ASTRONAUT

OCEAN TO ORBIT

# Simulating Microgravity with Buoyancy Lesson Plan

by Bill Andrake

**Science Lesson:** Simulating Microgravity with Buoyancy
**Grade Level:** 5-8
**Time:** Five (45-50 minute) class periods

## Introduction

Working in the weightless environment of space is a challenge for astronauts on the International Space Station. This is especially true when situations arise that demand leaving the space station to make repairs, as astronauts must work with specialized tools while wearing cumbersome spacesuits that protect them from the harmful radiation, extreme temperatures, and vacuum of space. To prepare for such scenarios, astronauts train underwater in NASA's Neutral Buoyancy Laboratory which is a huge indoor pool filled with 6.2 million gallons of water; 40 feet in depth, 202 feet long and 102 feet in width. In the pool are full-scale replicas of the International Space Station's sections that can give astronauts a realistic rehearsal for dealing with potential problems in space.

Whenever anything is placed in water, its buoyant force negates the effects of Earth's gravity. While wearing spacesuits modified for use underwater, with just the right amount of weight and air inflation, astronauts can achieve neutral buoyancy in the NBL, simulating what it is like to work in the microgravity of space.

## Next Generation Science Standards

***Disciplinary Core Ideas:***
- ***Forces and Interactions***

## Objectives

- To learn how and why things float or sink (Archimedes' Principle) as well as identifying the factors that affect buoyancy.
- To understand the relationship between density and buoyancy.
- To see and explain changes that occur from the interaction of forces.

## Contents

## Science Activity: Understanding Buoyant Force

### Vocabulary

**Buoyancy:** The force that allows objects to float in a fluid. Known as Archimedes' Principle, this upward force is equal to the weight of the amount of fluid displaced by the object.

**Density:** The amount of material (**mass**) in a given space (**volume**). It is calculated by dividing a material's **mass** by its **volume**. ( Density = mass ÷ volume )
Units are typically expressed in grams per milliliter (g/ml).

** *Important Fact: The density of water is about 1 gram per milliter.*

**Displacement:** When an object pushes a material out of the way. An object displaces its volume when submerged in a fluid.

**Fluid:** A liquid or gas. A fluid has no definite shape... it flows. Air and water are fluids.

**Force:** A push or pull

**Mass:** A measure of the amount of matter. The basic unit of mass in the metric system is the gram. Mass is measured using an object's weight on a balance.

**Neutral Buoyancy:** A condition experienced by an object underwater where the upward force of buoyancy is equal to the downward pull of gravity. It neither floats nor sinks.

**Pascal's Law:** States that when there is an increase in pressure at any point in a confined fluid, there is an equal increase in pressure on every other point in the container.

**Pressure:** The amount of force exerted per unit area. Example: Pounds per square inch or "psi."

**Volume:** The amount of space occupied by a quantity of material or object.
The basic unit of volume in the metric system is the liter (l). Smaller volumes are measured in milliliters (ml) 1 ml = 0.001 liters, also known as 1 cubic centimeter (cc).

**Weight:** The force of gravity on an object

## Science Activity: Understanding Buoyant Force

**Introduction:**
When an object is at rest on a table, the table pushes up on the object with a force equal to the downward force of gravity on the object. **When the same object is in a fluid, the fluid pushes up on the object with a force called buoyancy.**

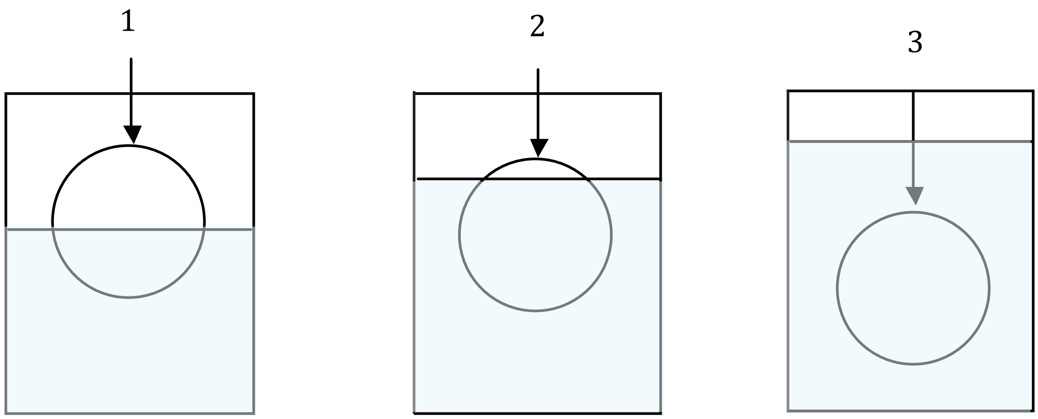
# Science Activity: Understanding Buoyant Force

**Materials:**

- Inflated ball, such as a basketball
- 5 gallon bucket of water

**Procedure:**

1. Place an inflated ball into a 5 gallon bucket filled about two-thirds with water.
2. Slowly push the ball down into the water. *It might take two hands*. Notice that there is an upward force of the water against the ball.
3. Keep pushing the ball SLOWLY deeper into the water. The upward force increases as more of the ball is pushed below the surface of the water. *It's important to note that the water level in the bucket is rising… is there a relationship?*




4. Keep pushing SLOWLY. Once the ball is **<u>totally submerged</u>** the upward force pushing back does not increase and remains constant, no matter how much deeper you push the ball into the water.

*Important..the water level has basically stopped rising once the ball has been totally submerged.*

**Discussion:**

This upward force that the water exerts on the basketball is called **buoyancy or buoyant force.**

***But where does this force come from?***

It was important to see that as the ball was pushed further into the water the **buoyant force** increased. At the same time more water was being displaced by the ball. Once the ball was completely submerged and <u>no more water was being displaced,</u> the buoyant force stayed the same.

**Conclusion: Buoyant force is due to the displacement of the water.**
Simply put… if you push water out of the way… it pushes back. This push back is the **buoyant force**.

***But why does water push back when it has been displaced ?***

If you let go of the ball submerged in the water, the ball goes back to the surface quickly. At the same time, the water level in the bucket returns to back to its original level. Gravity pulled the water back into its original position. Thus, when you push a ball into the water, the water pushes back with its weight.

***Conclusion: Buoyant force is the weight of displaced water = Archimedes' Principle***

*The principle of buoyancy was discovered by the Greek scientist Archimedes around 250 B.C.*

## Activity: Understanding Buoyant Force (cont'd)

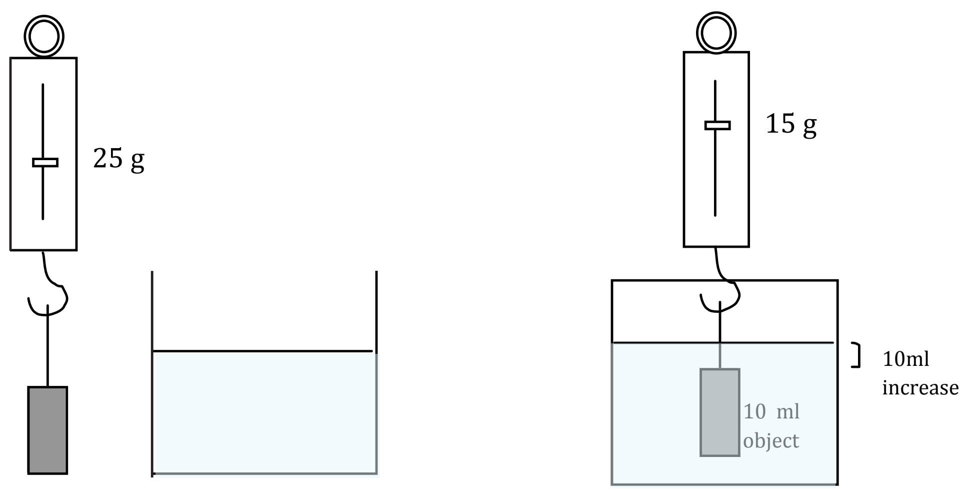
**Follow up:**

If the buoyant force on the object is equal to the weight of the fluid the object displaces…

***The weight that an object loses when placed in a liquid is equal to the weight of the liquid that the object displaces.***

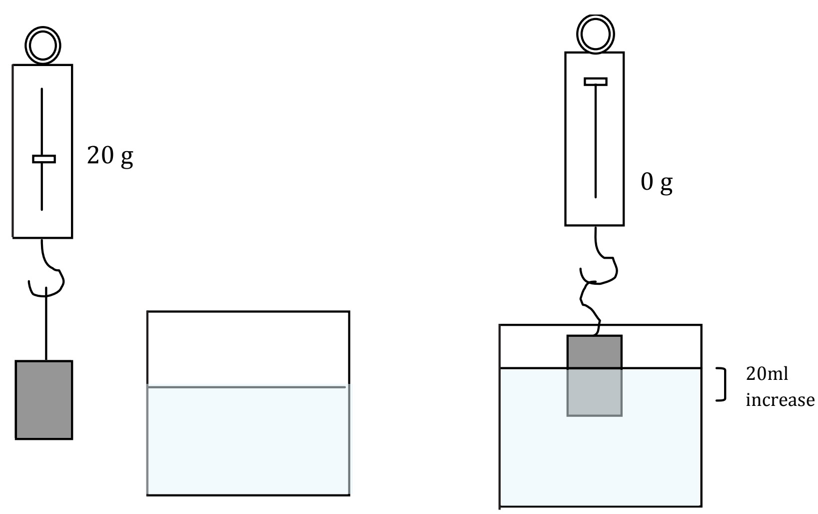
*For convenience, let's use gram force for the measurement of weight.*

- For example, a 25 gram weight is placed in water. When totally underwater, the object weighs 15 grams *so it lost 10 g of weight*.
- The water must be pushing back with a force of 10 grams; the buoyant force = 10 grams.
- Since water has a density of 1g per ml, then the **volume** of the displaced water must be 10 ml, thus the volume of the object is 10 ml.




***When an object floats: the buoyant force = the object's weight***

This means that the **weight of the water displaced** must equal the weight of the object. If an object weighs 20 g and floats in water, it must displace 20 g of water... or a volume of 20 ml.



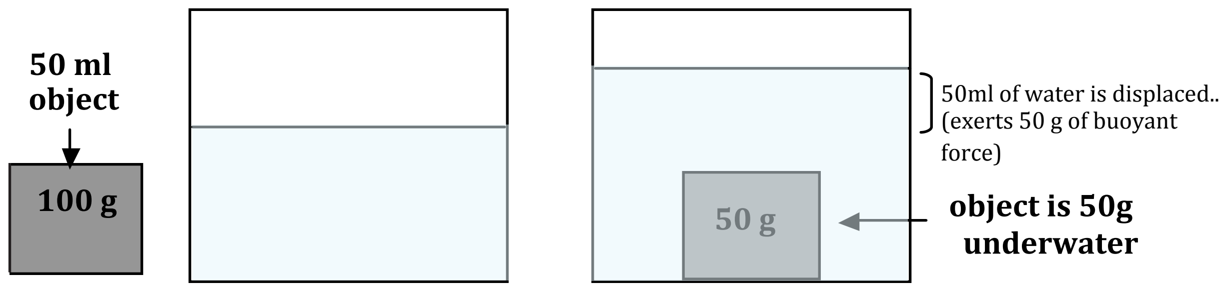
## Activity: Understanding Buoyant Force (cont'd)

***If an object sinks: the weight of the object is greater than the buoyant force.***
***Its density is greater than that of the liquid in which it is placed.***

This means that, in order to sink, the weight of the object is greater than the **weight of the displaced liquid.**

- Let's say we have an object with a volume of 50ml that weighs 100 g and sinks to the bottom.
- It can only displace 50 ml of water, which is 50 grams of water.
- Water can only exert a **buoyant force** of 50 grams on this object.
- Thus the object sinks, but it lost 50 g of weight when submerged.

*This example shows why something more dense than the fluid it is in will sink in that fluid. This object has a mass of 100 grams and a volume of 50 ml so its density (m ÷ v) is 2 grams/ml whereas water's density is 1g/ml.*




## Buoyancy Activity: Floating a Submerged Weight

In this activity you will calculate the amount of buoyant force needed to lift a sunken weight in an aquarium off the bottom. Then you will put together a float arrangement that can exert that amount of buoyant force. Attach the float to your sunken weight to see if it brings your weight off of the bottom.

**Materials:**

- For floats:
  - Small empty plastic bottles
  - Small pieces of styrofoam, corks, etc.
  - Wire hooks (bent paper clips) for attaching to the sunken weight
- Graduated cylinders, beakers of water, and droppers.
- Teriyaki sticks / skewers for pushing floats into graduated cylinders of water.
- Gram scale or balance. 500 g and 1000 g spring scales.
- At least ten gallon aquarium or 5 gallon bucket filled with water. With an a aquarium you can see the lift of the weight off the bottom; better visual learning.
- Weights. 250 – 1000 grams. (could be anything from lab weights to rocks with a way to hook a float on to it, such as being wrapped with string.)

## Buoyancy Activity: Floating a Submerged Weight (cont'd)

**Procedure:**

**Step 1: How to Calculate the Maximum Buoyant Force of a Float.**

***Buoyant force is the weight of displaced water.***

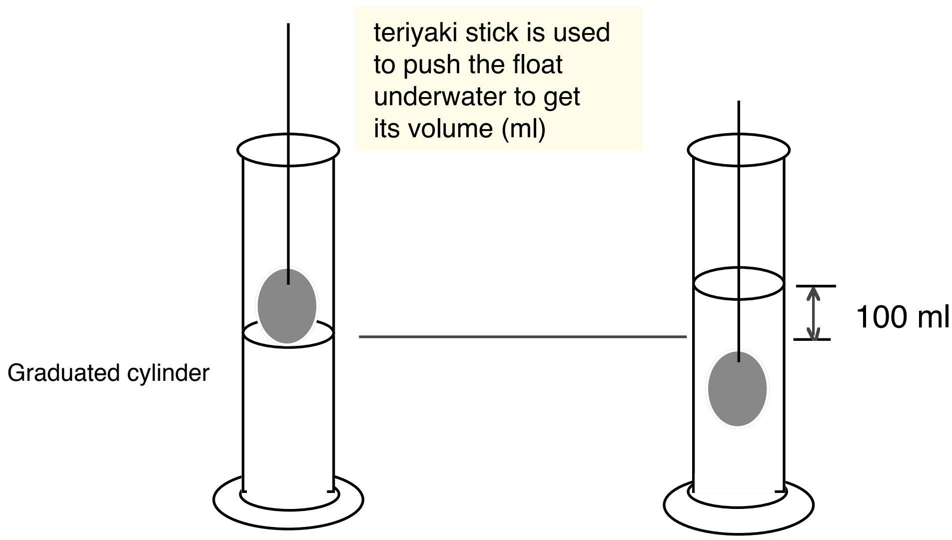
Floats work by **displacing a lot of water without adding much mass or weight**. So they expand volume without adding much mass... *thus floats decrease the **density** of the object to which they are attached.*

*Think of a life preserver… it increases volume without adding much mass to a person. Thus they displace more water and increase buoyant force without really increasing their weight.*

To determine the maximum buoyant force that a float can exert on a weight underwater you need to know two measurements.

1. You need to know the amount of water a float can displace which means that you need to know the volume of the float.
2. You have to take into consideration the weight or mass of the float. This will take away from the maximum buoyant force that a float can have.

So: **Buoyant force = the weight of displaced water minus the weight of the float**

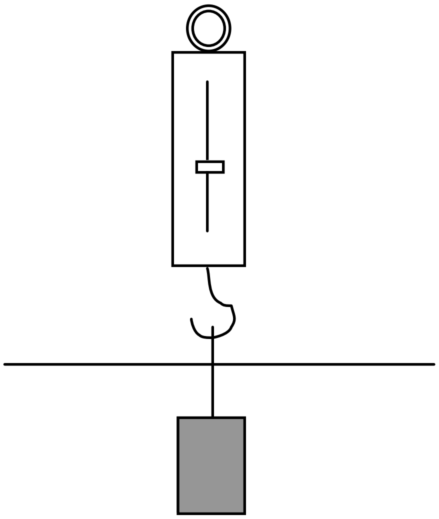



For example:

- A float displaces 100 ml of water... so the weight of the displaced water is 100 grams.
- The mass of this float out of water is 10 grams weighed on a scale.

Buoyant Force = weight of displaced water - weight of the float
Buoyant Force = 100 grams - 10 grams
Buoyant Force of the Float = **90 grams... which means that it is capable of lifting an object that weighs 90 grams underwater**

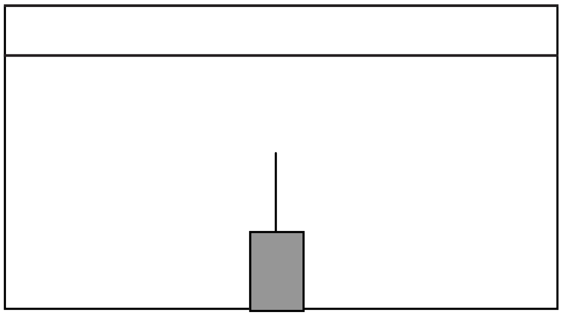


**Step 2: The weight to be raised.**

- Select a weight for this experiment.
- Hang the weight from a spring scale and lower it totally underwater.
- Measure the weight in grams of its weight **underwater** and record it on the next page in the data section.

- Next, lower the weight to the bottom of an aquarium or a tall bucket.



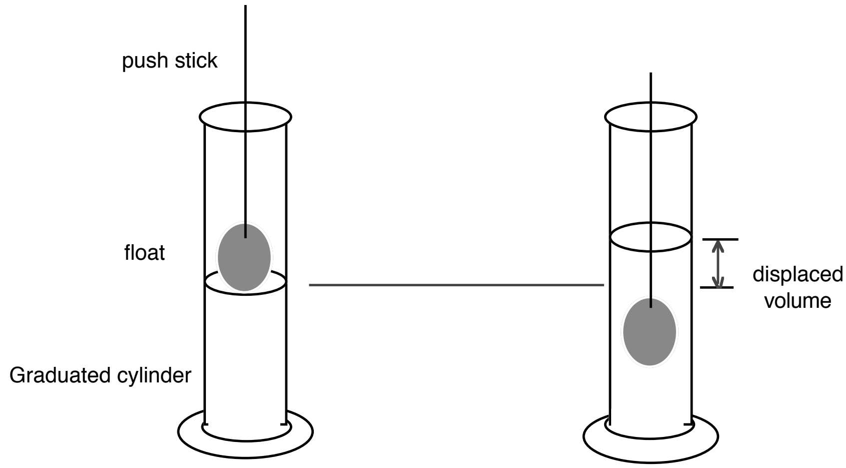
We will now try to raise the weight off the bottom using an assortment of floats made from small empty plastic bottles, small pieces of styrofoam, corks, etc. Each float will have a wire hook (such as large bent paper clip) for attaching to the sunken weight.

**Step 3: Buoyant Force of Floats**.

*As explained earlier…*

To determine the buoyant force of a float push it with a stick into a graduated cylinder with water and measure the amount of water it displaces. *Since water is 1gram for every ml of water... the number of ml displaced water is also the grams of displaced water.*

## Buoyancy Activity: Floating a Submerged Weight (cont'd)




- Next, **you must** get the weight or mass of the float (with its hook) on a balance or scale and subtract that from the weight of the water displaced by the float.

***So....***

**Maximum Buoyant force of a float = Weight of displaced water - Weight of the float**

*Record this information in the data table for each float.*

## DATA TABLE

Weight underwater of the sunken object on the bottom of the aquarium? ________ g

**Buoyant Force of Floats that You're Testing**

| **Float** | Volume of Displaced water (ml) | Weight of Displaced water (g) | Mass of the Float (g) | Buoyant Force of the float (g) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## Buoyancy Activity: Floating a Submerged Weight (cont'd)

**Step 4: Raising the weight off of the bottom.**

What is the weight underwater of the sunken object on the bottom of the aquarium? ___________ g

How much buoyant force would be needed to lift the weight off the bottom of the aquarium? ___________ g

From your data on the floats you have, describe the number and type of floats that you could attach to the sunken object to lift it off the bottom of an aquarium.

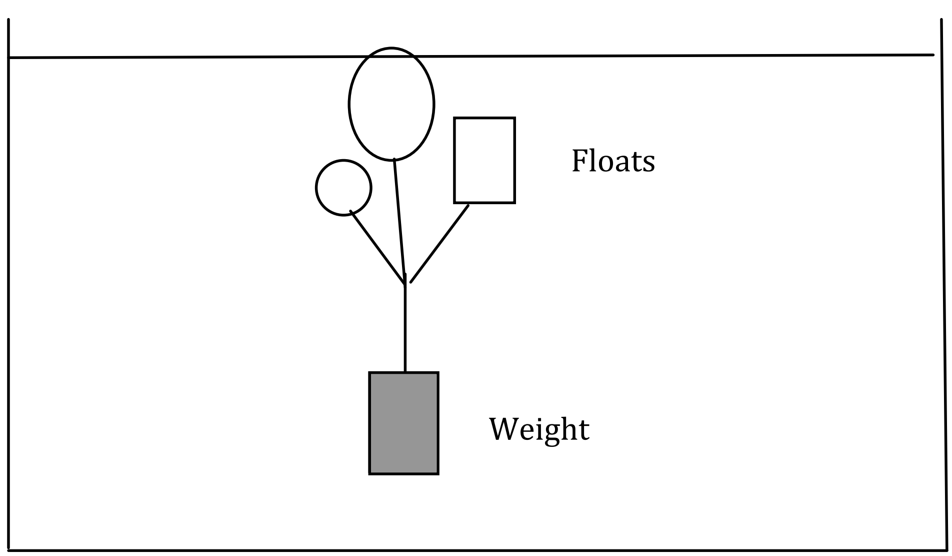
_______________________________________________

_______________________________________________

_______________________________________________

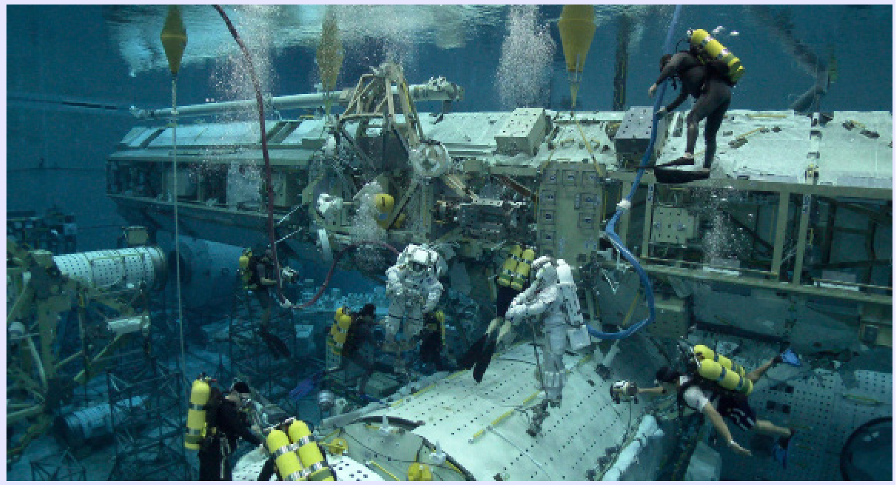
_______________________________________________

Hook your floats on to your weight and see if you are correct.



## Buoyancy Activity Continued: Neutral Buoyancy Challenge

For space walks, astronauts train underwater in the giant indoor pool of NASA's Neutral Buoyancy Laboratory. To simulate working in microgravity the astronauts must achieve **neutral buoyancy** when underwater, a condition where they are neither floating nor sinking. When the astronaut enters the pool, he or she is wearing a heavily weighted spacesuit inflated with air. Inflating the suit with air results in the suit being very buoyant when in water. So to be neutrally buoyant, the spacesuit is lined with weights to make the downward pull of gravity equal to the upward force of buoyancy when the astronaut is submerged into the pool.



Astronauts in the Neutral Buoyancy Laboratory, photo by Jonathan Bird

To help understand the factors needed to reach neutral buoyancy we can repeat the previous activity, but incorporate the challenge of getting a weight neutrally buoyant. Basically the lift from a float (or floats) must be exactly equal to the underwater weight of a sunken object.
and buoyant force is reduced.

### Reaching Neutral Buoyancy *(same materials and procedure as previous activity)*

1) Underwater weight of sunken object with spring scale: ____________ g

2) The <u>buoyant force</u> needed to be exerted by float(s) for neutral buoyancy = ____________ g*

3) Prepare a float or floats to hook on to your sunken object whose weight of:

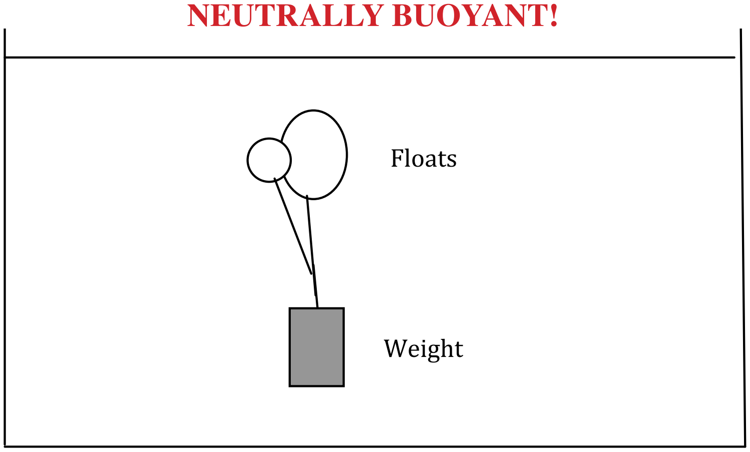
displaced water - weight of the float(s) = buoyant force that you need (p. 9).

***Total Buoyant Force of the Floats :*** ***__________ g - __________ g = __________ g ****

| | weight of displaced water | | weight of floats | | buoyant force of floats |
|---|---|---|---|---|---|

It isn't easy, but if you're successful, the floats and sunken object will be suspended in the water; not sinking or floating.

**NEUTRALLY BUOYANT!**

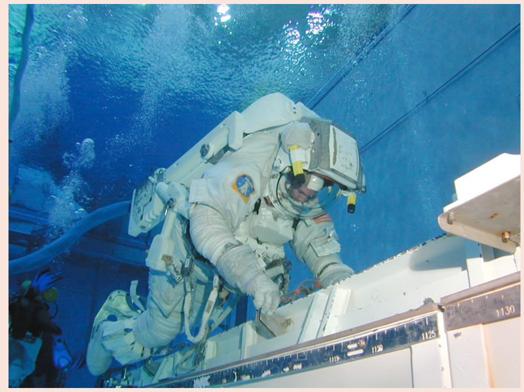





**Learn more at Astronaut-Movie.com!**

## Application Problem: Getting the Astronaut Neutrally Buoyant in the Pool

**For this problem we can use the unit "kilogram force" (kg f ) to represent force. This would be equal to the amount of push or pull equal to the weight of a 1kg mass.**



• Let's assume the water in the pool has a density of 1 g/ml. At this density, 1 liter of water (1000 ml) will have a mass of ______g or ______ kg.

• To maintain the proper air pressure for the astronaut to breathe, the spacesuit is inflated with air so that underwater it occupies a volume of 260 liters of water. Then according to Archimedes' Principle, what is the buoyant force exerted by the space suit? _________ kg force

• Let's suppose the astronaut's weight is 75 kgf and the weight of the spacesuit with air is 45 kgf. Then how much weight must be added to spacesuit to be neutrally buoyant? _________kgf

• A force exerted by 1kg is equal to 2.2 pounds.? How much weight must be added to the suit in pounds? _________ lbs.

## Activity: The Cartesian Diver

**Introduction:**

The "Cartesian Diver" is an activity with a simple set-up using common materials to show the relationship between density and pressure, which can then affect the buoyancy of objects underwater. The "Cartesian Diver" is named for the French mathematician and philosopher Rene Descartes, who lived from 1596 until 1650. This activity demonstrates Pascal's law which states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase in pressure on every other point in the container; the principle behind the hydraulic devices. Pascal's Law was established by Blaise Pascal, a French mathematician and physicist who lived from 1623 to 1662.

***Buoyancy and Water Pressure in the NBL***

As described in the previous activity, "Neutral Buoyancy Challenge," astronauts train for space walks by performing tasks underwater in the giant indoor pool of NASA's Neutral Buoyancy Laboratory. To simulate working in microgravity, the astronauts must be neutrally buoyant when underwater in their specially modified spacesuits. When the astronaut enters the pool he or she is wearing a heavily weighted space suit inflated with air. The weight is needed to neutralize the buoyancy of the suit caused by the air, which is needed for the astronaut to breathe underwater.

## Activity: The Cartesian Diver (continued)

Maintaining neutral buoyancy in a 40 foot deep pool is complicated by the changes to water pressure with depth. As astronauts go deeper into the pool the pressure increases, compressing air in the suit, which decreases its volume. In this case, less water is being displaced by the suit so buoyant force on the astronaut decreases and he or she will sink. (See Archimedes' Principle on p. 3). When the astronaut ascends to a shallow depth, there is a decrease in water pressure and the air inside the suit will expand. This enlarges the volume of the space suit, displacing more water and increasing buoyant force, causing the astronaut to float. To be neutrally buoyant at any depth (neither sinking nor floating) the level of air in the suit must be continuously adjusted. Air must be added to the suit when the astronaut goes deeper into the pool and air must be allowed to escape as the astronaut ascends to shallower parts of the pool.

Watch Webisode 65 of *Jonathan Bird's Blue World: Inner Space at NASA* to see how the challenge of achieving neutral buoyancy is met for astronauts in the NBL, when dealing with changing water pressure at different depths. http://www.blueworldtv.com/webisodes/watch/inner-space-at-nasa

**Materials:**
Clear plastic 2-Liter Soda Bottle
Glass Pipette
2 inch common nail
Foam pipe insulation
Food coloring
Scissors
Tall glass or container of water

**Procedure:**
**Step 1: Setting up the "Diver " (a glass pipette).**
Draw water with food coloring into a small glass pipette.
Adjust the amount of water in the pipette so that it floats in water.
Make sure that it is floating completely off the bottom.

**Step 2: Submerge the diver**
Place the pipette into a 2-liter bottle that has been filled with water and tightly screw on the cap.

Next squeeze the sides of the bottle until the pipette sinks to the bottom of the bottle. Release the pressure on the bottle and the diver will return to the surface.

With just the right amount of pressure applied to the sides of the bottle you can get the pipette to be neutrally buoyant (not sinking or floating) within the water of the bottle.

## The Cartesian Diver Activity (continued)

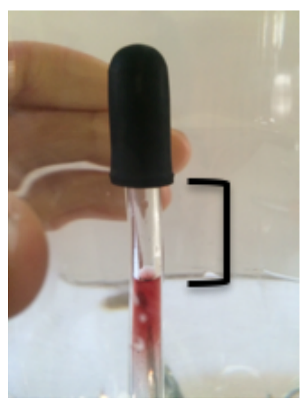
Pipette floats

Squeezing the bottle sinks the pipette

With just the right pressure the pipette is neutrally buoyant.

Repeat the sinking and floating of the pipette.
Carefully observe changes to the air and water level in the pipette as it rises and falls.

Air in the floating pipette.



Air level in pipette when bottle is squeezed and pipette sinks.

***When pressure is applied to the bottle, the pipette sinks and when the pressure is released the pipette will float. So why does this happen? Develop an explanation by answering the following questions.***

(1) When the bottle is squeezed what happens to the amount of water in the pipette?____________________

(2) What does this do to the air inside the pipette? ____________________________________________

*Change to density of the pipette*

With the change in water level to the pipette, will the mass of the pipette increase or decrease?____________

Does the external volume of the pipette change? ________________________________________________

ASTRONAUT

OCEAN TO ORBIT

## The Cartesian Diver Activity (continued)

Then what will happen to the density (mass ÷ volume) of the pipette when squeezing the bottle? ____________
Give a reason for your answer. ____________________________________________________________

With this change in density will the pipette float or sink? ______________________________
How do the changes to the pipette, when squeezing the bottle, demonstrate Pascal's Law? ______________

## Extending The Cartesian Diver Activity: Adjusting the Buoyancy of a Nail

In the previous activity, pressure changed the density of the pipette by changing its mass without changing its volume.

In this version of the Cartesian Diver the overall volume of the diver is changed with pressure in a way that is similar to what happens to astronauts in the NBL. Changing the volume of the foam changes the amount of water displaced by this "diver" thus changing its buoyant force, reinforcing Archimedes' Principle.

In this activity your Cartesian Diver will be a nail wrapped in a small piece of plastic foam whose volume changes with pressure changes to the water in the plastic 2 liter bottle.

**Procedure:**

(1) Cut a small piece of soft flexible plastic foam from pipe insulation or another source about ½ inch wide, ½ inch long, and 1inch tall.

(2) Take a 2 inch common nail and push it through the foam. See the photo above.

(3) Make sure that that the nail floats in a container of water and that it sits at the surface in a vertical position. If necessary, adjust the amount of foam that you use to make this happen. (The less foam used, the better)

(4) Next, place your nail in the 2-liter bottle filled with water. Tightly screw the bottle cap, leaving the nail/foam diver resting at the surface of the water. (See photo 1 below).

(5) Squeezing the bottle sinks the diver (photo 2). When releasing the pressure on the bottle, the diver will rise and squeezing the bottle with the right amount of force will result in the diver being neutrally buoyant (see photo 3 below).

## Extending The Cartesian Diver Activity: Adjusting the Buoyancy of a Nail (cont'd)




**When pressure is applied to the bottle the nail with its foam suit sinks and when the pressure is released the nail will float. So why does this happen?**

First, when the bottle is squeezed the foam gets compressed as well, demonstrating Pascal's Law.

What does this do to the overall volume of the nail/foam diver ? ______________________________

Then what will happen to the amount of water displaced by the nail/foam diver? ____________________

Will this increase or decrease the buoyant force on the nail and foam diver? ____________________. See Archimedes' Principle.

With this change in buoyancy, will the nail and foam diver float or sink? _______________

When squeezing the bottle, what does the compression to the foam do to the diver's density?____________

Explain your answer. ________________________________________________________________

________________________________________________________________________________

## Connection to training in NASA's Neutral Buoyancy Laboratory

This second version of the Cartesian Diver illustrates the challenge of maintaining neutral buoyancy for astronauts practicing spacewalks in the pool of the NBL. In the pool, increased water pressure at greater depths squeezes the spacesuit and reduces its buoyancy by shrinking its volume, just as an increase in pressure to the 2 liter bottle reduced the volume of the foam wrapping the nail and caused the nail/foam diver to sink.

A decrease in pressure allowed the foam around the nail to expand, increasing its buoyancy. As astronauts in the pool move to more shallow depths, water pressure decreases and their suits expand making them too buoyant.

So a system of adding or releasing air must be used with these underwater spacesuits. By maintaining the right amount of air, these suits can adjust to changes in water pressure and astronauts can remain neutrally buoyant at any depth; simulating microgravity.

## Lesson Notes: Getting the Astronaut Neutrally Buoyant in the Pool

• If we assume the water in the pool has a density of 1 g/ml then 1 liter of water (1000 ml) will have a mass of **1kg**. At a density of 1g/ml, 1000 ml (1 liter) is equal to 1000 g of water.1000 grams is 1 kilogram.

• To maintain the proper air pressure for the astronaut to breathe, the spacesuit is inflated with air so that underwater it occupies a volume of 260 liters of water. Then according to Archimedes' Principle, what is the buoyant force exerted by the space suit? **Answer: 260 kg force**

Archimedes' Principle states that the buoyant force on an object in water is equal to the weight of the water displaced by that object. The space suit displaces 260 liters of water. At a density of 1kg/ liter, 260 liters of water would exert a lift of **260 kg f.**

• Let's suppose the astronaut's weight is 75 kgf and the weight of the spacesuit with air is 45kgf. Then how much weight must be added to spacesuit to be neutrally buoyant? **Answer: 120 kg force.**

The lift from the buoyant force of the spacesuit is 260 kgf. So to be neutrally buoyant and counteract the lift, the total weight of the astronaut in the space suit must be equal to the buoyant force : **260 kgf.**

However, the total weight of the astronaut and spacesuit only exerts a downward force of 120 kgf. So, an additional 140 kgf of weight must be added to the spacesuit to get the astronaut to be neutrally buoyant.

| 260 kgf | - | 120 kgf | = | 140 kgf of additional |
|---|---|---|---|---|
| Buoyant Force of spacesuit | | Weight of astronaut and space suit | | weight to the suit |

• A force exerted by 1kg is equal to 2.2 pounds.? How much weight must be added to the suit in pounds rather than kg? **Answer: 308 lbs !!!**

At 2.2 pounds per kg, 308 pounds of weight would be added to the spacesuit. With a suit that heavy astronauts must be suited up on a platform which is then lowered into the pool with a crane.

Photo from NASA' s Neutral Buoyancy Lab website: http://dx12.jsc.nasa.gov/

## Lesson Notes: Changes to Buoyancy of the Pipette with Pressure

• *When pressure is applied to the bottle, the pipette sinks and when the pressure is released the pipette will float. Why does this happen?*

When the bottle is squeezed, the amount of water in the pipette ***increases which compresses the air*** inside the pipette. With more water in the pipette, the ***mass of the pipette will increase*** while the ***external volume of the pipette stays the same.***

• In this way squeezing the bottle will ***increase the density*** (mass ÷ volume) of the pipette to a point where it is more dense than water and it will sink.

• When the bottle is squeezed, water goes up the pipette and the air inside is compressed. ***This demonstrates Pascal's Law*** as the pressure applied to the bottle is exerted equally throughout the water, pushing water into the pipette and compressing the air.

## Lesson Notes: Changes to Buoyancy of the Nail and Foam with Pressure

• When pressure is applied to the bottle, the foam on the nail is compressed. This reduces the volume of the foam ***so it displaces less water.*** By displacing less water the ***buoyant force from the foam decreases*** and the nail/foam diver ***will sink***, demonstrating ***Archimedes' Principle***.

• When the foam is compressed, the overall ***volume of the nail/foam diver decreases without changing its mass***. This will ***increase the diver's density*** to a point greater than the density of water and it will sink.

• Without pressure applied to the bottle the nail rises to the surface as the foam expands back to its original volume, displacing more water and increasing its buoyant force