeat twice and average. Record data in the data chart.
3. Tape an empty (air-filled) drink pouch to the end of the tape measure.
4. Extend the tape measure 2 meters (79 inches) and press the lock on the tape measure to prevent the pouch from moving.
5. Before releasing the tape measure lock, record below what you predict will happen when you release the lock.
6. Release the lock and measure how long (to the nearest 0.00 of a second) it takes the air-filled pouch to travel two meters.
7. Repeat twice and average all three trials. Record data in the "Average time" column on the data chart.
8. Make a new prediction for using the liquid-filled drink pouch. Record your answer in the data sheet.
9. Tape a liquid-filled pouch to the tape measure and repeat experiment (steps 2-7).

PREDICTIONS

air-filled pouch ____

____

liquid-filled pouch____

____

DATA CHART

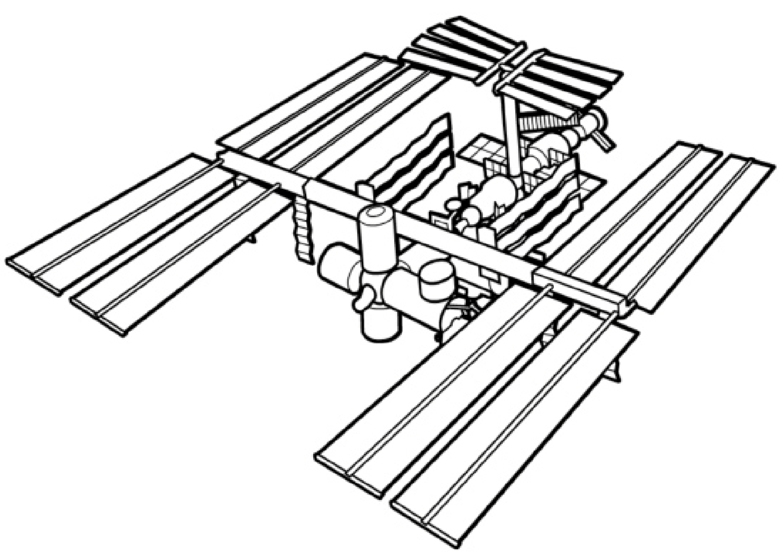
Mass (g)	**Trial 1 time (sec**	**Trial 2 time (sec)**	**Trial 3 time (sec)**	**Average time (sec) for trials 1-3**	**Average Speed distance/time (m/sec)**
no pouch = **0 g**					
air-filled pouch =					
liquid-filled pouch =					

1. How did your predictions compare to the actual data gathered during the experiments?

2. Compare the average speed of the air-filled pouch to the average speed of the liquid-filled pouch and explain how the difference in mass affected the speed of each pouch? (use back of page if needed)

3. Predict what will happen with the same experiment on-board the International Space Station (ISS) in a microgravity environment. Explain your answer. (use back of page if needed)

4. How did your prediction compare to the actual ISS experiment? What variables were different?



DATA

Newton’s Laws of Motion Introduction

Excerpt from *Rockets: Educator Guide With Activities in Science, Technology, Engineering and Mathematics* (EG-2008-05-060-KSC)

Newton’s Laws of Motion
In his master work entitled *Philosophia Naturalis Principia Mathematica* (usually referred to as *Principia*), Isaac Newton stated his laws of motion. For the most part, the laws were known intuitively by rocketeers, but their statement in clear form elevated rocketry to a science. Practical application of Newton’s laws makes the difference between failure and success. The laws relate force and direction to all forms of motion.

In simple language, Newton’s Laws of Motion:

First Law
Objects at rest remain at rest and objects in motion remain in motion in a straight line unless acted upon by an unbalanced force.

Second Law
Force equals mass times acceleration (or f = ma).

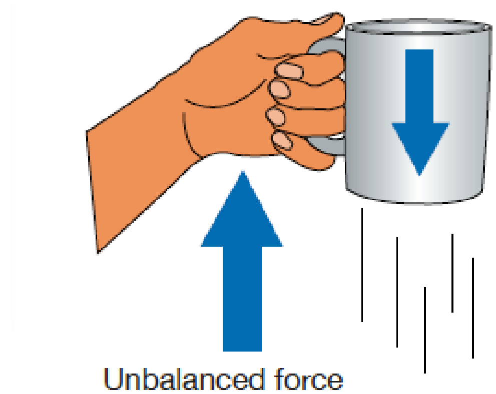
Third Law
For every action there is an equal and opposite reaction.

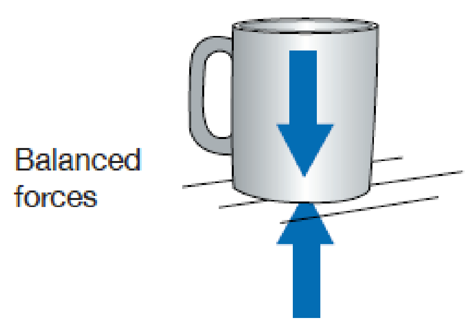
Before looking at each of these laws in detail, a few terms should be explained.

Rest and *Motion*, as they are used in the first law, can be confusing. Both terms are relative. They mean rest or motion in relation to surroundings. You are at rest when sitting in a chair. It doesn’t matter if the chair is in the cabin of a jet plane on a cross-country flight. You are still considered to be at rest because the airplane cabin is moving along with you. If you get up from your seat on the airplane and walk down the aisle, you are in relative motion because you are changing your position inside the cabin.

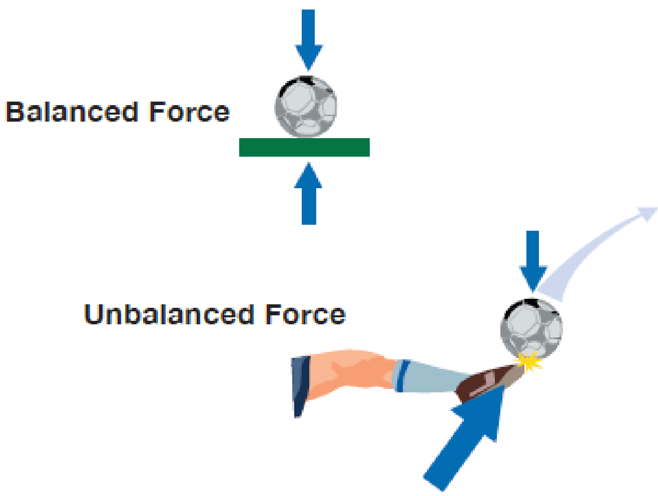
Force is a push or a pull exerted on an object. Force can be exerted in many ways, such as muscle power, movement of air, and electromagnetism, to name a few. In the case of rockets, force is usually exerted by burning rocket propellants that expand explosively.

Unbalanced Force refers to the sum total or net force exerted on an object. The forces on a coffee cup sitting on a desk, for example, are in balance. Gravity is exerting a downward force on the cup. At the same time, the structure of the desk exerts an upward force, preventing the cup from falling. The two forces are in balance. Reach over and pick up the cup. In doing so, you unbalance the forces on the cup. The weight you feel is the force of gravity acting on the mass of the cup. To move the cup upward, you have to exert a force greater than the force of gravity. If you hold the cup steady, the force of gravity and the muscle force you are exerting are in balance.



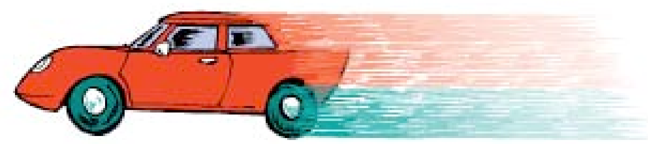


Unbalanced force also refers to other motions. The forces on a soccer ball at rest on the playing field are balanced. Give the ball a good kick, and the forces become unbalanced. Gradually, air drag (a force) slows the ball, and gravity causes it to bounce on the field. When the ball stops bouncing and rolling, the forces are in balance again. Take the soccer ball into deep space, far away from any star or other significant gravitational field, and give it a kick. The kick is an unbalanced force exerted on the ball that gets it moving. Once the ball is no longer in contact with the foot, the forces on the ball become balanced again, and the ball will travel in a straight line forever. How can you tell if forces are balanced or unbalanced? If the soccer ball is at rest, the forces are balanced. If the ball is moving at a constant speed and in a straight line, the forces are balanced. If the ball is accelerating or changing its direction, the forces are unbalanced.

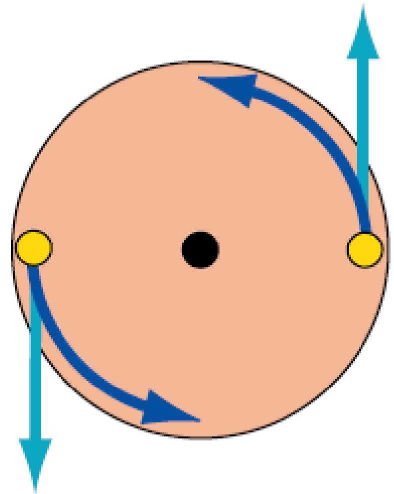


Mass is the amount of matter contained in an object. The object does not have to be solid. It could be the amount of air contained in a balloon or the amount of water in a glass. The important thing about mass is that unless you alter it in some way, it remains the same whether the object is on Earth, in Earth orbit, or on the Moon. Mass just refers to the quantity of matter contained in the object. (Mass and weight are often confused. They are not the same thing. Weight is a force and is the product of mass times the acceleration of gravity.)

Acceleration relates to motion. It means a change in motion. Usually, change refers to increasing speed, like what occurs when you step on the accelerator pedal of a car. Acceleration also means changing direction.



This is what happens on a carousel. Even though the carousel is turning at a constant rate, the continual change in direction of the horses and riders (circular motion) is an acceleration.



Top view of two riders on a carousel. The carousel platform exerts unbalanced forces on the riders, preventing them from going in straight lines. Instead, the platform continually accelerates the riders in a counterclockwise direction.

Action is the result of a force. A cannon fires, and the cannon ball flies through the air. The movement of the cannon ball is an action. Release air from an inflated balloon. The air shoots out the nozzle. That is also an action. Step off a boat onto a pier. That, too, is an action.

Reaction is related to action. When the cannon fires, and the cannon ball flies through the air, the cannon itself recoils backward. That is a reaction. When the air rushes out of the balloon, the balloon shoots the other way, another reaction. Stepping off a boat onto a pier causes a reaction. Unless the boat is held in some way, it moves in the opposite direction. (Note: The boat example is a great demonstration of the action/reaction principle, providing you are not the one stepping off the boat!)

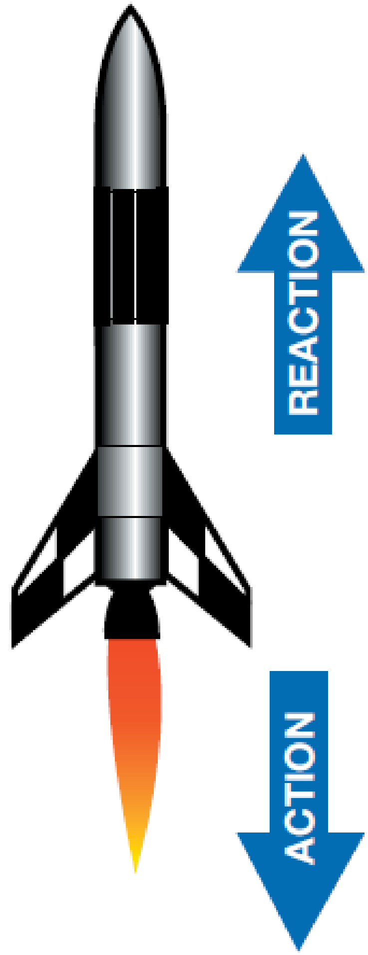
Newton's First Law

This law is sometimes referred to as Galileo's law of inertia because Galileo discovered the principle of inertia. This law simply points out that an object at rest, such as a rocket on a launch pad, needs the exertion of an unbalanced force to cause it to lift off. The amount of the thrust (force) produced by the rocket engines has to be greater than the force of gravity holding it down. As long as the thrust of the engines continues, the rocket accelerates. When the rocket runs out of propellant, the forces become unbalanced again. This time, gravity takes over and causes the rocket to fall back to Earth. Following its "landing," the rocket is at rest again, and the forces are in balance. There is one very interesting part of this law that has enormous implications for spaceflight. When a rocket reaches space, atmospheric drag (friction) is greatly reduced or eliminated. Within the atmosphere, drag is an important unbalancing force. That force is virtually absent in space. A rocket traveling away from Earth at a speed greater than 11.186 kilometers per second (6.95 miles per second) or 40,270 kilometers per hour (25,023 mph) will eventually escape Earth's gravity. It will slow down, but Earth's gravity will never slow it down enough to cause it to fall back to Earth. Ultimately, the rocket (actually its payload) will travel to the stars. No additional rocket thrust will be needed. Its inertia will cause it to continue to travel outward. Four spacecraft are actually doing that as you read this. *Pioneers 10* and *11* and *Voyagers 1* and *2* are on journeys to the stars!

Newton's Third Law

(It is useful to jump to the third law and come back to the second law later.) This is the law of motion with which many people are familiar. It is the principle of action and reaction. In the case of rockets, the action is the force produced by the expulsion of gas, smoke, and flames from the nozzle end of a rocket engine. The reaction force propels the rocket in the opposite direction.

When a rocket lifts off, the combustion products from the burning propellants accelerate rapidly out of the engine. The rocket, on the other hand, slowly accelerates skyward. It would appear that something is wrong here if the action and reaction are supposed to be equal. They are equal, but the mass of the gas, smoke, and flames being propelled by the engine is much less than the mass of the rocket being propelled in the opposite direction. Even though the force is equal on both, the effects are different. Newton's first law, the law of inertia, explains why. The law states that it takes a force to change the motion of an object. The greater the mass, the greater the force required to move it.



Newton's Second Law

The second law relates force, acceleration, and mass. The law is often written as the equation:

$$f = m\,a$$

The force or thrust produced by a rocket engine is directly proportional to the mass of the gas and particles produced by burning rocket propellant times the acceleration of those combustion products out the back of the engine. This law only applies to what is actually traveling out of the engine at the moment and not the mass of the rocket propellant contained in the rocket that will be consumed later.

The implication of this law for rocketry is that the more propellant (m) you consume at any moment and the greater the acceleration (a) of the combustion products out of the nozzle, the greater the thrust (f).