# Creating Neutral Buoyancy in ROVs

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## INTRODUCTION

In this activity, students will use readily available and inexpensive materials to determine how to make an object (representing a ROV) neutrally buoyant in water.

## BACKGROUND

Remotely Operated Vehicles (ROVS) are now an important part of ocean exploration. They are gaining favor over the previous submersibles that had to be piloted by humans. Because the ROVs can be controlled by scientists aboard the support surface vessel, there is little danger of human loss. The comfort of a ship-board control center also affords scientists the possibility of using the ROVs for 24 hours/day for many days at a time, thus increasing the exploration time.

“Hercules” is a ROV that is currently used in the expeditions of Dr. Robert Ballard. It is used in connection with another ROV called “Argus,” which maneuvers slightly above Hercules as a lighting platform. (See Hercules resource page within this document).

Hercules weighs 5,400 pounds and is 11 feet long and over 7 feet tall. If it is put into the water, it should “sink like a rock!” The problem now is to figure out how to make the ROV ***neutrally buoyant*** in water so it will not sink.

## MATERIALS


- 1 & ½ inch PVC pipe cut to 10 cm in length
- Balance or scale
- 1/2” thick polyethylene foam pipe insulation cut to 10 cm in length
- Rubber bands & scissors or plastic serrated knives
- Caliper or metric ruler
- Small aquaria and water (to represent the ocean)

## INSTRUCTIONS

- Go to the "Hercules Resource Page" (within this document) and read about a ROV that is presently in use by Dr. Robert Ballard as he explores the oceans
- Visit some of the Resource web sites that will give you more information about ROVs and buoyancy
- Answer the questions after reading the information on ROVs from the web sites

## BUOYANCY ACTIVITY

Our problem is to make the 10cm piece of PVC pipe **neutrally buoyant** in the water. (This would be partially submerged in the water, but not on the bottom & not floating on the top of the water.) There are two ways to solve our problem:

1] The traditional "trial and error" design which allows you to simply cut the foam into pieces and attach it to the PVC using increasingly smaller pieces until **neutral buoyancy** is reached.

- Now cut this foam and attach it to the piece of PVC pipe with an elastic band. Place it in the tub of water. Continue to cut off small pieces and test it on the PVC pipe till it is NEUTRALLY buoyant. (This is when it "floats" in the water BELOW the surface and ABOVE the bottom.)

2] STEM design, which is a form of backwards design that uses mathematical calculations and scientific measurements to determine the correct size of the foam that will make the 10 cm of PVC pipe **neutrally buoyant**. Once determined, you will then cut the foam and do your trial.

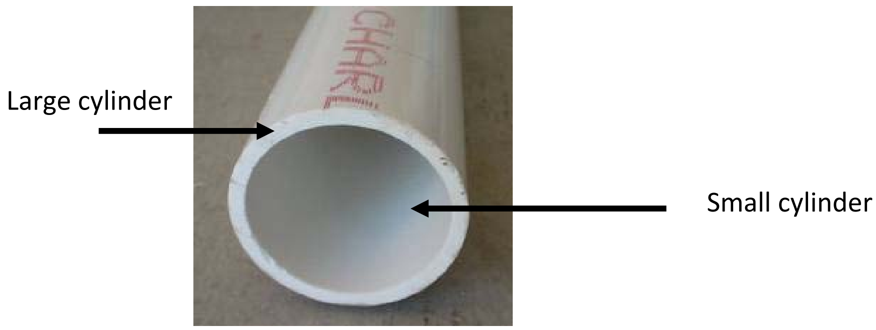
**<u>If you are using design #1,</u>** gather all of your materials and begin your experiment.

- Cut the foam and attach it to the piece of PVC pipe with an elastic band. Place it in the tub of water. Continue to cut off small pieces and test it on the PVC pipe till it is **neutrally buoyant**
  (This is when it "floats" in the water BELOW the surface and ABOVE the bottom.)

**<u>If you are using design #2</u>**, you will have to follow the instructions below which include finding the volume and weight of your 10cm PVC pipe and the volume & weight of your 10cm piece of your foam. You will then need to use some algebra to determine the correct size of foam to cut into a piece that will make the PVC pipe **neutrally buoyant**.

Use your **<u>Buoyance Calculation Sheet</u>** to fill in your calculations

- **<u>For part I</u>**, get the 10cm long piece of PVC pipe and make the necessary calculations to find the volume of the large & small cylinders




- **<u>For part II</u>**, make the calculations to find the volume of only the 10cm PVC pipe. Remember, the weight of the water displaced in grams is EQUAL to the volume of the PVC pipe in $cm^3$

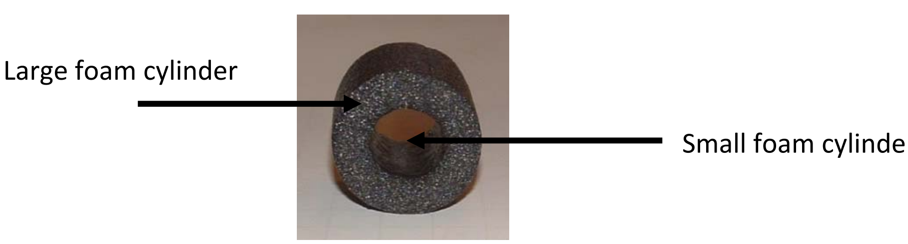
- **<u>For part III</u>**, use your balance and weigh your piece of PVC pipe in grams

- The formula for finding the buoyancy force is:

  $\mathbf{F_b}$ = object weight in air – weight of displaced fluid (water)

- Find the Buoyancy force ($\mathbf{F_b}$) by subtracting the weight of the displaced water from the weight of the PVC pipe
  (The $\mathbf{F_b}$ is a positive number, which means the buoyancy is negative and we will need to ADD a positively buoyant material (foam) to make the PVC pipe NEUTRALLY buoyant

- **<u>For part IV</u>**, get the 10cm piece of foam from and make the necessary calculations to find the volume of the large & small cylinders



- **For part V**, make the calculations to find the volume of the full piece of foam. Remember, the weight of the water displaced in grams is EQUAL to the volume of the foam cylinder in $cm^3$
- **For part VI**, use your balance and weigh the 10cm piece of foam in grams
- The formula for finding the buoyancy force is:

  $\mathbf{F_b}$ = object weight in air – weight of displaced fluid (water)

- Find the Buoyancy force ($\mathbf{F_b}$) by subtracting the weight of the displaced water from the weight of the PVC pipe
  (The $\mathbf{F_b}$ is a negative number, which means the buoyancy is positive and it will float)

Now that we have the buoyancy force for the 10cm PVC pipe (which is negative) AND the buoyancy force for the 10cm piece of foam (which is positive), you will need to use some algebra to solve the problem of how much of the foam is needed to add to the 10cm of PVC pipe to make it **neutrally buoyant**.

If 10cm of foam has a buoyancy force of $F_b$ (from Part VI), then how many cm of foam would be needed to equal the buoyancy force of the 10cm of PVC pipe? (from Part III)

If X = the length of foam required to reach neutral buoyancy, the formula would be:

10cm/$F_b$ foam = X/$F_b$ PVC      OR

X = (10 x $F_b$ of 10cm PVC pipe) / $F_b$ of 10cm of foam

Solve the equation and you will find out the **length** of foam necessary to make the 10cm of PVC pipe **neutrally buoyant**.

If we go one step further, we can find out the **weight** of the foam piece necessary to achieve neutral buoyancy. **THIS MIGHT BE THE EASIER WAY TO PROCEED!**

If you take the weight of 10cm of foam (from Part VI) and divide by 10 and then multiply by length X (from part VII) you will have the weight necessary to achieve neutral buoyancy.

You are now ready to cut your foam to the desired size. In this case, you will use the weight of foam to get the correct size. It is suggested to cut the foam slightly larger than the required weight.

View the diagram at the bottom of page #2

## HERCULES RESOURCE PAGE

Hercules is a neutrally buoyant ROV that is used exclusively in conjunction with its mating vehicle, Argus, to which it is connected with a 30m length of neutrally buoyant tether. It is launched and recovered with the deck crane, generally over the side of the fantail.

### *Hercules Specifications*

Weight in Air 5400 lb. (2450 kg)
Weight in Seawater Neutrally Buoyant
Dimensions 11 long x 6 wide x 7.5 tall
(3.4m x 1.8m x **2**.3m)
Power 2400 VAC, 3 phase, < 20 kW
Depth Rating 4,000m (13,124 ft.)

Hercules is tethered directly to Argus during tandem ROV operations. It is the vehicle with the most maneuverability and is used for the most precise and delicate operations. Hercules is neutrally buoyant and is equipped with six thrusters that allow it to 'fly' in any direction, like a helicopter. Because the vehicle is slightly positively buoyant, it will gently float up to the surface if its thrusters stop turning.

Using its sensor array consisting of a pressure/depth sensor, altimeter, and Doppler, Hercules can conduct a variety of precision documentation functions. These can include: close-up visual inspection using its high definition video camera; surface sampling using its two manipulators that can place recovered samples into sample drawers or place them in elevators dropped to the bottom from the surface ship above; or precision acoustic and visual mapping of a site using its high-resolution sonars and/or digital stereo still cameras.

## RESOURCES

The following is a short list of possible resources to find out more about ROVs.
http://oceanexplorer.noaa.gov/technology/subs/hercules/hercules.html
http://oceanexplorer.noaa.gov/facts/rov.html
http://oceanexplorer.noaa.gov/explorations/02quest/logs/may1/may1.html
http://en.wikipedia.org/wiki/Remotely_operated_underwater_vehicle
http://physics.weber.edu/carroll/archimedes/principle.htm
http://www.sciencekids.co.nz/videos/physics/archimedesprinciple.html
www.Nautiluslive.org

## QUESTIONS

1] What is some of the additional equipment that is commonly added to ROVs to expand their capabilities?

2] What are some of the disadvantages of using an ROV?

3] What was *Hercules* designed to do?

4] How does the bright yellow flotation package of *Hercules* work? What is it made of?

5] What is a “depressor,” and what do they do?

6] How are electrical cables on ROVs protected from corrosion in seawater?

7] How close were your calculations for your Buoyancy Force ($\mathbf{F_b}$) in part III with part VI? Can you explain why they were not equal?

## BUOYANCY CALCULATION SHEET

**Part I:** Calculation of the volume of the large cylinder ($\pi \times r^2 \times L$)

| | $\pi$ | diameter | radius | $r^2$ | Length | Volume ($cm^3$) |
|---|---|---|---|---|---|---|
| Large cylinder | 3.14 | | | | | |
| Small cylinder | 3.14 | | | | | |

**Part II:** Calculate only the volume of the PVC Pipe

- Take the volume of the Large cylinder & subtract the volume of the small cylinder

| | |
|---|---|
| Volume of the Large cylinder | $cm^3$ |
| Volume of the Small cylinder | $cm^3$ |
| Volume of the PVC pipe | $cm^3$ |
| Weight of water displaced | grams |

- Because water has a specific gravity of 1, its volume in $cm^3$ = its weight of the fluid displaced (water) in grams

**Part III:** Calculating the Buoyancy Force ($F_b$) of the PVC pipe

- $F_b$ = object weight in air – weight of displaced fluid (water)
- Using a balance, weigh your PVC pipe

| | |
|---|---|
| Weight of PVC pipe | grams |
| Weight of displaced fluid (water) | grams |
| Buoyancy Force $F_b$ | grams |

- If the $F_b$ is a positive number, the buoyancy is negative and we will need to ADD a positively buoyant material (foam) to make the PVC pipe **neutrally buoyant**
- If the $F_b$ is a negative number, the buoyancy is positive and we will need to ADD weight to make the PVC pipe **neutrally buoyant**

**Part IV:** Calculation of the volume of a foam cylinder ($\pi \times r^2 \times L$)

| | $\pi$ | diameter | radius | $r^2$ | length | Volume (cm3) |
|---|---|---|---|---|---|---|
| Large foam cylinder | 3.14 | | | | | |
| Small foam cylinder | 3.14 | | | | | |

**Part V:** Calculation of the volume of the piece of foam

- Take the volume of the large foam cylinder & subtract the volume of the small foam cylinder. That will give you the volume of the FULL piece of foam

| | |
|---|---|
| Volume of the large foam cylinder | $cm^3$ |
| Volume of the small foam cylinder | $cm^3$ |
| Volume of the FULL piece of foam | $cm^3$ |

**Part VI:** Calculating the Buoyancy Force (**$F_b$**) of the piece of foam

- **$F_b$** = object weight in air – weight of displaced fluid (water)
- Use the balance and weigh the piece of foam

| | |
|---|---|
| Weight of the piece of foam | grams |
| Weight of displaced fluid (water) | grams |
| Buoyancy force **$F_b$** | grams |

- If the **$F_b$** is a positive number, the buoyancy is negative and we will need to ADD a positively buoyant material (foam) to make the PVC pipe **neutrally buoyant**
- If the **$F_b$** is a negative number, the buoyancy is positive and we will need to ADD weight to make the PVC pipe **neutrally buoyant**

**Part VII:** Calculating the length of foam needed to make the 10cm of PVC pipe neutrally buoyant.

| | |
|---|---|
| $F_b$ of 10 cm of PVC pipe (from Part III) | |
| $F_b$ of 10 cm of foam (from Part VI) | |

X = (10 x $F_b$ PVC [ ] $F_b$ foam [ ]

X = [ ] This is the length of foam (cm) you can cut to achieve neutral buoyancy.

If we go one step further, we can find out the weight of the foam piece necessary to achieve neutral buoyancy.

If you take the weight of 10cm of foam (from Part VI) and divide by 10 and then multiply by length X (from part VII) you will have the weight necessary to achieve neutral buoyancy

( [ ] Weight of 10cm foam /10) x [ ] length X = [ ] weight needed to create neutral buoyancy

## TEACHER RESOURCE SHEET
## Buoyancy Calculation Sheet

**Part I:** Calculation of the volume of a cylinder ($\pi$ x $r^2$ x L)

| | $\pi$ | diameter | radius | $r^2$ | Length | Volume ($cm^3$) |
|---|---|---|---|---|---|---|
| Large cylinder | 3.14 | 4.24 cm | 2.12 cm | 4.494$cm^2$ | 10 cm | **141.124 $cm^3$** |
| Small cylinder | 3.14 | 3.47 cm | 1.735 cm | 3.01$cm^2$ | 10 cm | **94.514 $cm^3$** |

**Part II:** Calculate the volume of only the PVC Pipe

- Take the volume of the Large cylinder & subtract the volume of the small cylinder

| | |
|---|---|
| Volume of the Large cylinder | 141.124 $cm^3$ |
| Volume of the Small cylinder | 94.514 $cm^3$ |
| Volume of the PVC pipe | 46.61 $cm^3$ |
| Weight of water displaced | 46.61 grams |

- Because water has a specific gravity of 1, its volume in $cm^3$ = its weight of the fluid displaced (water) in grams

**Part III:** Calculating the Buoyancy Force ($\mathbf{F_b}$) of the PVC pipe

- $\mathbf{F_b}$ = object weight in air – weight of displaced fluid (water)
- Using a balance, weigh your PVC pipe

| | |
|---|---|
| Weight of PVC pipe | 63.8 grams |
| Weight of displaced fluid (water) | 46.61 grams |
| Buoyancy Force $\mathbf{F_b}$ | 17.19 grams |

- If the $\mathbf{F_b}$ is a negative number, the buoyancy is positive and we will need to ADD weight to make the PVC pipe NEUTRALLY Buoyant
- If the $\mathbf{F_b}$ is a positive number, the buoyancy is negative and we will need to ADD a positively buoyant material (foam) to make the PVC pipe NEUTRALLY Buoyant

**Part IV:** Calculation of the volume of a foam cylinder ($\pi$ x $r^2$ x L)

| | $\pi$ | diameter | radius | $r^2$ | length | Volume (cm3) |
|---|---|---|---|---|---|---|
| Large foam cylinder | 3.14 | 4.47 cm | 2.235cm | 4.995$cm^2$ | 10cm | 156.84$cm^3$ |
| Small foam cylinder | 3.14 | 1.83 cm | .915 cm | .837 $cm^2$ | 10cm | 26.28 $cm^3$ |

**Part V:** Calculation of the volume of the piece of foam

- Take the volume of the large foam cylinder & subtract the volume of the small foam cylinder. That will give you the volume of the FULL piece of foam

| | |
|---|---|
| Volume of the large foam cylinder | 156.84 $cm^3$ |
| Volume of the small foam cylinder | 26.28 $cm^3$ |
| Volume of the FULL piece of foam | 130.56 $cm^3$ |

**Part VI:** Calculating the Buoyancy Force ($\mathbf{F_b}$) of the piece of foam

- $\mathbf{F_b}$ = object weight in air – weight of displaced fluid (water)
- Use the balance and weigh the piece of foam

| | |
|---|---|
| Weight of the piece of foam | 2.6 grams |
| Weight of displaced fluid (water) | 130.56 grams |
| Buoyancy force $\mathbf{F_b}$ | -127.96 grams |

- If the $\mathbf{F_b}$ is a positive number, the buoyancy is negative and we will need to ADD a positively buoyant material (foam) to make the PVC pipe **neutrally buoyant**
- If the $\mathbf{F_b}$ is a negative number, the buoyancy is positive and we will need to ADD weight to make the PVC pipe **neutrally buoyant**

**Part VII:** Calculating the length of foam needed to make the 10cm of PVC pipe neutrally buoyant.

| | |
|---|---|
| $F_b$ of 10 cm of PVC pipe (from Part III) | 17.19 g |
| $F_b$ of 10 cm of foam (from Part VI) | -127.96 g |

X = (10 x $F_b$ PVC **17.19 g** **/** $F_b$ foam **-127.96 g**

X = **1.34 cm** This is the length of foam (cm) you can cut to achieve neutral buoyancy.

If we go one step further, we can find out the weight of the foam piece necessary to achieve neutral buoyancy.

If you take the weight of 10cm of foam (from Part VI) and divide by 10 and then multiply by length X (from part VII) you will have the weight necessary to achieve neutral buoyancy

(2.6g [Weight of 10cm foam] /10) x **1.34 cm** [length X] = **0.348 g** [weight needed to create neutral buoyancy]

**Teacher Information Sheet for**
**Creating Neutral Buoyancy in ROVs**

## GRADE LEVEL AND DURATION

This activity is designed for students in middle and high school. It will take about 60 minutes for the introduction to ROVs, the internet research, and the questions. It will take another 60 minute period to build and test for NEUTRAL buoyancy and to fill in the Buoyancy calculation sheets. (possibly longer) Students can work in groups of 2-4.

**Science Standards Connections: (NGSS)**

The eight practices of science and engineering that the *Framework* identifies as essential for all students to learn and describes in detail are listed below:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Engineering & Design:

| | |
|---|---|
| **MS-ETS1-1.** | **Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions** |
| **MS-ETS1-2.** | **Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem** |
| **MS-ETS1-3.** | **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success** |
| **MS-ETS1-4.** | **Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved** |

## ANSWERS TO QUESTIONS

1] These may include a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature.

2] The fact that the human presence is lost, making visual surveys and evaluations more difficult, and the lack of freedom from the surface due to the ROV's cabled connection to the ship.

3] Although *Hercules* was designed primarily to study and recover artifacts from ancient shipwrecks, it is also well suited to study biology and geology in the deep sea.

4] This makes *Hercules* just slightly buoyant, so it will float on the surface, but a small force generated by the vertical thrusters can drive the ROV up or down. The flotation package is made of "syntactic foam", composed of tiny, hollow glass balls mixed into epoxy resin.

5] The depressor is a large weight located approximately 50 meters up-cable from the ROV. The depressor acts as a "buffer" between the ship and the ROV so that the ROV can swim freely without being "tugged on" by the ship or the rest of deployed cable.

6] Electrical cables may be run inside oil-filled tubing to protect them from corrosion in seawater.

7] These should be EQUAL. If students are close, the difference can be written off by lack of exact measurements using the balances, metric rulers, string, etc.

**Hints:**

- The PVC is easily and cheaply purchased in stores like Home Depot. You should be able to get someone to cut the PVC into 10cm pieces. Once cut, they can be used over and over
- The foam insulation can also be bought cheaply at Home Depot. Cutting by scissors can be difficult as it is hard to cut evenly. You might want to cut the original 10cm pieces for your students using a serrated knife or saw
- Keeping the materials dry after each trial in the water is also difficult but very necessary so you are not weighing the water on the pieces

**Advanced:**

- Purchase 1/2" or ¾" PVC pipe (Home Depot) along with various "L" and "T" shaped connectors. Cut the PVC in various sizes and let the students put together ROVs of various shapes and sizes. Try to make them buoyant by using foam. The placement of the foam is critical to keeping them neutrally buoyant and not "flipping around"
- Contact actual ROV engineers and pilots at NOAA and at the NautilusLive.org website. Have students talk to them about career paths in this oceanographic field