Buoyancy

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Date Created: June, 2014

Subject: Physics

Grade Level: Upper Elementary & Middle School

Standards: *Next Generation Science Standards (www.nextgenscience.org)*

3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Schedule: 3 or 4 - 40 minute lessons

CCMR Lending Library Follow Up Activities:
Boat Building Kit
Density Kit

Objectives:	**Vocabulary:**
Students will learn the principals of buoyancy and the properties of air by observing/measuring a cup in water as mass is added to it. They will also build small “divers” in two-liter soda bottles.	Mass, Volume Density, Buoyancy Displacement, Force
Students Will: - Learn how to use a measuring cylinder to find out the volume of liquid in a container. - Learn how to measure mass with an electronic scale. - Understand that when you push an object into a liquid, the objects mass displaces an equal mass of the liquid. - Understand why objects are able to float. - Calculate the relationship between mass and volume. - Construct their own Cartesian divers.	**Materials:** **For Class** Electronic Scale Food Coloring **For Each Group (2-4 students)** Plastic Cup Washers Measuring Cylinder **For Each Student Pair** Plastic Pipette Hex Nut Small Cup **Provided by teacher** Scissors 2L Soda Bottles 3 different sized cups or beakers Large Bucket
Safety	There are no safety concerns for this activity.

Science Content for the Teacher:

Buoyancy is the ability of an object to float in a liquid. The relation of the object's weight to the weight of the water displaced is what determines if the object will float; although the size and shape of the object do have an effect, they are not the primary reason why an object floats or sinks. If an object displaces more water than its weight, it will float. Buoyancy is an important factor in the design of many objects and in a number of water-based activities, such as boating or scuba diving.

The Archimedes Principle

The mathematician Archimedes, who lived in the third century B.C., is credited with discovering much of how buoyancy works. According to legend, he was getting into a bath one day and noticed that the more he immersed himself in the water, the more its level rose. He realized that his body was displacing the water in the tub. Later, he determined that an object under water weighed less than an object in air. Through these and other realizations, he established what came to be known as the Archimedes Principle:

An object in fluid is buoyed up by a force equal to the weight of the fluid the object displaces.

Positive, Negative, and Neutral Buoyancy

An object that floats in a liquid is positively buoyant. This means that the amount of water displaced by the object weighs more than the object itself. For example, a boat that weighs 50 lbs (23 kg) but displaces 100 lbs (45 kg) of water will easily float. The boat displaces more water than its weight in part because of its size and shape; most of the interior of a boat is air, which is very light. This explains why massive ocean liners float: as long as the water displaced weighs more than the ships themselves, they will not sink.

Negative buoyancy is what causes objects to sink. It refers to an object whose weight is more than the weight of the liquid it displaces. For example, a pebble may weigh 25 grams, but if it only displaces 15 grams of water, it cannot float. If the 50 lbs (23 kg) boat was loaded down with 75 lbs (34 kg) of freight, it would no longer float because its weight (125 lbs or 56.69 kg) is heavier than the weight of the water it displaces (100 lbs or 45 kg).

It is also possible for an object to be neutrally buoyant. This means that the object's weight and the amount of liquid it displaces are about the same. A neutrally buoyant object will hover in the liquid, neither sinking nor floating. A submarine can adjust it weight by adding or expelling water in special tanks called ballast tanks. By properly balancing its ballast, the sub can hover at various levels under the surface of the water without sinking.

Size and Shape

How much of an object's surface touches the water has an effect on its buoyancy. A very large ship has a lot of surface area, which means that the ship's weight is spread out over a lot of water, all of which is pushing up on the ship. If the same ship was in the water with the bow pointing down, it would start to sink because all of the weight is concentrated in one small area, and the water it is displacing weighs less than the weight of the ship.

A common example used to demonstrate this is a person floating in water. If the person floats on her back, her entire body can stay at or near the water's surface. When she floats in the water with her feet down, she'll sink farther; typically, only her upper body will stay at the top of the water.

Stability

Stability in a fluid depends on the location of an object's center of buoyancy in relation to its center of gravity. An object's center of gravity is the point in the object where all of the object's weight appears to be concentrated; it can also be thought of as the average location of the object's weight. The center of buoyancy is the center of gravity of the water that the object has displaced. This is not in the water, but in the object floating on it.

When the center of buoyancy is directly above the center of gravity, then the object will be stable. If, however, the center of gravity is above the center of buoyancy — as in a ship that is loaded with freight high above the water line — then the object becomes unstable. If the freight shifts to one side for any reason, the center of gravity and the center of buoyancy will no longer line up. The ship will tip over as the center of buoyancy tries to rise above the center of gravity again.

In the human body, the center of gravity is usually in the area of the navel. The center of buoyancy is slightly higher, which is why a body tends to float upright with the shoulders and torso above the legs. Turned upside down, where the legs are above the torso, the body's center of gravity is above the center of buoyancy. This makes the body unstable, and the position can only be maintained through effort.

Buoyancy in Practice

By applying the principles of buoyancy, engineers can design boats, ships, and seaplanes that remain afloat and stable in water. This is true of many other objects, such as life preservers and pontoons. Just about anything designed for water relies on an understanding of these principles.

Many swimmers know that there are ways to make their bodies more buoyant, such as lying on their backs or holding a full breath. In addition, trying to dive to the bottom of a pool takes effort because the body naturally floats. Scuba divers in particular need to know how to float, hover, and sink, and they often wear extra weights and other gear to help them manage these maneuvers.[1]

What is a Cartesian Diver?

The Cartesian diver is a classic science experiment named after René Descartes (1596-1650), a French scientist and philosopher who invented coordinate geometry and made major contributions to the philosophy of science. Descartes used the diver to demonstrate the laws of buoyancy, or the tendency of an object to float in a fluid.

Traditional Cartesian divers have been constructed out of glass medicine droppers or delicate glass ampules. The divers constructed in this lab will consist of a safe and easy to use plastic medicine dropper that is weighted with a hex nut. When the dropper buoyancy is properly adjusted, the Cartesian diver will sink when pressure is applied to the outside of the bottle and will float when the pressure is released.

How Does the Diver work?

When you build a Cartesian Diver, you are exploring three scientific properties of air:

1) Air has weight
2) Air occupies space
3) Air exerts pressure

[1] "What Is Buoyancy? (with pictures) - wiseGEEK." 2012. 10 Jun. 2014 <http://www.wisegeek.org/what-is-buoyancy.htm>

Generally speaking, an object will float in a fluid if its density is less than that of the fluid (density = mass/volume). If the object is more dense than the fluid, then the object will sink. For example, an empty bottle will float in a bathtub that is filled with water if the bottle is less dense than the water. However, as you start filling the bottle with water, it's density increases and its buoyancy decreases. Eventually, the bottle will sink if it is filled too full with water.

The Cartesian diver, consisting of a plastic medicine dropper and a metal hex nut, will float or sink in the bottle of water depending on the water level in the bulb of the dropper. When pressure is applied to the outside of the bottle, water is pushed up inside the diver and the air inside the bulb is compressed into a smaller space. Molecules of gases are more easily compressed than molecules of liquids. The more water that is inside the diver, the less buoyant it becomes and the diver sinks. When the pressure on the outside of the bottle is released, the compressed air inside the diver expands and this pushes some of the water back out of the diver. As the water level inside the diver drops, the diver floats to the top.

A submarine operates in a similar way. When the submarine is ready to dive, it takes water into tanks until its mass is enough to make the submarine sink. This increased mass caused by the water in the tanks increases the density of the submarine and it descends. When its time for the vessel to resurface, very high pressure air is blown into the submarine's tanks, the water is forced out, and the submarine ascends to the surface.

Preparation:

- Get materials together for buoyancy lab.
- Prepare printed materials for students
- Create your own version of the diver to show students, or acquire one of the hand-held water games that operates on buoyancy.
- Have each student bring in an empty two-liter soda bottle.

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Classroom Procedure:

Buoyancy Lab:
You will need a large bucket for each group. Have each group read the activity directions and then perform the activity. They should notice that for the cup to float, the ratio of mass/volume will be less than 1. When the cup sinks, the ratio of mass/volume will be greater than 1.

After the activity, have the students read about Archimedes' Principle and answer the questions. Discuss the results they came up with. If they have done density, can they figure out why 1 is the magic number for floating or sinking (water has a density of $1 g/cm^3$).

Give each group 3 different sized cups/beakers. If the cups do not have known volumes you can have the students find that out by using a measuring cylinder. Have the groups take each cup and apply a force down on the cup into the water. What do they feel? They should feel a force pushing back up on them. This is called the **buoyant force**. What do they notice about this force with each cup? They should notice that the buoyant force gets larger as the cup gets larger. The more surface area of the cup pushing down on the water, the more water is displaced. This will produce a larger upward force.

For a challenge, you can give the students use a container with a lid. They can first predict how many washers they would need to add for the jar to have neutral buoyancy in the water. Then they can test to see if their prediction is correct.

Cartesian Diver:
Either find a hand-held water game that operates on buoyancy, or else create your own game version of the Cartesian diver. If you wish to create a game, you can do so by fashioning a wire hook on your diver, then making sure it just barely floats when placed in water. Create a second diver that just barely sinks when placed in water. Attach a piece of wire to it, shaped like a loop above it for the hook to catch on. (If you feel creative, fashion several with different sized loops that can be worth different points in the game).

Show your game to the students and let them attempt it. Challenge them to make some initial predictions about how the game works and then think of other ways principals of buoyancy or density affect our lives.

Students will work to create their own version of the Cartesian diver and will begin thinking about the principals that allow them to work. Have them form groups to discuss their findings.

Have student groups present their ideas to the class, explaining both why the Cartesian diver works and how they came to this conclusion.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term "expectations" here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

4= exceeds expectations
3= meets expectations consistently
2= meets expectations occasionally
1= not meeting expectations

	Engage	Explore	Explain
4	Shows leadership in the discussion and activity, displays good understanding of buoyancy.	Completes work accurately while providing an explanation for what is observed. Works very well with partners.	Provides an in-depth explanation of findings. Makes excellent and thoughtful comparisons to everyday life. Completes activity sheet and reading questions.
3	Participates in the discussion and activity; shows an understanding of buoyancy.	Completes work accurately and works cooperatively with partners.	Provides clear explanation of findings. Notes good correlations to everyday life. Completes activity sheet and reading questions.
2	Contributes to the discussion and activity, but shows little understanding of buoyancy.	Works cooperatively with partners, but makes some mistakes with the procedure.	Provides a limited explanation of findings. Struggles to make comparisons to everyday life. Completes some of the activity sheet and reading questions.
1	Does not participate in discussion and/or activity.. Shows no understanding of buoyancy.	Has trouble working cooperatively. Does not complete work..	Provides little to no explanation of findings. Struggles to make comparisons to everyday life. Does not complete the activity sheet and reading questions.

Extension Activities:

Neutral Buoyancy

For an extension activity, mark off three different distances from the bottom of the bottle with tape or a marker. Try to make your diver descend to the first mark, hold for 3 seconds, rise or descend to the second mark, hold for three seconds, then rise or descend to the third mark and hold for three seconds. This demonstrates the concept of neutral buoyancy. Neutral bouyancy occurs when an object has equal density to the water around it and hovers at a certain depth. Notice that being neutrally buoyant at different depths requires different amounts of pressure.

Rescue Diver

For an engineering challenge have students perform "diver rescues" by attaching a paper clip, bent in a "J" shape to the bottom of their diver. Then sink a small loop or hook of something like copper wire that the diver can hook to and lift to the surface. Make sure the object is light enough so that the diver can lift it. This is hard, and should only be attempted by older students.

Fresh Water Salt Water

To help understand some of the differences between fresh and salt water, try your diver in a bottle filled with water saturated with salt. Does it take more or less pressure to make the diver sink? What does this tell you about the density of salt water as compared to fresh? It will take more pressure to sink the diver. Use this extension to demonstrate that salt water is denser, and therefore makes objects more buoyant. [2]

Other Resources:

Archimedes Principle Video - Learn about Buoyancy." 2009. 8 Jul. 2014 <http://www.sciencekids.co.nz/videos/physics/archimedesprinciple.html>

Archimedes' Boat - scienceteacherman.com." 2012. 8 Jul. 2014 <http://scienceteacherman.com/archimedes-boat/>

"Eye Dropper Cartesian Diver | Experiments | Steve Spangler ..." 2013. 3 Feb. 2015 <http://www.stevespanglerscience.com/lab/experiments/eye-dropper-cartesian-diver>

Cartesian Diver Activity Page Index." 2009. 4 Mar. 2015 <http://thunderbay.noaa.gov/pdfs/cartndiver.pdf>

[2] "Cartesian Diver Activity Page Index." 2009. 4 Mar. 2015 <http://thunderbay.noaa.gov/pdfs/cartndiver.pdf>