Build Your Own Cartesian Diver from a Pen

A Cartesian Diver is a toy based on scientific principles—a toy you can make yourself using things found around the house. The Cartesian Diver sinks or floats when gas pressure (and volume) change inside the diver. A Cartesian Diver can be made using any object that contains air, can be compressed to reduce the volume of air, and can have ballast attached. (Ballast is weight in addition to the weight of the diver itself.) Items from which a diver can be made include an eye dropper, an unopened ketchup, mustard, or mayo pack that floats in water, a balloon minimally filled with air, a pen with the ink cartridge removed, and a bent soda straw with bobby-pin or paperclip as ballast.

This Cartesian-Diver activity provides directions for making a diver from a pen with the ink cartridge removed. The ICE Virtual Chem Camp website has alternative Cartesian-Diver activities if you don't have the materials for this one.

Materials

- A 1-L (quart-sized) or 2-L (half gallon) plastic bottle with a cap, such as one used for soda. You need to be able to see the diver inside this bottle, so try to find one that is clear and colorless and remove the labels.
- A ball-point pen with a plastic outer shell that can be made watertight after the ink cartridge has been removed. A Bic Cristal pen is ideal for the activity.
- A thumbtack or dab of glue (needed to close the small hole roughly ½ way up the side of the Bic Cristal pen and for attaching ballast weights).
- Washers of various sizes, to be used as ballast weights. Ballast weights must be small enough to fit through the hole at the top of the plastic bottle.

This activity is courtesy of ICE, the Institute for Chemical Education at UW-Madison's Chemistry Department. This activity was adapted from the ACS Celebrating Chemistry Cartesian Diver Activity found here:
https://www.acs.org/content/dam/acsorg/education/resources/k-8/science-activities/solidsliquidsgases/gases/cartesian-diver-science-for-kids.pdf

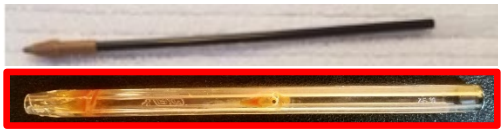
- Paperclips and/or safety pins that can fit through the top of the bottle, to be used as ballast weights.
- A clear plastic cup that is tall enough to contain the pen (which will become the diver) when the pen is standing vertically. (A glass will work but be careful not to break it.)
- Water. (It is a good idea to do this in the kitchen because water might be spilled.)

Remove the Ink Cartridge from the Pen

1. Select a pen. The one shown here is a Bic Cristal pen, which works well for the activity.

2. After removing the cap, which is not used for the diver, grasp the tip of the ink cartridge (circled in red), twist, and pull. For some pens this is easy; for others you will need pliers to hold the ink cartridge tight enough to pull it out.

3. Your pen should now look like this, with the ink cartridge separated from the pen shell.



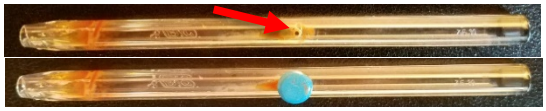
4. Use the pen shell (the clear part in the red box) as your diver. (The clear pen shell is on a dark background for visibility.)
5. Save the ink cartridge and pen cap so you can recycle them by putting the pen back together later.

Construct the Cartesian Diver

1. Fill a clear cup with water. This is your test site for the diver before you put it into the 1-L or 2-L plastic bottle.
2. Place the pen shell into the glass of water. If the pen shell floats, it can be used; if the pen shell sinks, it won't work. (Consider why!)
3. The Bic Cristal pens have a small hole in the side of the pen shell, roughly at the midpoint of the pen. Plug the small hole with a thumbtack and retest the buoyancy of the pen. The pen should still float. If the pen sinks, try to find a lighter tack to plug the hole.

Steps 1, 2 and 4.

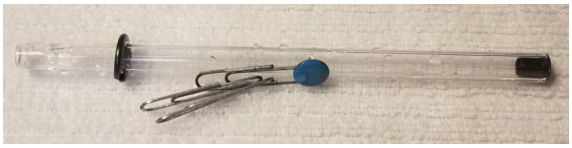
4. To make sure that it is still buoyant, test the pen in the cup of water after plugging the hole. (The weight of the thumbtack changes the pen's buoyancy.)



Step 3. (On black background for visibility.)

This activity is courtesy of ICE, the Institute for Chemical Education at UW-Madison's Chemistry Department. This activity was adapted from the ACS Celebrating Chemistry Cartesian Diver Activity found here:
https://www.acs.org/content/dam/acsorg/education/resources/k-8/science-activities/solidsliquidsgases/gases/cartesian-diver-science-for-kids.pdf

5. Add ballast weights to the pen until the pen barely floats and is nearly vertical in the glass of water. Start by adding a washer to the bottom of the pen stem. The hole in the washer should be roughly the diameter of the pen so that the washer slips onto the pen but does not fall off. (If the washer falls off the pen stem, put a rubber band around the pen stem, beneath the washer.) It is likely that this step will take a lot of trial and error. Test a combination of washers, tacks, paperclips, and other weights.



Step 5.

6. With the ballast added, test the pen in the cup of water. The pen should just barely float in the cup of water. Notice the difference in how far above the surface of the water the pen is in the image to the right versus the image for steps 1, 2, and 4.

Step 6.

7. Make sure the labels have been removed from the 1-L or 2-L plastic bottle and fill it with water.
8. Add your Cartesian Diver to the bottle, add water until it runs over the edge of the bottle's neck, and then close the cap tightly. The bottle should be full enough that water runs down the side of the bottle as the cap is tightened.
9. Squeeze the bottle. The Cartesian Diver should sink when the bottle is squeezed and rise when you let go! (See troubleshooting on the next page if it doesn't.)

Steps 7 and 8

Step 9.

This activity is courtesy of ICE, the Institute for Chemical Education at UW-Madison's Chemistry Department. This activity was adapted from the ACS Celebrating Chemistry Cartesian Diver Activity found here:
https://www.acs.org/content/dam/acsorg/education/resources/k-8/science-activities/solidsliquidsgases/gases/cartesian-diver-science-for-kids.pdf

Troubleshooting:

- *The pen does not float when a tack is used to plug the hole...*

  Test different tacks to see which ones work and which ones do not. If the pen can float without the hole plugged but then sinks when the hole is plugged, try making the diver without plugging the hole in the side of the pen. Because the pen diver fills with water up to the unplugged hole, it contains less air and won't float as high, but if it floats you can use it without plugging.

Pen diver with hole unplugged.

- *The pen keeps sinking with ballast added…*

  Test many combinations of ballast (weights). Some pens are not very buoyant initially and may not even need added ballast. Other pens may only need a few paper clips as ballast. With the appropriate quantity of ballast the pen diver should barely float.

Pen diver with appropriate ballast.

- *The pen does not dive when you squeeze the bottle …*

  This is the most difficult part of the activity to troubleshoot. Check and make sure your bottle is filled completely and that the cap is on tightly. If these two suggestions do not solve the setback, add additional ballast to the pen. Some pens may require more ballast than the pen used in this activity. Make certain that air is not bubbling out of the diver when you squeeze the bottle. Try squeezing harder. Some bottles are made of stronger plastic than other bottles and therefore need a harder squeeze. A 2-L bottle is usually the easiest to squeeze.

This activity is courtesy of ICE, the Institute for Chemical Education at UW-Madison's Chemistry Department. This activity was adapted from the ACS Celebrating Chemistry Cartesian Diver Activity found here:
https://www.acs.org/content/dam/acsorg/education/resources/k-8/science-activities/solidsliquidsgases/gases/cartesian-diver-science-for-kids.pdf

What Happened? What Are the Scientific Principles?

- *Why does the Cartesian Diver sink when the bottle is squeezed?*
  Carefully observe the pen shell when it is floating in the water. How high is the water level inside the pen when it is floating? What occupies the space above the water inside of the pen? Now squeeze the bottle and watch the water level inside the pen shell as it sinks. What changes?

  Initially, the density of the pen shell, ballast, and the air inside is less than that of the water, so the diver floats. When the bottle is squeezed, water compresses the air pocket inside the pen. This decreases the volume of pen + ballast + air, but the mass stays the same. Thus the density of the pen + ballast + air increases and it sinks.
- *Which pens work and which ones do not?*
  Only airtight and watertight pens work for the Cartesian Diver activity! Pens that are airtight and watertight enable a pocket of air to be trapped in the shell of the pen and thus add buoyancy to the pen. Pens that do not have this feature, such as a Pilot G2, likely will not work because the pen itself is denser than water. It is the pocket of air that makes the pen shell float.
- *What kinds of experiments were needed to get the Cartesian Diver to work?*
  Trial and error is a major part of what researchers do! Researchers learn from both successes and failures in the laboratory. Even if your initial attempt to make a Cartesian Diver sinks directly to the bottom of the glass of water, you can learn something and make a better, more informed decision about how to design a diver that works. The activity is all about testing different combinations of weights and different pens. Which work, which don't, and why?
- *Why is there a hole in the side of the Bic Cristal pen?*
  Think about what would happen inside the pen if there were no hole in the side. The pen is airtight and watertight. As you use ink from the ink cartridge, the volume of ink inside the pen decreases so the volume of air must increase. What happens to the pressure of air when its volume increases? And what would this do to the pressure inside the pen? Also, air expands when it gets hotter. (That's why a hot-air balloon can fly.) Suppose the airtight pen got hotter. What would happen to the ink? If the pen were in your pocket, would you need to clean up the pocket?

This activity is courtesy of ICE, the Institute for Chemical Education at UW-Madison's Chemistry Department. This activity was adapted from the ACS Celebrating Chemistry Cartesian Diver Activity found here:
https://www.acs.org/content/dam/acsorg/education/resources/k-8/science-activities/solidsliquidsgases/gases/cartesian-diver-science-for-kids.pdf