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Cartesian Diver Design Challenge Kit

Guided-Inquiry Kit

Introduction

Explore the world of Cartesian divers! Cartesian divers are fun toys that can be used to teach the concepts of density and Boyle's law. After examining the design of a basic Cartesian diver, be prepared to modify the design to perform different challenges! Dive right in to this fun activity!

Concepts

- Density
- Boyle's Law
- Engineering design

Materials

Beaker, 600-mL
Food dye (optional)
Forceps (optional)
Glue gun and sticks
Hex nuts, 10
Magnets, 2
Paper clips, 2
Paper towels
Pipets, disposable plastic, 10
Plastic soda bottle, with cap, 1- or 2-L
Scissors
Water
Weighing dish, 3
Wire, insulated, 12 inches

Safety Precautions

The materials in this activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all laboratory safety guidelines.

Procedure

Part A. Making a Cartesian Diver

1. Fill the 600-mL beaker approximately 4/5 full with tap water.
2. Screw the hex nut securely onto the stem. The hex nut will form its own threads as it turns. Cut off the remaining pipet stem (see Figure 1).

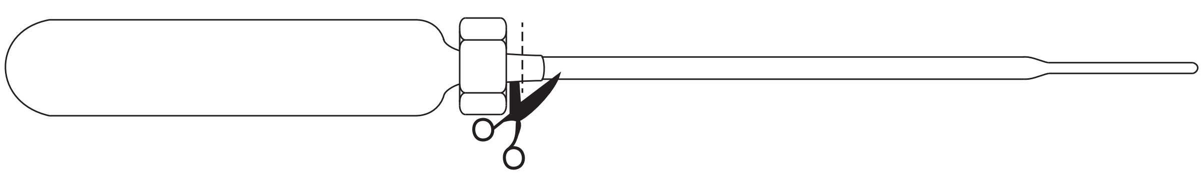

Figure 1. Cutting the Pipet

3. Place the pipet-nut diver assembly into the 600-mL beaker of water and observe that it floats in an upright position with the hex nut acting as ballast.

4. Squeeze out some of the air from the bulb and draw some water up into the pipet. Now check the buoyancy. If you draw up too much water, the diver will sink. If this happens, simply lift it out of the water, squeeze out a few drops of water and let air back in to replace the water.
5. Using this technique, adjust the amount of water in the diver so that it just barely floats in the beaker.
6. Place the diver assembly in a plastic 1- or 2-L bottle completely filled with water and screw on the cap securely (Figure 2). Observe how the diver assembly dives to the bottom as you squeeze the bottle and how it rises to the surface as you release the squeeze.
7. Answer the questions below and then go on to Part B.

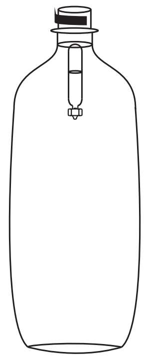

Figure 2.

Questions

Form a working group with other students. Observe the Cartesian diver made in Part A and discuss the following questions.

1. Explain what is happening when the diver rises and falls.
2. Using forceps, remove the diver. Let out five drops of water and retest the diver.
3. Continue to adjust the amount of water in the diver, in five-drop increments. Record observations and test the diver again. continue testing until the diver will no longer dive.
4. Consider the pressure applied to the bottle. How did the amount of pressure required to sink the diver change as the amount of water in the diver decreased? Explain.
5. How did the beginning density of the diver change when the above adjustments were made?
   a. What variables were changed?
   b. What variables were held constant?

Part B. Making a Closed-System Diver

1. Follow steps 1–5 of Part A.
2. Remove the diver from the beaker and squeeze out one or two drops of water. Using a paper towel, pat dry the inside rim of the open stem.
3. Holding the bulb with the stem end upward, squeeze the bulb very slightly to expel a very small amount of air. Hold the squeeze while carefully placing a drop of hot, melted glue in the stem opening of the diver and then relax the squeeze. The drop of hot glue will be pulled into the stem (see Figure 3).

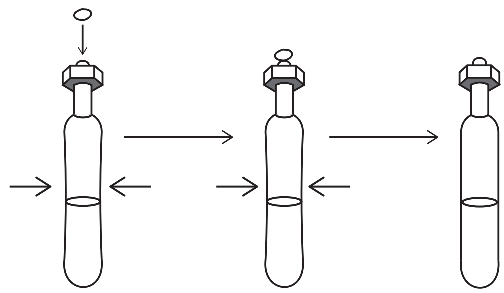

Figure 3.

4. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.
5. Place the diver assembly in the plastic 1- or 2-L bottle completely filled with water and screw on the cap securely (Figure 2). Observe how the diver assembly dives to the bottom as you squeeze the bottle and how it rises to the surface as you release the squeeze.
6. Compare and contrast the open and closed divers.
7. What are the advantages and disadvantages to each?

Part C. Design Challenge

Your instructor will assign a Design Challenge to your group.

Design Challenge I. Create a diver that retrieves a sunken diver from the bottom of the bottle.

Before creating the divers, brainstorm with your group.

1. How is the diver going to retrieve the sunken diver at the bottom?
2. What requirements are necessary for the sunken diver? Why?
3. What requirements are necessary for the retriever diver? Why?
4. Will the divers be open or closed for your design? Explain your reasoning.
5. What materials are needed?
6. What safety precautions should be taken?
7. How will the diver be tested once it is finished? What data will be recorded?
8. What criteria make for a successful design?
9. What are the strengths and limitations of this design?

Design Challenge II. Design a set of 3 divers that descend in a specific order.

Before creating the divers, brainstorm with your group.

1. Will the divers be open or closed for your design? Explain your reasoning.
2. What materials will be needed?
3. What safety precautions should be taken?
4. How will the final design be tested? What data will be recorded?
5. What variables are going to change with each diver? Why?
6. What variables will be held constant? Why?
7. What criteria make for a successful design?
8. What are the strengths and limitations of this design?

Design Challenge III. Create a diver that spins the most on one dive.

Before creating the diver, brainstorm with your group.

1. What design is your group going to use and why? Remember you are creating a diver to spin the most in one dive.
2. Will the diver be open or closed for your design? Explain your reasoning.
3. What materials will be needed?
4. What variables might affect the number of turns the diver makes?
5. What safety precautions should be taken?
6. How will the diver be tested once it is finished? What data will be recorded?
7. What variables will be held constant? Why?
8. What criteria make for a successful design?
9. What are the strengths and limitations of this design?

Teacher's Notes

Cartesian Diver Design Challenge Kit

Materials Included in Kit (for 30 students working in pairs)

Hex nuts, 200
Magnets, 35
Paper clips, 1 box
Pipets, disposable plastic, 200
Plastic soda bottle, with cap, 1-L, 3*
Weighing dishes, 50
Wire, 1 spool

*Three bottles are included for teacher examples.

Additional Materials Needed (for each lab group)

Beaker, 600-mL
Food dye (optional)
Forceps, 10″
Glue gun and sticks
Hole punch
Paper towels
Scissors
Water

Pre-Lab Preparation

1. Cut the wire into 12-inch pieces. Each group will get one piece.
2. Optional: Prepare an example of the Design Challenges.
3. Design Challenge I (optional): Magnets can be used to retrieve the sunken diver. Another option is to use a hook and loop.
4. Design Challenge II (optional):
   a. Create three divers using Part A of the instructions.
   b. Test and adjust each diver in the 600-mL beaker of water until you have three different densities.
   c. Make sure there is a minimal amount of air in each diver or it will be very difficult to make the divers descend.
   d. Place all three in a plastic soda bottle full of water, screw on the cap, and apply pressure slowly.
   e. If they do not descend separately, try again with gentle pressure at first.
   f. If gentle pressure does not work, take the divers out and adjust the densities again.
   g. (Optional) Letters or phrases can be attached to the divers to spell a word or tell a joke.
   h. (Optional) The divers can be made closed divers. Closed divers can also be dyed different colors. To make a colored diver, add a drop or two of food coloring to a small beaker of water. Then, fill the diver with the colored water, check its density, and then seal with the hot glue (see Part B for how to create the closed-system diver design).

5. Design Challenge III (optional):
   a. Multiple versions of a spinning diver can be made. Students can make propellers, pinwheels, and other attachments to create a spinning diver.
   b. One example is the propeller. To prepare a spinning diver, cut a small circle out of the plastic weighing dish. Use a hole punch to punch a hole in the center.
   c. Make 4–8 incisions around the circle (represented on Figure 4, with the dotted lines). Then bend the petals with one corner up and one corner down, like a propeller (fold lines are represented with the gray lines on Figure 4).
   d. Fit the propeller onto the stem of the pipet, just above the hex nut.
   e. Finish making the diver according to Part A, steps 2–6 (see Figure 5).
   f. Mark one of the blades to help with counting rotations.
   g. Another version of the spinning diver can be done with the design in Figures 6 and 7.

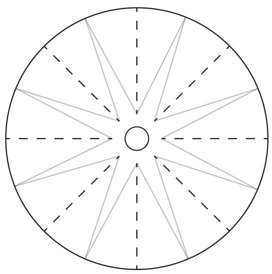

Figure 4.

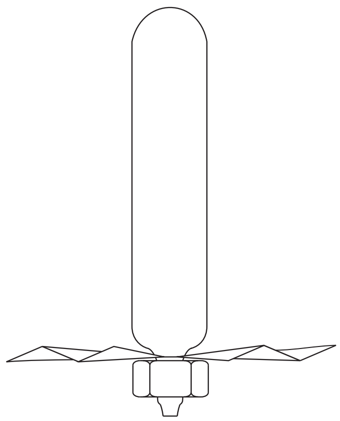

Figure 5.

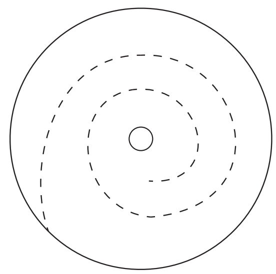

Figure 6.

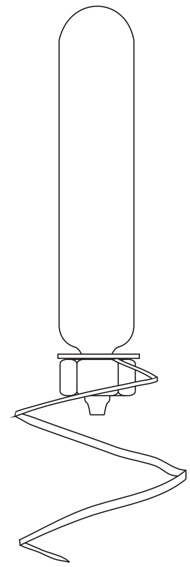

Figure 7.

Safety Precautions

The materials in this activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all laboratory safety guidelines.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS2 Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion
MS-ETS1 Engineering Design
ETS1.A: Defining and Delimiting Engineering Problems
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution

Science and Engineering Practices
Asking questions and defining problems
Developing and using models
Constructing explanations and designing solutions

Crosscutting Concepts
Patterns
Cause and effect
Structure and function

Lab Hints

- Enough materials are provided in this kit for 30 students working in pairs, or for 15 groups of students. All parts of the laboratory activity can reasonably be completed in two 50-minute class periods.
- The plastic from the weighing dishes makes great spinning divers.
- Enough pipets are given so each lab group can have 12 pipets to work with during the lab and Design Challenges.
- Depending on how in-depth the testing is and if all the Design Challenges are performed, this activity could be expanded to take longer than the two 50-minute class periods.
- It is much easier to adjust the density of the diver and to test for flotation using a 600-mL beaker or a cup of water, rather than testing in the bottle itself.
- Placing a mark on the spinning diver helps when counting rotations.
- Forceps can be used to remove the diver when it is inside the plastic bottle (Flinn Catalog No. AB1093).
- When filling the plastic bottle, fill it completely with water. If there is too much air in the bottle, the pressure could compress the air in the bottle instead of the smaller air pocket in the diver.
- One advantage of the closed diver is that a drop or two of food coloring may be added before sealing the pipet stem with a drop from the glue gun. The main disadvantage is the bulb must be reopened if any adjustments need to be made to the density. One method is to heat a stiff wire in a flame and use the hot end to melt a hole in the plug of glue.
- The manufacturers of plastic pipets change their designs and specifications occasionally. Therefore, the ¼-inch hexnut may not exactly fit the pipet. In this case, wrap the stem of the pipet near the bulb with clear tape to increase its diameter.
- Have plenty of paper or cloth towels handy to wipe up spills. Setting the 1-L plastic bottle in a large disposable weighing dish (Flinn Catalog No. AP1279) or other plastic dish will help catch spills.
- When finished with the Cartesian divers, remove the divers from the bottle with forceps. If the divers are left in the water for long periods of time, the hex nuts will rust.

Teaching Tips

- This is a great hands-on activity for incorporating STEM, engineering design, and scientific inquiry. This activity also helps to emphasize Boyle's law and density.
- Each challenge can be assigned to different groups. Alternatively, the entire class may attempt one challenge and see which group can create the best product.
- It is important to allow students time to brainstorm ideas and consider the pros and cons of each proposed design. If time allows, students may present their designs to the class.
- For Design Challenge I, hints can be given to use magnets or hooks to retrieve objects.
- For all the Design Challenges, students can add creativity by decorating their divers. Pipe cleaners, food dye, permanent markers, and glitter are just some of the things that can be used to enhance the diver.
- For Design Challenge II, additional conditions may be added to students' designs. The divers could spell a word or tell a joke as the divers descend. Up to ten divers in a 2-L bottle is possible, but squeezing the bottle enough to get all the divers to descend may be difficult.
- This assembly is formally known as a Cartesian diver after Rene Descartes, a 17th century French mathematician.
- Additional divers can be shown to students. Two manufactured divers are Squidy and Hook Cartesian Divers. These are available from Flinn Scientific (Catalog Nos. AP8721 and AP4548, respectively).
- Two videos of this lab activity are available for viewing as part of the Flinn Scientific "Best Practices for Teaching Chemistry" video series. Cartesian Divers, presented by Jesse Bernstein, and Cartesian Diver-sions, presented by Bob Becker are located in Flinn's Teacher Resource Videos. Please visit the Flinn Website at http://flinnsci.com for viewing information.

Teacher’s Notes *continued*

Answers to Lab Questions (*Student answers will vary.*)

Part A. Making a Cartesian Diver

1. Explain what is happening when the diver rises and falls.

   When external pressure is applied, additional water is pushed into the opening of the diver, increasing the mass. Since the volume of the diver stays the same, the density then increases (density = mass/volume) and the diver sinks when the density is greater than water.

   The sinking diver can also be explained using Boyle’s Law. The external pressure on the bottle compresses the air pocket in the diver making the volume of the gas smaller, changing the density of the diver, and causing it to sink (Boyle’s law states pressure and volume have an inverse relationship. Therefore, an increase in pressure causes a decrease in volume of the gas).

2. Using forceps, remove the diver. Let out five drops of water, and retest the diver.
3. Continue to adjust the amount of water in the diver, in five-drop increments. Record observations and test the diver again. Continue testing until the diver will no longer dive.

   The diver gradually becomes more difficult to sink. More pressure was needed to sink the diver as less water was placed in the initial diver, increasing the buoyancy of the diver.

4. Consider the pressure applied to the bottle. How did the amount of pressure required to sink the diver change as the amount of water in the diver decreased? Explain.

   As the water inside the diver decreased, more pressure was needed to sink the diver. Since the gas inside the diver was increasing, more pressure was needed to decrease the volume of the gas to the volume necessary for the diver to sink.

5. How did the beginning density of the diver change when the adjustments were made above?

   The diver becomes less dense as more water was removed from the diver.

   a. What variables were changed?

   b. What variables were held constant?

   Multiple variables can be examined and discussed. Some variables students may explore are

   - *Volume of water in the diver*
   - *Volume of air in the diver*
   - *Mass of the diver*
   - *Pressure applied*
   - *Pipet bulb assembly*
   - *Plastic bottle used*
   - *Temperature of the water*
   - *Temperature of the room*

Part B. Making a Closed-System Diver

6. Compare and contrast the open and closed divers.

   The open and closed diver, have the same setup, except the closed diver cannot take in more water due to the glue plug. The closed system diver does not take in extra water when the bottle is squeezed. Instead, the sides of the closed diver curve inward, decreasing the volume. Since the volume is decreased and the mass stays the same, the density increases and the diver descends.

7. What are the advantages and disadvantages to each?

   Adjustments are difficult to make with the closed diver. In order to adjust the diver, the plug must be reopened with a hot wire and then resealed again. An advantage to the closed diver is that it can be filled with colored water, making it easier to see in the bottle. An open diver is easier to adjust since it is not sealed.

The *Cartesian Diver Design Challenge Guided-Inquiry Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP7921	Cartesian Diver Design Challenge Kit
AP9011	Glue Gun
AP9012	Glue Sticks, 24/pkg
AB1093	Forceps, 10″
AP4548	Hook – Cartesian Diver

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.