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The Incredible Shrinking Cup Lab: Connecting with Ocean and Great Lakes Scientists to Investigate the Effect of Depth and Water Pressure on Polystyrene

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ABSTRACT Pressure increases rapidly with depth in a water body. Ocean and Great Lakes scientists often use this physical feature of water as the basis of a fun pastime performed aboard research vessels around the world: the shrinking of polystyrene cups. Depending on the depth to which the cups are deployed, the results can be quite striking! Capitalizing on this fascinating display of ocean physics, the authors describe an activity designed to familiarize students with the effects of increased water depth on pressure and volume. This activity incorporates ocean and aquatic sciences into classroom curricula, an important goal of the Ocean Literacy Campaign and associated Great Lakes Literacy Campaign. Students will develop hypotheses to investigate the effects of depth and thus pressure on the volume of polystyrene cups. To test their hypotheses, they will determine the volume of polystyrene cups before and after they are submerged to differing depths in the ocean and the Laurentian Great Lakes. Students will also calculate the density of the cups and learn about the depths of the world's ocean and the Great Lakes. This lab also encourages students to contact scientists and engage with professionals in the field of oceanography and limnology.

KEYWORDS Boyle's law, Great Lakes, ocean depth, pressure, research vessels

INTRODUCTION

This lab takes advantage of a common activity that scientists do for fun on research vessels operating in deep waters around the world: shrinking of polystyrene cups. When compressible polystyrene is sent to deep depths, usually in a mesh bag attached to sampling equipment, the result is quite pronounced (Figure 1). This pastime can be incorporated into a captivating classroom tool that explores how pressure changes with depth in the ocean and excites students about the fields of deep sea science and limnology. This lab can also be used to introduce concepts such as hypothesis development, reading a meniscus, taking scientific measurements using a triple beam balance, determining volume

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FIGURE 1 **Polystyrene cups predeployment (left), after being deployed to 95 m in Lake Superior (center), and after deployment to approximately 250 m in the Atlantic Ocean (right) (color figure available online).**

by displacement, using the metric system, and the importance of carefully conducting and recording accurate scientific observations. It can also be a review to practice these skills. Furthermore, if this activity is repeated over the course of several years, the instructor may retain the growing dataset to demonstrate simple statistical analyses (e.g., calculation of the mean, standard deviation, and linear regression) to investigate and evaluate the relationship between the change in volume relative to deployment depth. Before the lab begins, the instructor and students must contact and coordinate with a deep sea or Great Lakes researcher (see suggested links section) who will be able to sink the polystyrene cups and provide station depth and ship location at the time of deployment.

BACKGROUND

Pressure is the physical force per area exerted upon objects by the fluid environment. On land, the weight of the Earth's atmosphere exerts pressure on the land and waters of the world. At sea level, the weight of the atmosphere overhead (and stretching to the edge of space) creates 1 atmosphere (atm) of pressure (1.01 bar), which is equivalent to 101,325 newtons (N) of force pressing on every square meter (= 14.7 lbs. per sq. in.) of an object. Once we pass underwater, this pressure increases very rapidly with depth, because water is much denser than air. For every 10 m (33 ft.) of depth, the pressure increases by an additional one atmosphere. This pressure from the water is added to the original 1 atm at the surface. So at 10 m, the absolute pressure on an object is 2 atm (29.4 lbs. per sq. in. = 2.02 bar = 202,650 pascals [Pa] [1 Pa = 1 N/m^2]).

The effect of water depth and resulting pressure on gases is explained by Boyle's law, which states that within a closed system, there is an inverse relationship between the absolute pressure and volume of a gas, if the temperature is kept constant. The mathematical equation for Boyle's law is $pV = K$, where

p denotes the pressure of the system (force per area);
V denotes the volume of the gas; and
K is a constant value representative of the pressure and volume of the system.

Boyle's law has many interesting oceanographic applications that could be of interest to students, such as scuba diving safety (why divers' breathing compressed gas shouldn't hold their breath upon ascent to the surface!), why deep sea fish die when brought to the surface (the volume of gases in their bodies increases and pops swim bladders, while disrupting cells and cell membranes), and differences between compressible versus noncompressible materials under pressure. Although the high pressure at depth has only a slight effect on the water (at a depth of 4,000 m, water decreases in volume by only 1.8%), it has a much greater effect on easily compressible materials, such as neoprene (the material used to make wetsuits) and polystyrene. These materials contain tiny, compressible air bubbles. In this exercise, students will observe that the cups become deformed and shrink because the air bubbles in the polystyrene are compressed at depth. When the cup is brought back up to the surface, it does not resume its original shape because the structure of the polystyrene is permanently altered. The deeper the cup is deployed in the water, the smaller it gets because of the effect of pressure on the volume of the air bubbles in the material increases, following Boyle's law.

MATERIALS

- Polystyrene cup
- Permanent markers
- Large graduated cylinder (1,000 ml)
- 10 g weight of known volume (volume measured in milliliters)
- Metric ruler
- Triple beam balance
- Calculator
- Lab worksheet

PROCEDURE

This activity is usually taught in two 40-min sessions. Note that the time interval between Part I and Part II can vary depending on the location and duration of the research cruise that is deploying the cups for the students.

Contact Researchers

Using the suggested links below, the instructor and students must contact deep sea or Great Lakes researchers who are willing to take the preweighed and labeled cups on their research vessels and sink cups while at sea. You will be pleasantly surprised to find how willing scientists are to accommodate such requests from a student classroom. Before the cups are sent to researchers, initial observations should be recorded and hypotheses developed (Part I). In Part II, students will record postdeployment observations of the shrunken cups and compare their measurements with the hypotheses generated during Part I. Ask the scientists aboard the research vessels to record the latitude, longitude, and depth to which the cups were deployed. Instructors will need to request a shipping address in order to send the prelabeled cups to the scientist before the cruise. The instructor should also inquire as to how far in advance the cups will need to be delivered in order to be loaded onto the ship.

Part I: Predeployment

This activity takes place before the cups are sent on the deep sea or Great Lakes research cruise.

1. Divide the class into small groups.
2. Students will uniquely label (and decorate and personalize, if desired) their polystyrene cup using the permanent markers.
3. Students will sketch and describe their cups on the lab worksheet.
4. Students will measure the mass, in grams, of the polystyrene cup using a triple beam balance and record their measurement.
5. Students will measure the volume of their polystyrene cup, in milliliters, using water displacement. To do so, fill the graduated cylinder to a determined mark and record the initial volume of water. Place a 10 g weight in your polystyrene cup (to help sink the cup) and place the cup in the graduated cylinder. Record the amount of water displaced by subtracting the initial volume of water from the final volume of water. Subtract the volume of the weight used to sink the cup from the volume of water displaced, to obtain the volume of the cup. Record the calculated volume (in milliliters) of the polystyrene cup.
6. If this activity is intended to practice measurements, students can calculate density of the cup using the formula density = mass/volume. Students will record their calculated density in grams/milliliter. Explain to the students that a material's density is defined as its mass per unit volume. It is a measurement of how tightly matter is packed together at a given temperature and pressure.
7. Students should develop null and alternate hypotheses to test the research question "What are the effects of depth and pressure on the volume of a polystyrene cup?"
8. For further research, students can consult bathymetric maps to learn how the average and maximum depth varies across the world's oceans and the five North American Great Lakes. Students should compare the depths of the Great Lakes with average and maximum ocean depths.

Part II: Postdeployment

This activity takes place after the cups are returned to the students from the deep sea or Great Lakes research cruise. Steps from Part I are essentially repeated so that students can investigate how the physical properties of the cups changed when submerged to different depths.

1. Reunite the students with their assigned group and return their shrunken cups.
2. Students will sketch and describe their cups.
3. Students will measure and record the mass, in grams, of the polystyrene cup using a triple beam balance.
4. Students will measure and record the volume of the polystyrene cup, in milliliters, using water displacement as in Part I.
5. Students can calculate density, in grams/milliliter, as in Part I.
6. Students will answer questions on the worksheet (Appendix).

7. Students can test their hypotheses stated during Part I by comparing and contrasting measurements from Parts I and II.

DISCUSSION AND FINDINGS

This activity has been used successfully in several high school science classes, including freshman Physical Science classes at Graham High School. Graham High School is a rural public school in St. Paris, Ohio, located in the central part of the state and far from the oceans and even the Great Lakes. This activity provided students the opportunity to explore depth, pressure, and volume interactions while being exposed to oceanographic and large lake research and research vessels in waters worldwide. This activity may be adapted for older elementary and middle school students.

The Graham High School students anxiously awaited the return of their cups and were amazed to see the effect of pressure on the polystyrene cups (Figure 2). As the cups were returned, they were excited to quantify the differences in their samples and mark the cups' submerged locations on a wall-sized map of the world's oceans. According to the teacher,

> [b]eing able to personalize the polystyrene cups really allowed students to connect with the lesson as their cups left our high school and traveled on their own adventures. This activity encouraged students to engage in ocean topics, especially students who would not normally find the ocean and ocean topics so relevant and accessible.

Discussions were held regarding what type of vessels deployed their cups and the scientific objectives of the expeditions. This activity led to an increased awareness of marine and Great Lakes research and possible future career fields.

FIGURE 2 **The Graham High School collection of shrunken polystyrene cups from the U.S. Great Lakes and world's oceans (color figure available online).**

Scientists also benefit by interacting with students in this activity. By agreeing to deploy cups and share cruise data and information with students, scientists are "promoting teaching, training, and learning" via integration of research activities into the teaching of science (NSF 2007), a requirement for research funding at federal science agencies such as the National Science Foundation and the National Oceanic and Atmospheric Administration.

This activity incorporates ocean and aquatic sciences into classroom curricula, an important goal of the Ocean Literacy Campaign and associated Great Lakes Literacy Campaign (Schoedinger, Uyen Tran, and Whitley 2010). As this activity explores the fundamental science concept of changes of properties in matter and the relationship of ocean depth and pressure, it is aligned with the Ocean Literacy Campaign's Essential Principle 1: "The Earth has one big ocean with many features," specifically Fundamental Concept 1b, "An ocean basin's size, shape, and features vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys, and flattest vast plains are all in the ocean" (National Geographic Society 2005). This activity can also be used to explore organisms' adaptations for diving, which supports Essential Principle 5: "The ocean supports a great diversity of life and ecosystems," specifically Fundamental Concept 5d, "Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms that do not occur on land" (National Geographic Society 2005). A matrix aligning the Ocean Literacy Principles and Fundamental Concepts to the content standards in the National Science Education Standards is available at http://oceanliteracy.wp2.coexploration.org/?page_id=130. Furthermore, *The Ocean Literacy Scope and Sequence for Grades K–12* is an instructional tool that shows educators how the seven Ocean Literacy Principles and 44 Fundamental Concepts could be taught at various grade bands (K–2, 3–5, 6–8, 9–12) and is available at http://oceanliteracy.wp2.coexploration.org/?page_id=1073 (Schoedinger, Uyen Tran, and Whitley 2010). Currently, ocean and aquatic sciences are underrepresented disciplines in K–12 educational curricula (Schoedinger, Uyen Tran, and Whitley 2010). The oceans and Great Lakes are motivating teaching tools that can capture students' imaginations and encourage the next generation of aquatic researchers, as well as help create a more ocean literate society.

EXTENSIONS AND CROSS-CURRICULAR APPLICATIONS

Scientific organizations most likely willing to sink cups for student classes:

U.S. EPA Great Lakes National Program Office (www.epa.gov/glnpo) conducts annual water quality surveys using the *R/V Lake Guardian* in all five Great Lakes. Contact Jacqueline Adams (adams.jacquline@epa.gov) or Elizabeth Hinchey (hinchey.elizabeth@epa.gov) for details on where to mail cups for deployment.

The Woods Hole Oceanographic Institution ship schedule page (http://www.whoi.edu/marops/ship_schedules.html) and the University-National Oceanographic Laboratory System vessel page (http://www.unols.org/info/vessels.htm) can both be used to search for ships and investigators who are conducting deep-sea cruises throughout the year.

National Oceanic and Atmospheric Administration's Ocean Explorer program (http://www.oceanexplorer.noaa.gov) provides opportunities for educators to learn more about NOAA ocean exploration and research and how they can use the mathematics, science, and technology content associated with exploring the ocean in their classrooms. Contact them to see if they can help arrange for your cups to go to sea!

Depth and pressure activities Web sites for middle school and high school students:

National Maritime Center. N.d. The hunt for the Alligator: The U.S. Navy's first submarine. http://sanctuaries.noaa.gov/alligator/m lessonplans.html.

National Oceanic and Atmospheric Administration's Aquarious Reef Base. N.d. Dive in! http://aquarius.fiu.edu/education/lesson-plans.

University of Arizona. N.d. Physiology and physics of diving. http://marinediscovery.arizona.edu/lessonsF99/elenaruiz/index.html.

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APPENDIX: EXAMPLE LAB WORKSHEET THAT CAN BE USED BY STUDENTS TO RECORD THEIR OBSERVATIONS AND PROVIDE ANSWERS TO CRITICAL THINKING QUESTIONS

Incredible Shrinking Cup Lab Worksheet

Part I. Predeployment

This activity takes place before the cups are sent on the research cruise.

Materials (for each lab group):

- Polystyrene cup
- Permanent markers
- Large graduated cylinder (1,000 ml)
- 10 g weight of known volume
- Metric ruler
- Triple beam balance
- Calculator
- Lab worksheet

Activity:

1. Label (and decorate) the polystyrene cup using permanent markers.

2. Sketch the cup. Measure the diameter of the top of the cup, the diameter of the bottom of the cup, and the height of the cup. Label the sketch with these measurements.

3. Measure the mass of the cup using a triple beam balance. Record.

Mass of polystyrene cup = _______ grams

4. Measure the volume of the cup using water displacement. Fill the graduated cylinder to a determined mark and record the volume of water (initial water volume = _______ ml). Place a 10 g weight in the cup and place the weighted cup in the graduated cylinder. Record the new volume of water (final water volume = _______ ml). Calculate the amount of water displaced by subtracting the initial volume of water from the final volume of water. Subtract the volume of the weight used to sink the cup. Record the calculated volume of the polystyrene cup.

Displaced water volume_______ – volume of weight = volume of cup_______ml

5. Calculate density of the cup, in g/ml, using the formula density = mass/volume. Record.

6. What is the maximum depth of the each of the five Great Lakes and the world oceans? (Students should consult bathymetric maps.)

7. How does pressure change with depth in the ocean?

8. Discuss what you think will happen to your cup if it is deployed to the maximum depth in Lake Superior.

Part II. Postdeployment

This activity takes place after the cups are sent on the research cruise.

Materials (for each lab group):

- Polystyrene cup
- Sharpie markers
- Extra large graduated cylinder
- Metric ruler
- Triple beam balance
- Calculator
- Lab worksheet

Activity:

1. Sketch the cup. Measure the diameter of the top of the cup, the diameter of the bottom of the cup, and the height of the cup. Label the sketch with these measurements.

2. Measure the mass of the cup using a triple beam balance. Record.

Mass of polystyrene cup = ______ g

3. Measure the volume of the cup using water displacement. Fill the graduated cylinder to a determined mark and record the volume of water (initial water volume = ______ml). Place a 10 g weight in the cup and place the weighted cup in the graduated cylinder. Record the new volume of water (final water volume = ______ml).

Calculate the amount of water displaced by subtracting the initial volume of water from the final volume of water. Subtract the volume of the weight used to sink the cup. Record the calculated volume of the polystyrene cup.

Displaced water volume_______ − volume of weight = volume of cup_______ml

4. Calculate density of the cup using the formula density = mass/volume. Record.

5. How do your observations from Part I compare with those from today?

6. Explain why the appearance of your cup changed after deployment. (HINT: Think about how and why the volume of gases in the polystyrene changed.)

7. What implications does Boyle's law have on equipment used for deep ocean exploration?