Cartesian Divers

An object floats in a liquid when it is less dense than the liquid. Do you think that you could make a floating object sink without changing the density of the liquid? Does your answer change when you consider an object that includes a pocket of trapped air? Try the following activity and see what you find.

Materials

- beral pipet (provided)
- hex nut (provided)
- scissors
- tall glass or cup
- water
- plastic soft drink bottle with cap
- super glue or hot melt glue gun and glue (if available)

Exploration

Step 1 Screw the hex nut onto the pipet up to the bulb. Cut off the pipet stem below the hex nut, creating a “Cartesian diver.” (See Figure 1.) Place the Cartesian diver in a tall glass full of water. What does it do? Adjust the amount of water in the diver so it floats with its top just at the water line. (You can control how much the diver sinks or floats by squeezing the bulb to draw in or release water.) Why do the amounts of water and air in the diver cause it to sink or float?

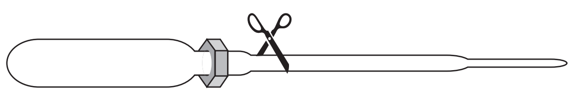

Figure 1: Screw a hex nut onto the pipet and cut off the stem.

Step 2 Fill the soft drink bottle with water to within 2 or 3 cm of the top. Place the diver in the bottle and screw the cap on tight. (See Figure 2.) Note the location of the diver. Squeeze the bottle firmly. What happens to the diver? What happens to the air inside the top of the bottle and inside the diver? Explain your observations.

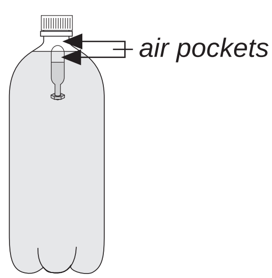

Figure 2: Float the diver in the bottle.

Step 3 Remove the diver from the bottle. Place the diver in the glass of water and adjust it so it just barely sinks. Place it in the completely filled bottle. Find a way to make the diver float to the surface. (There are several ways that you can do this.) Describe what you did and why it worked.

Step 4 Remove the diver from the bottle. Place the diver in the glass of water and adjust it so it floats. Seal the open end of the diver with a minimum of super glue or hot melt glue (if these are available). Allow the glue to dry. Place the diver in the completely filled bottle, and screw on the cap. What happens now when you squeeze the bottle? How and why does this differ from the diver's behavior in Step 2?

Step 5 Using a 3-inch x 3-inch piece of aluminum foil, try to make a Cartesian diver. Be creative. Describe what you did to make it dive. (If all else fails, wad it up and try.)

Step 6 Try different shapes and sizes of plastic bottles, such as dishwashing detergent bottles. How do they behave differently?

Challenge

What two properties of a gas are changed to operate a Cartesian diver and what is their mathematical relationship to density?

Cartesian Divers

Concepts

Charles' law, density, Boyle's law

Expected Student Responses to Exploration

Step 1 (a) When the diver is first put in water, it floats.

(b) The relative amounts of water and air in the diver determine its density; when enough air has been replaced by water, the diver is more dense than water and it sinks.

Step 2 (a) When the diver is first put in the bottle, it floats.

(b) When the bottle is squeezed hard enough, the diver descends to the bottom of the bottle. Squeezing the bottle increases the pressure inside the bottle and diver, thus decreasing the air volumes (Boyle's law).

(c) When the bottle is squeezed, the volume of air inside the bottle and inside the diver decreases.

(d) As the volume of air inside the diver decreases, the volume of water inside the diver increases. When enough water enters the diver, it becomes more dense than the water and sinks.

Step 3 Three of the more common ways:

(a) Squeeze the bottle slightly while screwing on the cap. When you stop squeezing, the diver rises to the surface. Squeezing the bottle without the cap pushes out some of the inside contents (water). When you stop squeezing the bottle, it tries to resume its original shape. This decreases the inside pressure, thus increasing the air volume inside the diver (and decreases its water volume), making the diver less dense than water.

(b) Add sugar, salt, or another water-soluble solid to the water. After enough dissolves, the diver rises to the surface. The density of an aqueous solution is greater than water itself. The diver floats because it is less dense than the solution.

(c) Warm the bottle and the diver rises to the surface. Increasing the temperature increases the volume of the air (Charles' law) inside the diver (and decreases its water volume), making the diver less dense than water. (The temperature increase also increases the volume of the water, but too little to make much difference.)

Step 4 (a) When the bottle is squeezed, the walls of the diver move inward and the diver descends to the bottom of the bottle.

(b) In Step 2 the density of the diver was increased by increasing the mass. Since this diver is closed, its mass cannot change, only its volume. When the inside pressure is increased, the walls of the diver are pushed inward to reduce its volume. The reduced volume of the diver increases its density.

Step 5 A wadded up piece of aluminum foil with air trapped in it can act as a Cartesian diver.

Step 6 In general, the shape of the bottle makes no difference. However, squeezing the widest sides of an oval bottle can make a "barely-sunk" diver rise (as in Step 3). Squeezing the widest sides makes the bottle more cylindrical, thus increasing its volume, decreasing the inside pressure, and hence increasing the air volume inside the diver.

Expected Student Answer to Challenge

The two properties of a gas that are changed to make a diver operate are pressure and volume. The pressure and volume of a gas are inversely proportional to the density.

References

"Cartesian Divers"; *Fun with Chemistry: A Guidebook of K–12 Activities;* Sarquis, M., Sarquis, J., Eds.; Institute for Chemical Education: Madison, WI, 1993; Vol. 2, pp. 121–168.

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Acknowledgment

This activity was developed as a part of the NSF-funded "General Chemistry: Discovery-Based Advances for the Two-Year College Chemistry Curriculum" project, grant #DUE-9354378.