1. Archimedes' Principle

Eureka! It's Buoyancy.

Objectives

In this activity, students are introduced to Archimedes' principle and the nature of buoyant forces. Students learn that gravity exerts a pulling force on objects that is greater in air than it is in water and investigate how the water exerts a force of its own on objects immersed in it.

Students will investigate the buoyant force of water while they:

- Recognize that a force is a push or a pull
- Recognize that forces have magnitudes (strengths) and directions
- State Archimedes' principle in their own words
- Formulate explanations and predictions from evidence and then draw logical conclusions
- Identify variables that can affect the outcome of an experiment; in addition, they learn to identify other variables in an experimental design that must be controlled in order to isolate the effect of one variable
- Gain skills and confidence in using scientific measurement tools, the force sensor, as well as the graphing capability of a computer to represent and analyze data
- Design and conduct a scientific investigation

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in gravitational force on an object in the air and on that same object immersed in water

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
Lab activity, Part 2 – Gravity in air	25 minutes
Lab activity, Part 3 – Buoyancy	25 minutes
Analysis	30 minutes

Materials and Equipment

For each student or group:

- ☐ Date collection system
- ☐ Force sensor with hook
- ☐ Objects to be suspended in water
- ☐ Water
- ☐ Balance
- ☐ String (10 to 20 cm per object)
- ☐ Bucket or tub
- ☐ Towel

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Mass is the amount of matter in an object while weight is a measure of the gravitational force on the object
- How to find the mass of an object with a balance
- Water has a mass of 1 gram for every milliliter of volume – so a known volume of water has a known mass
- Have heard the term *buoyancy* before, even if not familiar with its meaning
- How to read and interpret a coordinate graph, as well as be familiar with the SI unit of measure for force (newtons)
- The basics of using the data collection system

Related Labs in This Guide

Labs conceptually related to this one include:

- Newton's First Law of Motion
- Simple Machines and Force
- Work and Mechanical Advantage

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system (identified by the number following the symbol: "�"). Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Recording a run of data �(6.2)

- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)

Background

Buoyancy was first articulated by Archimedes, a Greek mathematician living in the Roman city of Syracuse in the third century BC. He realized that an object partially or entirely submersed in water has an upward force exerted on it by the water. Furthermore, that upward buoyant force is equal to the weight of the water it displaces.

The legends about Archimedes say that he was sitting in his bath pondering a problem related to the density (and therefore the purity) of the gold metal comprising the king's crown, when his realization of buoyancy dawned upon him. In his excitement at his discovery, he is said to have jumped up out of the bath and run outside (quite naked) shouting, "I have found it! I have figured it out!" Since Archimedes spoke Greek, this came out as, "Eureka! Eureka!"

One common and familiar example of the buoyant force in action is seen in boats and ships, which are made of steel and other metals that are denser than water. Why do they not sink? Because they were designed to displace an amount of water whose weight is greater than their own. The designers and builders of ships take advantage of the fact that displaced water pushes back against the object that displaces it.

In terms of objects that float or sink in a fluid such as water, we are interested in looking at two forces – the downward pull of gravity, and the upward push of the buoyant force. When these two forces are in equilibrium, the object does not move up or down (neglecting any "bobbing" on the water waves or currents).

According to Newton's second law of motion, force is equal to the product of mass multiplied by acceleration. If an object's mass is known, and it is subjected only to the downward pull of gravity, then its weight may be calculated as follows:

Weight = (mass) x (acceleration due to gravity)

Weight is a force — it is the downward force of gravity pulling on an object near a planet's surface. The larger the planet, the greater the force of gravity.

For example, a person whose mass is 20 kilograms has a weight of (20 kg) x (9.8 m/s^2) = 196 N on earth, while the same person on the moon has a weight of (20 kg) x (1.6 m/s^2) = 32 N. The difference is in the acceleration due to gravity, which is 9.8 m/s^2 on earth and 1.6 m/s^2 on the moon; the person's mass never changes.

Archimedes' principle is very general, and applies to objects floating or submerged in any fluid, including other types of liquids and gases, including air. For example, a hot-air balloon has a buoyant force exerted on it by the surrounding denser, cool air. When the buoyant force of the cool air on the balloon is greater than the weight of the balloon, the forces are unbalanced and the balloon gains altitude (rises up). When the buoyant force of the surrounding cool air is less than the weight of the balloon, the forces are also unbalanced and the balloon loses altitude (descends). A hot-air balloon pilot manipulates the balance of these forces, deciding when to ascend, descend, or remain at a constant altitude.

Pre-Lab Discussion and Activity

Engage the students in the following discussion or activity:

Ask students why the Moon's gravity is less than that on Earth. If necessary, suggest that the Moon is much smaller than Earth, so it exerts less gravity. Help students to remember or understand that weight is the force of gravity pulling on an object with mass. If some force were to counteract the pull of gravity on an object, it would then seem like the object weighed less.

Direct students to "Thinking About the Question." After a few minutes, have the lab groups share their ideas. List several of their contributions on the board.

Direct student to "Investigating the Question."

Preparation and Tips

These are the materials and equipment to set up prior to the lab:

- Install hooks on each of the force sensors ahead of time. Since the hooks and bumpers are small parts that easily get lost, put the bumpers away so students do not have access to them. Remind students (as often as you know will be necessary) not to push or pull the force sensor hooks past 50 newtons. Doing so can damage the sensor.

- You may want to cut lengths of string ahead of time, or even tie the objects to be tested to the hooks of the force sensors, to save time. Use non-elastic string, fishing line, or even fine-gauge electrical wire.

- Be certain that the test objects have some way of attaching to the hook of the force sensor. If you cannot find suitable objects, empty soda cans are ideal because they have a metal loop that can be used to attach them to the hook and they can be filled with a known volume of water to change their mass. Possible objects to use include hooked masses blocks of wood, film canisters filled with marbles or small rocks.

- If possible, mount the force sensors on ring support stands, as this provides a much steadier platform from which to hang the objects than having students hold the sensors. If support stands are not available, just encourage students to hold the force sensors as still and steady as they can.

- Advise students to bring the bucket of water up to the object, rather than lowering the object into the water. This method allows the student holding the force sensor to keep it steady, while another student moves the water. Also, it is helpful for students to see the water moving up and then exerting an upward force on the object. This is a good visual reinforcement of the phenomenon of buoyancy.

- Provide students with towels in case of spills or overflows of displaced water.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Do not apply a pushing or pulling force greater than 50 newtons to the force sensor (doing so will damage the sensor).

Driving Question

What is the buoyant force?

Thinking about the Question

Gravity pulls on everything on Earth, from the smallest particle of dust to the largest jumbo jet flying over the earth's surface. Gravity even does its best to keep the space shuttle from launching at Cape Canaveral and escaping into orbit. Whales however, despite their enormous size, do not feel the pull of gravity quite so strongly – at least not as much as they would if they lived on land.

Have you ever been in a swimming pool and dove below the water? Have you ever tried to pick someone up in the swimming pool? You can easily carry people in water that you would not be able to lift on land. Water makes the creatures swimming in it seem lighter.

Discuss with your lab group members whether a whale (or a person) can really get lighter in water. What is meant by "getting lighter?" What is the difference between weight and mass? What do you think water has to do with this phenomenon? Discuss within your group the meaning of the term buoyancy.

> Answers will vary. Students may say that the whale does not actually lose any mass in the water. When we say that it gets lighter, we mean that its apparent weight has decreased. This is because the gravitational force pulling on the whale near the earth's surface is being opposed by the buoyant force on the whale from the weight of the water it displaces. Weight is a force acting on the whale's mass, while mass is a property of matter.
>
> Water has a particular density, with sea or saltwater being denser than fresh water. Since density is mass per unit of volume, the greater the density of a fluid, the greater its buoyant force. For example, a liter of sea water has more mass than a liter of fresh water, which has more mass than a liter of air. This explains why a whale can float in the ocean, but not in the air.

Sequencing Challenge

Note: This is an optional ancillary activity.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

5	1	4	2, 3	3, 2
Attach object to be submersed to the hook of the force sensor. Submerge and measure the force.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Zero the force sensor by pushing the "zero" button on the side.	Find the mass of each object.	Fill container with enough water to submerse objects.

Investigating the Question

Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1: Making predictions

1. ☐ Write your predictions for the following:

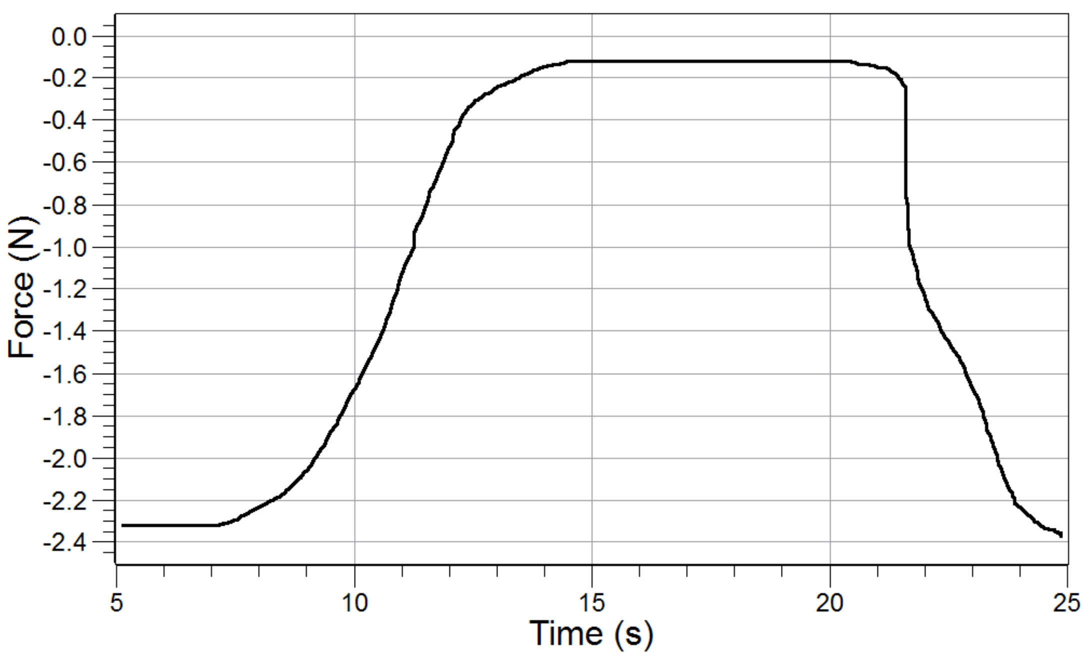
   a. How will a graph of force versus time look when you hang an object from the hook of the force sensor and hold it steady for a few seconds?

   b. How will a graph of force versus time look when you put a heavier object than the first one on the hook of the force sensor and hold it steady for a few seconds?

   c. What will happen to the graphs of both objects when you suspend each object in water?

   When we put a light object on the hook, the force graph will decrease a little. When we put on a heavier object, the graph will decrease more. When we put them in water, the force graphs will increase, showing that gravity is not pulling on them with the same force.

2. ☐ In the space below, sketch a force versus time graph that reflects your predictions.



Part 2 – Investigating the pull of gravity on objects in air

3. ☐ Find the mass in grams of each of your two objects, and record that mass below.

   Mass of Object 1 __260___ grams

   Mass of Object 2 __310___ grams

4. ☐ Start a new experiment on the data collection system. �(1.2)

5. ☐ Connect a force sensor to the data collection system. �(2.1)

6. ☐ Display Force with pull positive on the y-axis of a graph with Time on the x-axis. �(7.1.1)

7. ☐ Begin data recording. �(6.2)

8. ☐ Hold the force sensor with its hook down, and press the “zero” button. Why do you think this is important?

   If the sensor is not zeroed, the force readings will be inaccurate.

9. ☐ Gently attach the first object to the hook of the force sensor, and hold the entire system steady until the force reading stabilizes. Why do you think that moving the force sensor, even a little bit, results in variations in the force data?

   Every time the force sensor or any part of our system moves, the reading changes. It is because the force sensor is sensitive and gravity is pulling on it a little differently whenever it moves.

10. ☐ Stop data recording. �(6.2) Remove the first object from the force sensor's hook.

11. ☐ Start data recording for a new run of data. �(6.2)

12. ☐ Gently attach the second object to the hook of the force sensor and hold the entire system steady until the force reading stabilizes.

13. ☐ Stop data recording. �(6.2) How can you tell by looking at your data which object was the heavier one? How is the force of each object related to its mass?

    We can tell if we were testing the heavier or lighter object because the heavier the object, the more gravity is pulling it down, and the more newtons of force on the graph. The 310 g object is pulled with more negative newtons than the 260 g object.

    The heavier the object, the more gravity pulls on it. So in this example, the graph shows that the 310 g object is pulled with more negative newtons than the 260 g object.

Part 3 – Investigating the buoyant force

14. ☐ Fill your bucket or other container with water. Fill it with enough water so that you can fully immerse the objects without causing the water to overflow. How is the amount of water displaced or pushed aside related to the size and mass of your object?

    The larger object will displace more water than the smaller one.

15. ☐ Start a new experiment on the data collection system. �(1.2) Display force (push positive) versus time on a graph. �(7.1.1)

16. ☐ Hold the force sensor with its hook down, and press the “zero” button.

17. ☐ Attach the first object gently to the force sensor's hook.

18. ☐ Begin data recording. �(6.2)

19. ☐ Holding the container of water underneath the object, raise it until the object is either floating or is submerged in the water. Allow the force reading to stabilize. Observe the graph and record your observations.

Answers will vary. One student group answered as follows: The graph went up, and stayed level. It went up from –2.6 newtons to zero newtons (and a little above because we moved it too much). Our cans actually floated in the water, they did not sink or submerge all the way.

20. ☐ Stop data recording �(6.2) and set the bucket of water down. Remove the first object from the force sensor's hook.

21. ☐ Attach the second object gently to the force sensor's hook.

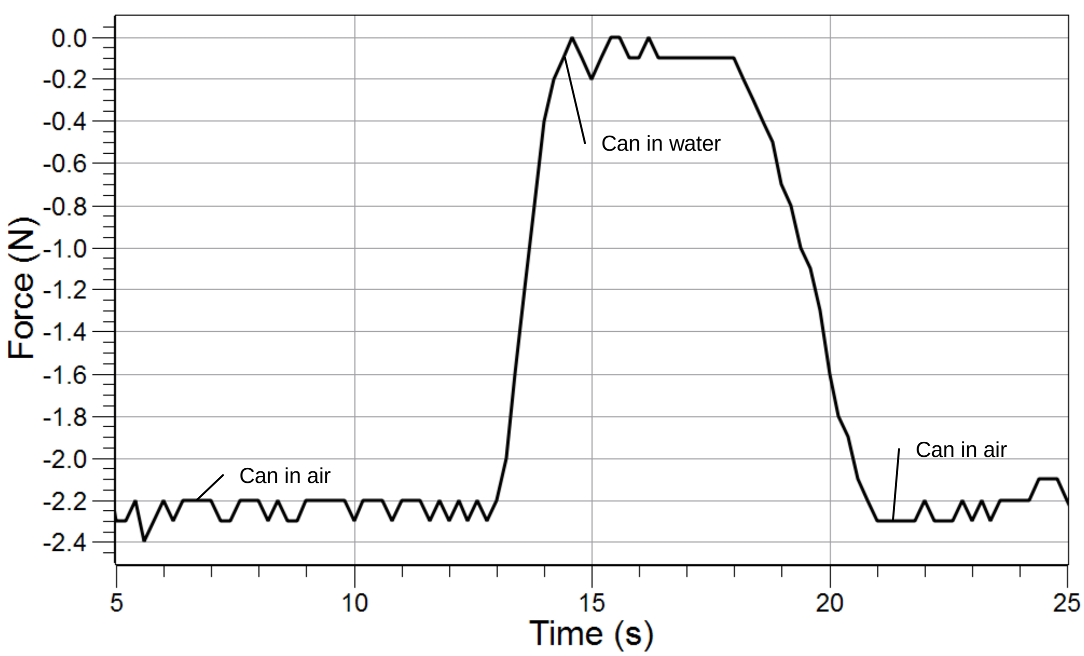
22. ☐ Begin data recording. �(6.2)

23. ☐ Holding the container of water underneath the object, raise it until the object is either floating or is submerged in the water. Allow the force reading to stabilize. Observe the graph and record your observations.

Answers will vary. One student group answered as follows: The same thing happened as with our lighter can. When we immersed it in the water, the graph went up from –3.1 newtons to about zero newtons, and floated without totally sinking.

24. ☐ Stop data recording. �(6.2)

Sample Data



Answering the Question

Analysis

1. How did your predictions from Part 1 compare to the results in Part 2?

   Answers will vary. Students should find that the heavier objects pulled with a greater force than the lighter objects, and that the force on the objects decreased as they were immersed in the water.

2. Archimedes' principle of buoyancy states that an object immersed in a fluid such as water is acted upon by an upward force equal to the weight of the fluid that is displaced. This upward force is called *buoyancy*. How does your data from Part 3 provide evidence for buoyancy? Explain your reasoning.

   Answers will vary. One student group said: We noticed on our graphs that the newtons of force pulling on the objects is not a coincidence. We think this because the amount of newtons is almost the same as the number of grams of each object. For example, our 260 gram object pulled on the force sensor with about –2.6 newtons, and our 310 gram object pulled on the force sensor with about –3.1 newtons. This happened in the air only. Once we put our cans in the water, they lost all their pull. Since we learned that weight is a pulling force, we think the water gives a pushing force.

3. How could you re-state or paraphrase Archimedes' principle in your own words?

   Answers will vary. One student group said the following: When you put an object in water, it loses weight but not mass by the amount of water it pushes aside. If it pushes aside an amount of water that weighs more than it does, it floats.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. What is the force that determines an object's weight on Earth?

   A. Mass
   B. Gravity
   C. Volume

2. Which force pushes on an object in an upward direction, opposite the pull of gravity?

   A. Buoyancy
   B. Volume
   C. Weight

3. Weight is measured with a force sensor while mass is measured with

   A. A gravitational sensor.
   B. A graduated cylinder.
   C. A balance.

4. If you were on the Moon, which quantity would be less than it is on Earth?

   A. Your mass
   B. Your weight
   C. Your volume

5. Which of the following is a pull of Earth's gravity on objects close to the earth's surface?
   - **A. Weight**
   - B. Buoyancy
   - C. Mass
6. An object fully under water is said to be:
   - A. Balanced
   - B. Less massive
   - **C. Submerged**
7. Which term describes the amount of space an object takes up?
   - **A. Volume**
   - B. Buoyancy
   - C. Weight
8. The buoyant force on an object acts in which direction?
   - **A. Opposite the force of gravity**
   - B. In the same direction as gravity
   - C. At a right angle to the force of gravity
9. In order for an object to experience a buoyant force, it must:
   - A. Have a very large mass
   - B. Have a very large volume
   - **C. Displace some type of fluid**
10. What fluid is displaced by a helium balloon tied to a child's wrist by a string?
   - **A. Air**
   - B. Helium
   - C. No fluid is displaced

Further Investigations

Foil boats: Use your understanding of Archimedes' principle of buoyancy to design and construct an aluminum foil boat that can carry the most mass. Challenge your classmates to see whose design take the best advantage of buoyancy. Who can float the most pennies or marbles on the smallest sheet of foil?

Test the buoyant force of very salty water. Use your discovery to discuss why ships float higher in the ocean than they do in fresh-water rivers, and why bathers can rest on their backs and read a newspaper while floating in the Dead Sea.

Test the buoyant force of different liquids such as oil.

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.