Cartesian Diver-sions

Boyle's Law

Introduction

A variety of squeezable/sinkable Cartesian divers can be made with the simplest of equipment and materials . . . and a little imagination.

Concepts

- Density
- Boyle's law

Materials

Beaker, 600-mL
Hex nuts, stainless steel
Pipets, Beral-type, disposable plastic
Plastic soda bottle, 2-L
Scissors

Safety Precautions

The materials used in this activity are considered nonhazardous. Please follow all standard laboratory guidelines.

Procedure

1. Fill the 600-mL beaker approximately 4/5 full with tap water.
2. Cut off all but 15 mm of the pipet stem (see Figure 1). Then screw the hex nut securely onto the truncated stem. The hex nut will make its own threads as it goes.

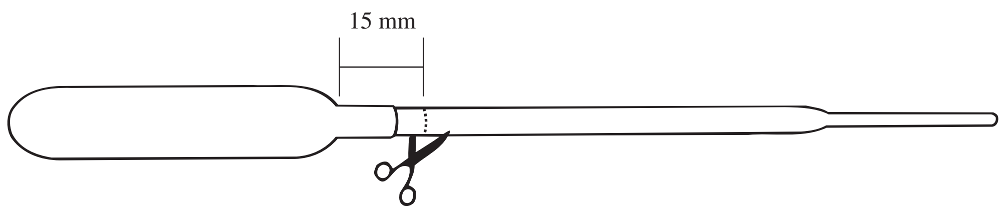

Figure 1. Cutting the Pipet

3. 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.
4. Squeeze out some of the air and draw some water up into the pipet. Now check the buoyancy. If you draw up too much water, the assembly 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 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).
6. Place the diver assembly in a plastic 2-L bottle filled with water and screw on the cap securely (see Figure 2). Observe how the assembly dives to the bottom as you squeeze the bottle and how it rises to the surface as you release the squeeze.

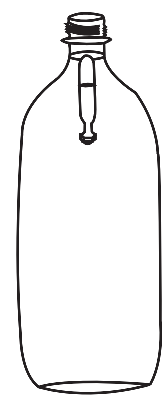

Figure 2.

Discussion

Whether an object floats or sinks in a fluid depends on the object's density versus the density of the fluid. Density = mass/volume (D = m/v). Thus, if the mass of an object increases while its volume remains constant, the object's density will increase. The density of an object will also increase if its volume is reduced while its mass remains constant. Boyle's Law states that as the pressure on a gas sample is increased, the gas is compressed into a proportionately smaller volume. That

Publication No. 91652
061616

is, an inverse relationship exists between the pressure exerted on a gas and its volume. While gases are compressible, liquids and solids are not.

In this lab a Cartesian diver was constructed. Initially the diver was placed in the water containing gas and no water inside. Since the density of the air in the diver was less than the density of the water, the diver floats. As the diver was filled with water, its density increased and therefore sank in the beaker.

The Cartesian Diver was placed in a 2-L bottle. In this case, the density of the diver remained the same but the density of the surrounding fluid changed. As the 2-L bottle was squeezed, the air pocket in the bottle was compressed and thus the total volume of the assembly decreases. Since the mass remains constant, the diver assembly's density increases. Conversely, as the 2-Liter bottle is released the air pocket is allowed to expand thus expanding the total volume of the apparatus. Since the volume is increasing the divers density decreases and therefore rises back to the top of the bottle.

Tips

- It is considerably more convenient to adjust the density and to test for flotation in the 60-mL beaker or in a tub of water, rather than in the bottle itself. A cut-off 2-L bottle works well as a testing tank!
- It is also advisable to fill the 2-L bottle completely with water. That way, when the bottle is squeezed, the work will go into compressing the air pocket in the diver and not into compressing a large air space at the top of the bottle.

Extensions

Although the standard diver described above is amusing and educational, the real fun comes in trying some creative variations, such as those listed below

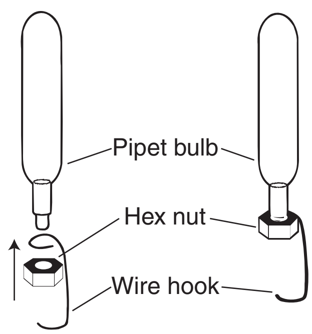

Figure 3.

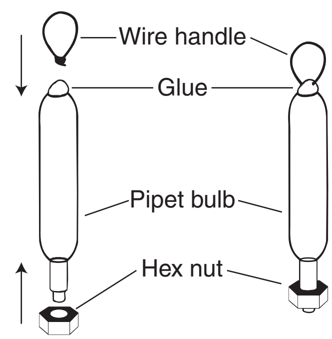

Figure 4.

1. **The Sunken Diver.** Adjust a diver's density so that it just barely sinks and then put it in a bottle of water. Try to find a way to make the diver ascend to the surface. Some ideas might include: taking the cap off and heating the bottle, or placing it in a vacuum jar, or perhaps adding a solute to increase the density of the surrounding water.
2. **Cartesian Retrievers.** Place two divers in the same bottle—one that barely floats and one that barely sinks, but with mechanisms or devices attached to them that will enable the floating one to dive down and retrieve the sunken one off the bottom. Use magnets, chewing gum, Velcro, a suction cup, a net, a hook and handle—whatever works (see Figures 3 and 4)!
3. **Cartesian Counters and Messages.** Place several numbered divers together in one bottle, but all with different densities, so they descend in order—1, 2, 3 . . . (or letter the divers to spell out a secret message!) (see Figure 5).
4. **Diving Whirligigs.** Cut a small sheet of plastic into a pinwheel. Punch a hole in the center and fit it onto the stem of the pipet, just above the hex nut. Now the diver will spin gracefully as it sinks, and reverse its spin on the way up. Attach pipe-cleaner arms and legs to make an unusual diving ballerina!

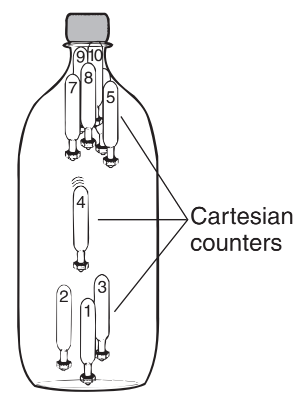

Figure 5.

5. **Closed-System Divers.** After the density has been adjusted, try sealing the mouth of the diver with a drop of hot-melt glue. Now, when the bottle is squeezed, instead of water being forced up into the diver's mouth, the sides of the diver are forced noticeably inward (see Figure 6). This closed system allows the use of colored water inside the diver and results in divers that can be stored and transported outside the bottle. What's more, the shape distortion may be used in several ways: for instance, wires may be attached to the sides of the diver and fashioned into "jaws" that hang downward. Then, when the middle gets pushed inward, the jaws spring open and a ferocious cartesian shark dives downward with his mouth open to snatch a unsuspecting diver off the bottom!
6. **Density Column Divers.** Make a density column inside the bottle. This can consist of anything that forms layers (half oil/half water, for example). Use several divers—all adjusted to suspend themselves at different levels throughout the bottle.

7. **Remote-Controlled Divers.** Use airline tubing (aquarium tubing) or Tygon® tubing to connect two plastic bottle caps together. Screw one cap onto a water-filled bottle containing a standard diver (or any of the variations listed above) and screw the other cap onto a second bottle (the remote control) that just contains water. When the remote control is squeezed, the diver in the first bottle will descend, even from across the room through several meters of tubing! As mentioned above, it helps to have the bottles as full as possible and to have the tubing completely filled with water as well. Try replacing the water-filled bottle with a bottle of soda. Instead of squeezing, just shake! Or use the carbon dioxide-producing reaction between baking soda and vinegar to create the pressure in the remote control bottle.
8. **The Cartesian See-Saw.** Try to construct two cartesian divers and attach them to the ends of a see-saw structure that alternately tips back and forth as you squeeze and release the bottle. At first, this might seem impossible, for both divers would increase in density as the bottle is squeezed. But by varying the length of the lever arms or by making one diver more sensitive than the other (by using, for example, a regular diver on one end and a closed-system diver on the other), an underwater see-saw is feasible!
9. **Concentric Divers.** Make a diver small enough to fit inside another one, so as the little one dives inside the bigger one, the bigger one dives inside the bottle!
10. **The Electric Diver.** Build a diver with a built-in circuit that causes a light to go on or a bell to ring when the diver descends.

Note: This list of variations has been presented with the intention of demonstrating the versatility and expandability of a concept that many may have considered very limited. From buoyancy to pressure to surface tension to density to chemical reactions and electrical conductivity, the cartesian diver can act as a springboard (pun intended!) for a variety of fun and exciting educational activities.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, density, mass and volume

Acknowledgments

Special thanks to Bob Becker for providing us with this activity.
Cartesian Diver drawings provided by Susan Gertz.

Further Reading

Sarquis, M.; Sarquis, J. L. *Fun with Chemistry: A Guidebook of K-12 Activities;* Institute for Chemical Education, University of Wisconsin: Madison, WI, in press; Vol. 3.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Cartesian Diver-sions* activity, presented by Bob Becker, is available in *Boyle's Law*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Cartesian Diver-sions* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Cartesian Diver Construction—Super Value Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP9082	Cartesian Diver Construction—Super Value Kit
AP1516	Beral-Type Pipets, Graduated, Pkg/500

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