Making a Cartesian Diver Toy

Abstract:
The purpose of this activity is to construct a Cartesian Diver device illustrating the concept described by Boyle's Law, so that a theory may be constructed explaining how the diver/water/bottle system works.

Introduction:
This apparatus is named for René Descartes, a French mathematician, scientist philosopher. He laid the foundations of analytical geometry, algebra, and other subjects such as buoyancy and pressure. René Descartes sought truth by first doubting everything, even his own existence. He concluded that in order to be able to doubt his existence, he must exist. Descartes accepted traditional Christian beliefs, and he deduced the existence of God and then the existence of the physical world. He is perhaps best known for his statement, "I sink, therefore I am."

The apparatus can be made with one diver to illustrate a property of a gas as it is affected by pressure changes, or with two divers as in this procedure to make a toy. Try to hook the sinking device with the floating one.

Materials:

- 2-Liter soda bottle with cap, empty
- 2 plastic pipets
- 2 hex nuts, of a size to fit securely on the necks of the pipets
- Sharpie marker or other water resistant marker
- 2 12-inch lengths of coated wire; preferably copper; different colors are nice
- 1-Liter beaker or other such container (to test the pipets before assembling the bottle)
- Water to fill the container (above) to a depth of several inches
- Water to fill the 2-Liter bottle
- Scissors

Safety:
Use care with scissors and glassware. The pipets are not squirt guns.

Procedure: NOTE: You may work from your own design if you like.

1. Slide one nut on the stem of each pipet, snug against the bulb (Fig 1.) Cut the stem off about 1 inch below the nut. More can be trimmed later if necessary. If the nut does not fit securely, place a wrap or two of masking tape around the pipet stem next to the bulb.

2. Fill the 1-liter beaker or container with water to a depth of several inches. This beaker will be used to "test dive" the divers.

3. Attach a length of wire to each pipet as shown in (Fig. 2 and 3) by wrapping it snugly around the pipet neck between the bulb and the hex nut. One pipet will function as a hook, and the second with a handle will be the object that is "hooked.".

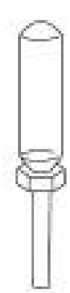

Fig.1

4. Place each pipet in the container of water. Fill the first with water until it barely but distinctly sinks, then add 1 drop more. Remove it carefully without disturbing the water level, dry it gently, and use the sharpie to mark the exact level by drawing a line around the bulb at the air-water level with a sharpie or wax pencil.

5. Do the same with the second pipet, but fill it with water to a level at which it barely but distinctly floats, and squeeze out one drop more water. Remove it, dry it, and mark the water level.

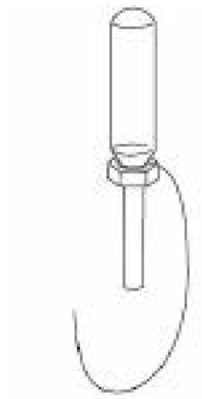

Fig. 2

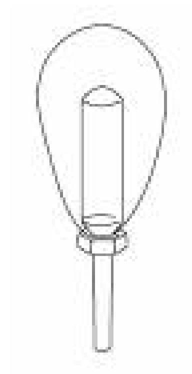

Fig. 3

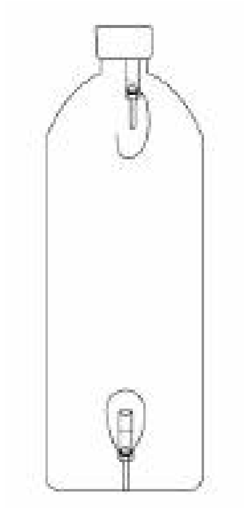

Fig. 4

6. Fill the 2-Liter bottle nearly to the top with water. Gently place each pipet in the bottle, one at a time, taking care not to disturb the water level in the pipet. Carefully add water until it spills out the top, and cap the bottle moderately tightly. (Fig 4)

7. To operate the device, squeeze the sides. What do you see?

Discussion:

1. Describe your observations of the bulb as the bottle was squeezed. Discuss the water level in the bulb with respect to the line you drew.

2. Offer an explanation as to why the water levels change as they do. Include pertinent properties of the water in the bottle and the air inside the pipet in your explanation. What property of gas is responsible for the behavior of the gas inside the pipet?

3. What happens when the top floater hooks the bottom sinker? Explain your observation.

4. Which pipet displaces more water? Explain your answer.
5. Can you describe the relationship between density and buoyancy that the diver might be illustrating?
6. What would happen if the bottle were only half full of water or there was no cap? How can this difference be explained?
7. What are some possible modifications to the diver that would cause it to sink quicker? Slower? Can you think of other items that could be used to create similar results, such as different containers or divers?

Conclusion:
Write your own theory as to how the diver works. Name the theory. Devise a viable way to test the theory. To think about:

What happens to the volume of air in the eyedropper?

Can you compress air? Or gas?
Can you compress water?
What happens to the mass of air in the diver?
What does density mean?
How does the density of the air change?
Why does the diver fall when the bottle sides are squeezed?
How does this relate to the swim (air) bladders in fish?
How does this relate to submarines?
What causes the diver to rise and fall?

Further Investigation:

Try putting water dyed with food coloring inside the pipet. What do you think would happen?

Would this work with liquids other than water? Explain.

What might happen it the entire container was to be slightly heated? Greatly heated?

What effect would it have on the system to invert the bottle and squeeze it?

Is there any way to reverse the effect of squeezing the bottle so that the dropper begins at the bottom and when you squeeze it, it rises?

Possible Extensions

* What effect does the temperature of the water have upon the activity of the diver? Construct an experiment to test your hypothesis.
* If the diver was placed into a bottle containing a different liquid, such as vegetable oil, and the same technique was used, what do you predict would happen?
* What are some practical applications of Pascal's Law? How about Archimedes' Principle?

What other objects might function as Cartesian divers? Bring some in to test.

Other ways to make a diver:
1. A Bic™ ballpoint pen with transparent plastic body.
Pliers.
A small lump of modeling clay the size of a pea.
2. Find a plastic pen top and stick a small piece of Blu Tack onto one end as in the diagram. Put the top into the bottle. The Blu Tack weighs down one end so that the top stays up right with a bubble of air inside.

3. A condiment packet.

4. Balloon with fishing weight stuffed inside

Other hints:
The Greek philosopher Archimedes was the first person to notice that the upward force that water exerts on an object, whether floating or submerged, is equal to the weight of the volume of water that the object displaces. That is, the buoyant force is equal to the weight of the displaced water.

As you squeeze the bottle, you increase the pressure everywhere in the bottle. The higher pressure forces more water into the eyedropper, compressing the air in the eyedropper. This causes the dropper to displace less water, thus decreasing its buoyancy and causing it to sink. When you release the sides of the bottle, the pressure decreases, and the air inside the bulb expands once again. The dropper's buoyancy increases, and the diver rises. If you look carefully, you can see the level of water changing in the dropper as you vary the pressure on the bottle.

If you use a thin, flat bottle, squeezing on the wide sides of the bottle will increase the pressure inside the bottle, but squeezing on the narrow sides will cause the volume of the bottle to expand and the pressure inside to decrease. If you use such a bottle, adjust the weight or water content of a Cartesian diver so that it barely floats. When this diver reaches the bottom of the bottle, it will stay there, even when you stop squeezing on the wide sides. You must squeeze the narrow sides to drive the diver to the surface. It will then stay at the surface even when the squeezing stops.

The key to this behavior is to carefully adjust the diver initially, so that it barely floats. As the diver sinks, the pressure outside the diver increases slightly with the water's depth. This increase is in addition to the increase in pressure you cause by squeezing the bottle. When the diver reaches the bottom and you stop squeezing, the pressure resulting from the increase in depth remains and continues to compress the air bubble a little. If the diver has been carefully balanced, this small compression of the bubble will be enough to keep the diver submerged. The process reverses when you squeeze the narrow sides to raise the diver.

Since ships float, their weight must be equal to the buoyant force of the water. The weight of a ship is therefore called its displacement.