Cartesian Diver Design Challenge

Introduction

Cartesian divers are great toys that can be used to teach important science concepts. Several variations of Cartesian divers are on the market. Imagine that you and your classmates are members of a research and development team at a toy company and are challenged to design a new Cartesian diver toy. Can you design a toy that includes at least three divers that will descend and ascend in a particular order?

Concepts

- Density
- Buoyancy

Materials

Beaker, 600-mL or plastic cup
Hex nut, ¼-inch
Hot-melt glue gun and glue stick (optional)
Pipets, disposable plastic, graduated
Plastic soda bottle, clear, 1- or 2-L with cap
Scissors

Safety Precautions

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

Standard Diver Preparation

1. Cut off all but 15 mm of the pipet stem (see Figure 1).

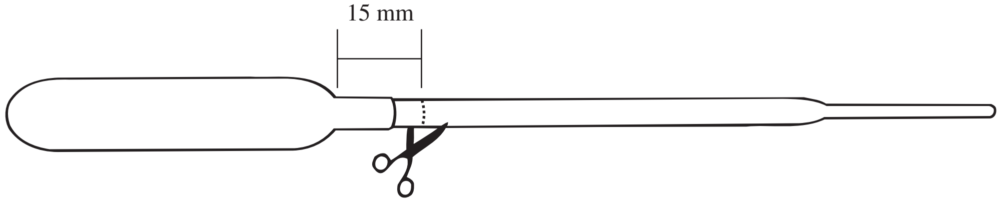

Figure 1. Cutting the Pipet

2. Screw the nut securely onto the pipet stem. The hex nut will make its own threads as it goes.
3. Fill the 600-mL beaker approximately ⁴⁄₅ full with tap water.
4. Place the pipet–nut diver assembly into the beaker of water and observe that it floats rather buoyantly in an upright position with the hex nut acting as ballast.
5. Squeeze out some of the air and draw water up into the pipet. Now check the buoyancy. If too much water is drawn up into the diver, it 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. Using this technique, adjust the amount of water in the assembly so that it just barely floats. (In other words, fine-tune the assembly's density to make it slightly less than that of water.)

Variation: Closed-System Diver

1. Follow steps 1–5 in the *Standard Diver Preparation* section.
2. Remove the diver from the beaker and squeeze out one or two drops of water. Using a cotton swab or 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-melt 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 2).

4. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.

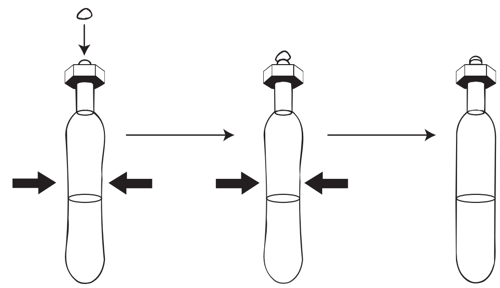

Figure 2.

Procedure

1. Place the standard diver assembly in a plastic 1-or 2-L bottle that has been *completely* filled with water and securely screw on the cap (see Figure 3).
2. Test the standard diver by squeezing the bottle and observe any changes in the position or behaviour of the Cartesian diver.
3. Release the "squeeze" and observe any "return" behaviour of the diver.
4. Repeat the process and propose an explanation for the results.
5. Test the closed-system diver in the 1-or 2-L bottle. Observe and record its behaviour as you squeeze and release the bottle.
6. Does the behaviour or action of the closed-system diver reinforce or change your proposed explanation for the results observed in the standard diver test?

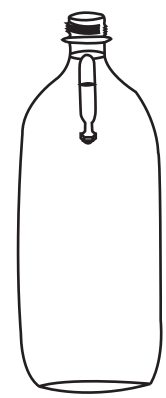

Figure 3.

Design Challenge

The challenge is to design a Cartesian diver toy with three or more divers that will descend in a pre-determined order. The toy should have a "theme" that enhances the design.

1. Form a working group with 2-3 other students and consider the following questions relating to the effects of density and buoyancy on the properties of a Cartesian diver.
   a. Can the density of the diver be quantified?
   b. Is the relationship between the amount of water in a diver and its density linear?
   c. Should the divers be open (standard) or closed? What are the advantages and disadvantages of each type?
   d. Will the temperature of the water or the temperature of the room affect the results?
   e. Does the size of the bottle matter?
2. Students should then plan, discuss, test, and evaluate their designs.
   a. Decide upon the number of divers to include and determine the theme of the toy—other than density, why are the divers descending in a particular order?
   b. Discuss and design a procedure to test the divers.
   c. List any safety concerns and the precautions that will be implemented to keep yourself, your classmates, and your instructor safe during testing.
   d. Consider the strengths and limitations of your design.
   e. How will the testing data be recorded?
   f. How will you analyze the data to determine a successful design?
   g. Review your design, safety precautions, procedure, data tables, and proposed analysis with your instructor prior to testing the design.

Tips

- It is considerably more convenient to adjust the density of the diver and to test for flotation in a 600-mL beaker or in a cup of water, rather than in the bottle itself.
- It is advisable to fill the plastic bottle completely with water. If the bottle contains too much air, then when the bottle is squeezed, the work will go into compressing the large air space at the top of the bottle rather than the smaller air pocket in the diver.
- This assembly is formally known as a Cartesian diver after René Descartes, a 17th century French mathematician.
- The manufacturers of plastic pipets change their designs and specifications occasionally. Therefore, the hex-nut size of ¼ -inch 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.
- One advantage to the closed-system diver is that a drop or two of food colouring may be added before sealing the pipet stem with hot-melt glue. The main disadvantage is that the bulb must be reopened if any adjustments need to be made to the density. One method it to heat a stiff wire in a flame and use the hot end to melt a hole in the plug of glue.
- Instructors may want to limit the number of divers included in the challenge. 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.
- Students may need one or two examples of a theme for multiple descending divers—numbered divers that descend in order, lettered divers that spell a word or secret message, etc.
- Show students a few manufactured or homemade variations of the standard Cartesian diver before presenting the Design Challenge. Two manufactured variations, *Squidy* and *Hook Cartesian Divers* are available from Flinn Scientific Canada (Catalogue Nos. AP8721 and AP4548, respectively).
- A *Cartesian Diver Construction—Super Value Kit* is available from Flinn Scientific Canada (Catalogue No. AP9082). Enough pipets and hex nuts are provided to build 100 Cartesian divers. A *Cartesian Diver Design Challenge—Guided-Inquiry Kit* (Catalogue No. AP7926) is also available and includes instructions and materials for three different design challenges.
- A video of this activity, *Cartesian Diver-sions*, presented by Bob Becker, is available for viewing on the Flinn Canada Website at http://www.flinnsci.ca.

Discussion

The sinking and rising of a standard Cartesian diver can be explained in two ways.

1. Consider the diver assembly to consist of the pipet bulb, the hex nut, and the air and water inside. As the bottle is squeezed, water is forced up into the assembly (because the air pocket inside the bulb is compressible, but the water in the bottle is not). This adds to the mass of the diver assembly without changing the volume, thus increasing the density of the diver assembly (density = mass/volume).
2. On the other hand, consider the diver assembly to consist of the bulb, the hex nut, and the air inside, but not the water—it is part of the surrounding fluid. As the bottle is squeezed, it compresses the air pocket and thus decreases the total volume of the diver. Since the mass remains constant, the diver assembly's density increases.

Either way, when the Cartesian diver's density increases, it becomes greater than that of the surrounding water, and the diver sinks. When the pressure is released, the compressed air pocket inside the bulb pushes the extra water back out, and the diver assembly assumes its original density, which is slightly less than the density of the water, and it rises to the surface.

The closed-system diver responds differently to the increased pressure since the glue plug prevents water from entering the diver. When the bottle is squeezed, the sides of the pipet bulb curve inward, decreasing the volume. With no change in mass, the density increases and the diver sinks.

Acknowledgement

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Cartesian diver drawings provided by Susan Gertz.

References

Sarquis, M. & Sarquis, J. L. *Fun with Chemistry: A Guidebook of K–12 Activities;* Institute for Chemical Education, University of Wisconsin: Madison, 1993; Vol. 2; pp. 123–140.

Materials for *Cartesian Diver Design Challenge* are available from Flinn Scientific Canada Inc.

Catalogue No.	Description
AP7926	Cartesian Diver Design Challenge—Guided-Inquiry Kit
AP9082	Cartesian Diver Construction—Super Value Kit
AP8721	Squidy—Cartesian Diver
AP4548	Hook—Cartesian Diver

Consult www.flinnsci.ca or your *Flinn Scientific Canada Catalogue/Reference Manual* for current prices.