Cartesian Diver Classroom Kit

P1-2000-01

BACKGROUND ON THE PROPERTIES OF AIR AND BUOYANCY:

We are so accustomed to the invisible air surrounding us that we sometimes forget that air has mass and weight, occupies space, and exerts pressure. Each of these properties are directly related to the concept of air *density*. Below is a table with the densities of various gases.

Densities of Various Gases

Gas	Density (kg/m3)*
Dry air 0ºC	1.29
10ºC	1.25
20ºC	1.21
30ºC	1.16
Helium	0.178
Hydrogen	0.090
Oxygen	1.43

* At sea-level atmospheric pressure and at 0ºC (unless otherwise specified) (Hewitt, 285)

(Under standard conditions, liquid water has a density of 1,000 kg/m^3.)

Let your students calculate the number of cubic meters in your classroom and multiply by 1.21 kg/m^3. They may be surprised at how much the room's air weighs. (Hewitt, 287)

Air density simply reflects the relation between its weight and the amount of space it occupies. Decrease the volume and the density goes up because the same amount of mass is being squeezed into a small area. Increase the volume and the density goes down as the mass is spread over a larger area.

Air density is also related to air pressure. A scientist named Robert Boyle discovered this relationship and it is now called *Boyle's Law*. The law simply states that if the density goes up or down, then the pressure goes up or down with it. Conversely, if you apply pressure to a gas by, say, pushing it into a smaller container, the density goes up. If you release pressure, the density goes down.

Air pressure and density can help explain the barometric property of air. When two air pressures meet, they push on each other (they are forces, after all). The two pressures will push on each other until they balance. For example, your windows don't break because the air pressure on one side is equal to the air pressure on the other. But, get caught in a tornado or hurricane and there can be a great difference in air pressure shattering the window and balancing the pressure. There is another example: a classic physics demonstration in which an aluminum can is partially vacuumated by heating the air and a little water inside. When enough air has been forced out of the can, it is capped and allowed to cool. As it cools the can is crushed. By what? The pressure inside is small (due to it's low density) compared to the heavier atmospheric pressure outside. The can is crushed until the density and pressure inside equal the density and pressure outside.

Buoyancy rules are also related to density. The buoyancy law states that an object surrounded by a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object. In the case of a boat, as long as the boat weighs less than the total weight of the water that it displaces, it will float. Or, in terms of density, the boat can not be more dense than the water.

KIT CONTENTS:

30	Pipets
30	Nuts
1	Cartesian diver
1	Pressure pumper, liter bottle
7	6" pieces of black wire
5	10" pieces of red wire

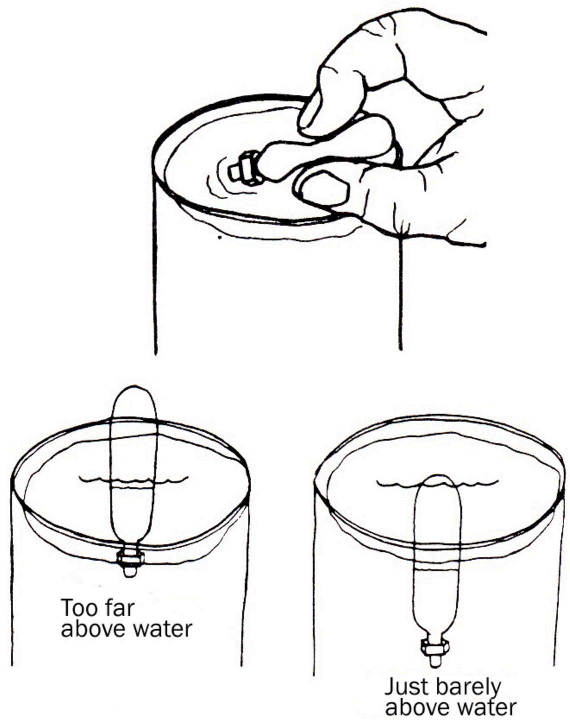
THE CARTESIAN DIVER:

Buoyancy laws apply to the Cartesian diver as well. As long as the combined density of the pipette, rubber cover, steel mass, and the air/water mixture inside are less than the density of the water it displaces, it will float. These Cartesian divers were designed with just enough weight to bring it very close to the point of sinking, but not quite. In fact, it floats quite well. But as soon as outside pressure is exerted, the air inside compresses. The volume of the air decreases, becomes denser, and more water is pushed into the pipette. The diver now is too dense to remain buoyant - hence, it sinks.

ACTIVITIES:

ACTIVITY #1: THE TRADITIONAL DIVER

1. Place the diver in a cup of water that contains water at least four inches deep. Notice that the diver floats. Why? While the diver is still in the water, squeeze the bulb of the pipette to force air out and release pressure to draw water up into the diver. Continue squeezing air out and drawing water up into the diver until the pipette is about half full of water. Let go of the diver and see if it still floats in the water. When properly adjusted, the diver should just barely float in the cup of water. If the diver sinks to the bottom, squeeze out a few drops of water and re-test.
2. Carefully transfer the diver to the soda bottle that is full to the brim with water. Be careful not to accidentally lose any of the water in the diver when you are transferring it to the soda bottle. Place the cap on the bottle.



3. Use both hands to squeeze the sides of the bottle. You may have to squeeze hard depending on how you adjusted the water level inside the diver. Watch the diver sink when you squeeze the bottle, or float when you release the squeeze.

ACTIVITY #2: THE SUNKEN DIVER

Materials Needed:

One sunken Cartesian diver

(If your diver sank to the bottom of the bottle on its own, then this activity is for you!)

Method #1

What do you do when a Cartesian diver sinks to the bottom of the bottle on its own?

1. Make sure that the plastic soda bottle is completely full to the brim with water and a diver is resting on the bottom of the bottle.

2. Place the bottle on the table, and hold on to the neck of the bottle with one hand.
3. Make a fist with your other hand and rapidly tap the side of the bottle with your fist. As you tap the bottle, the diver should float up to the top of the bottle. When you stop tapping, the diver will sink.

Method #2

Unscrew the cap and slightly squeeze the sides of the bottle (this will force a little water out of the bottle). Screw the cap back on and release your squeeze on the bottle.

The sides of the plastic bottle are squeezed inward as you squeeze the bottle, but the water inside the bottle pushes outward and restores the bottle to its original shape. In doing so, you create a partial vacuum in the bottle. The lower pressure inside the bottle causes the pocket of air in the diver to expand, and this action forces water back out of the diver. The combination of less water and more air in the diver results in it floating back up to the top.

Method #3

Can a change in temperature affect the buoyancy of the diver? Yes!

If the water inside the bottle cools, the pocket of air in the diver contracts, and the diver sinks. On the other hand, warming the water will cause the pocket of air in the diver to expand. The expanding air forces water back out of the diver, making it more buoyant, and allowing it to float to the surface.

This makes for an interesting science fair project: Could you make a Cartesian diver thermometer out of five divers that all contain different amounts of water?

ACTIVITY #3: COUNTING DIVERS

Materials needed:

Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
Five assembled divers
Scissors
Permanent felt tip marker
8 ounce or larger, clear, plastic cup
Pressure Pumper (included in this kit)

Create “trained” Cartesian divers with this activity and at the same time learn how mass affects density. You will construct five divers, each containing different amounts of water and labeled “1” through “5”. When you squeeze the bottle, diver #1 will descend followed by #2 and so on. The divers will descend in an order dependent upon the amount of water in each bulb. The special pump will allow you to make the divers float and sink without having to squeeze the bottle.

1. Number the divers “1” through “5” using a permanent ink marker.
2. Place all five divers in the cup of water and adjust the water level inside the pipettes so that they are all about half full. Make sure that all of the divers just barely float.
3. Carefully remove diver #2 and squeeze out 5 drops of water. Squeeze out 10 drops of water from diver #3, 15 drops of water from diver #4, and 20 of water from diver #5. When you are finished, diver #1 should have the most amount of water and diver #5 should have the least amount of water in its bulb.
4. Carefully transfer the divers to the soda bottle full of water. Be careful not to accidentally lose any of the water in the divers when you are transferring them to the soda bottle. Instead of sealing the bottle with the regular cap, screw on the special pump that is included in the kit. The pump was specially made to fit on a standard plastic soda bottle.

When you gently squeeze the sides of the bottle, diver #1 should sink first because it is the least buoyant. Squeeze harder and #2 will fall, and so on. You can have a lot of fun with this activity just in the way you present it.

“Here is a bottle with five trained Cartesian divers. What?...You don’t believe me? I’ll show you. Watch as I command diver #1 to sink.”

Hold the bottle up and gently squeeze to make diver #1 sink to the bottom. Don’t let anyone know that you are squeezing the bottle!

“Now, it’s #2’s turn.”

Secretly squeeze the bottle a little harder and make the second diver sink. Divers #3 through #5 are more difficult to sink because they have less water and may require the use of the special pump. Lift the top of the pump and push it back down. The pump forces a small amount of air into the bottle and this, in turn, increases the pressure on the air in the divers. By repeating the pumping action, it is very easy to make all of the divers sink. Loosen the cap just as you would when you open a bottle of soda and the divers will jump back up to the top.

How does it work?

Diver #1 contains the greatest amount of water because you adjusted the water level inside so that it would just barely float. Since diver #1 has the most water, it has the smallest pocket of air. When you squeeze the bottle, this diver will descend first. On the other end of the scale, diver #5 contains the least amount of water and has the largest pocket of air. Diver #5 is the most buoyant of the five divers and should be the last one to sink. The divers will progressively sink in the order 1 to 5 if the densities of the divers are properly adjusted.

You will also notice that you have to squeeze harder and harder to get each successive diver to sink. In essence, you have created a strength tester. One person may only be strong enough to sink three divers while someone else may have the strength to sink all five. How strong are you?

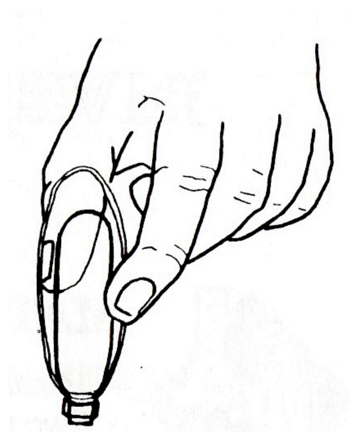
ACTIVITY #4: THE HOOK

Materials needed:

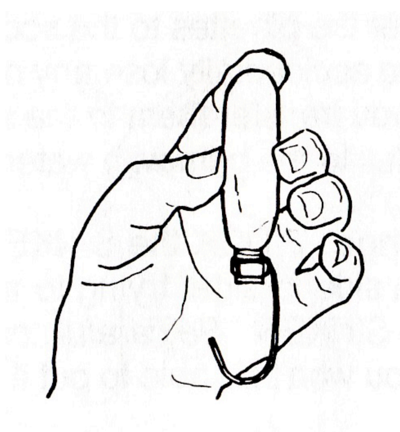
Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
Two divers
One red wire (10 inches) and one black wire (6 inches)
Scissors
12 ounce or large, clear, plastic cup

For this activity you will attach one wire to one diver in the shape of a HOOK, and attach a loop of wire the other diver, called the SINKER, where the loops extends over the top. The object of the game is to HOOK the SINKER in the bottle.

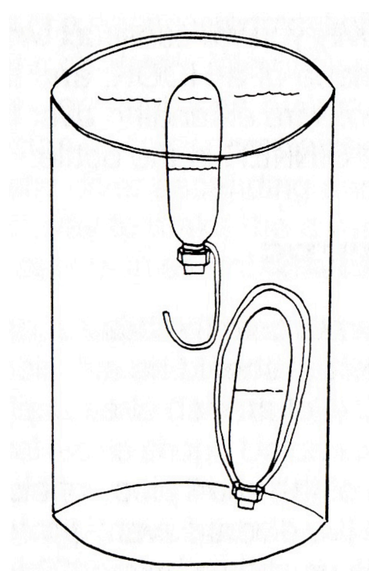
Assembly Steps



1. Wrap one end of the short piece of black wire around the base of one of the divers several times. Form the other end into a hook. This is the HOOK.



2. Wrap one end of the long piece of red wire around the base of the other diver, and form a large loop over the diver. Wrap the other end of the wire around the base of the diver. This is the SINKER.



3. Place the HOOK and the SINKER in the cup of water. Make sure that the cup contains at least six inches of water. Adjust the water level in the HOOK so that it just barely floats. Adjust the water level in the SINKER so that it just barely sinks.

4. Carefully transfer the divers to the soda bottle full of water. Be careful not to accidentally lose any of the water in the pipettes when you transfer them to the soda bottle. The bottle must be full to the brim with water. Replace the cap on the bottle.
5. Now, try to HOOK the SINKER by squeezing and tipping the bottle from side to side, trying to maneuver the HOOK around the loop of the SINKER.

HELPFUL HINTS:

- Make sure you fill the bottle to the *very* top with water.
- Use room temperature water when filling your bottle. Otherwise, as the water heats up or cools, it will affect the pressure in the bottle and the water level in the diver.
- The diver may sink on its own over time due to temperature and atmospheric pressure changes and gas coming out of solution in the water. To correct, first try opening the 2-liter bottle and releasing the pressure. If this doesn't work, remove the diver and readjust the water level as in step 1.
- Try not to leave the rubber squid in the water for a long period of time because it may start to deteriorate.
- If you decide to remove the rubber squid from the pipette, put a few drops of oil on the pipette before replacing. This will allow it to slide on easily and will help make a tight seal so that water doesn't get underneath.

RELATED PRODUCTS:

Arbor Scientific also sells individual **Cartesian Divers** (P1-2000) dressed up like a colorful squid, complete with tentacles!

BIBLIOGRAPHY:

Conceptual Physics by Paul G. Hewitt. Pearson Education, Inc. pp.270-292.