How Does the Diver Work?

When you build a Cartesian diver, you are exploring three scientific properties of air:

1. Air has weight
2. Air occupies space
3. Air exerts pressure.

Generally speaking, an object will float in a fluid if its density is less than that of the fluid (density = mass/volume). If the object is more dense than the fluid, then the object will sink. For example, an empty bottle will float in a bathtub that is filled with water if the bottle is less dense than the water. However, as you start filling the bottle with water, its density increases and its buoyancy decreases. Eventually, the bottle will sink if it is filled too full with water.

The Cartesian diver, consisting of a plastic medicine dropper and a metal hex nut, will float or sink in the bottle of water depending on the water level in the bulb of the dropper. When pressure is applied to the outside of the bottle, water is pushed up inside the diver, and the air inside the bulb is compressed into a smaller space. Molecules of gases are more easily compressed than molecules of liquids. The more water that is inside the diver, the less buoyant it becomes and the diver sinks. When the pressure on the outside of the bottle is released, the compressed air inside the diver expands and this pushes some of the water back out of the diver. As the water level inside of the diver drops, the diver floats to the top.

Can you think of something that descends and ascends in water similar to a Cartesian diver? How about a submarine? Indeed, a Cartesian diver and a submarine work in similar ways. When the submarine is ready to dive, it takes water into tanks until its mass is enough to make the submarine sink. This increased mass caused by the water in the tanks increases the density of the submarine and it descends. When it’s time for the vessel to resurface, very high pressure air is blown into the submarine’s tanks, the water is forced out, and the submarine ascends to the surface.

Preparing the Plastic Soda Bottle

You will need to start collecting plastic soda bottles with caps. While almost any size bottle will work, the most popular sizes are 1 liter, 1.5 liter, and 2 liter bottles. Smaller children will find that the 1 and 1.5 liter bottles are easiest to squeeze. The best soda bottles are those that are clear from top to bottom so that you can see everything that is happening in the bottle.

Here’s an easy method for cleaning the plastic soda bottles:

- Rinse out the bottle using warm water.
- Remove the label by first filling the bottle with hot water and letting it sit for 1-2 minutes. The hot water will melt the glue that adheres the label to the bottle. Then, slowly peel off the label.
- There are several commercially available cleaning products that will remove the sticky glue residue from the outside of the bottle.
DIVER ACTIVITY #1:
The Standard Cartesian Diver

MATERIALS
- Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
- One pipette (plastic medicine dropper)
- One hex nut
- Scissors
- 8 ounce or larger, clear, plastic cup

ASSEMBLY STEPS
1. The standard Cartesian diver is made from a plastic medicine dropper known as a pipette and a hex nut. Screw the hex nut onto the base of the pipette as shown below. Several turns of the hex nut should be sufficient to hold it in place.

2. Cut off all but 1/4 of an inch of the pipette stem. This is the standard diver.
3. Place the diver in a cup of water, making sure that the water in the cup is 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.

4. 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.

5. 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.

HOW DOES THE DIVER WORK?

When you squeeze the bottle, the pressure on the water pushes on the pocket of air inside the pipette. You can see the level of the water in the diver rise as you squeeze the bottle. As the water level inside the diver goes up, it compresses the air above it into a smaller space. This demonstrates that gases are considerably more compressible than liquids.

As the water level rises in the diver, it becomes less buoyant and the diver sinks. As you release the pressure on the bottle, the compressed air expands and forces the water back out. The diver floats to the top of the bottle because now it is more buoyant.

SOLUTIONS:

WHEN I SQUEEZE THE BOTTLE, THE DIVER WILL NOT SINK?

It is very important to initially adjust the diver so that it just barely floats in the cup of water. If the diver requires a very strong squeeze to make it sink, then there is not enough water in the pipette. Remove the diver from the bottle and re-adjust the water level so that the diver just barely floats. (Hint: The diver should be about half full of water.)

THE DIVER STAYS ON THE BOTTOM OF THE BOTTLE. WHY?

If the diver sinks to the bottom of the bottle on its own, there is too much water in the pipette. Remove the diver from the bottle and adjust the water level so that the pipette is about half full. Test to make sure that the diver just barely floats in the cup of water before placing it back in the soda bottle. (Conserve water! Make a wire hook to fish the sunken diver out of the bottle instead of dumping the water down the drain.)

If your diver is resting on the bottom of the bottle, read through the next activity before you remove the diver from the bottle.
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 variation 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? Novelty stores will sometimes sell very ornate thermometers made out of blown glass ampules that work on the same principle. Save yourself a few hundred dollars and build a "Cartesian thermometer" out of plastic pipettes!
DIVER ACTIVITY #3: Making a Sealed Cartesian Diver

MATERIALS
- Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
- One pipette
- One hex nut
- Scissors
- Hot-melt glue gun (available at arts & crafts stores)
- 8 ounce or larger, clear, plastic cup
- OR...USE THE DIVER THAT YOU MADE IN ACTIVITY #1

SAFETY NOTE
Be very careful when using the hot-melt glue gun because the gun and the melted glue are both very hot. Use care when handling this equipment. Adult supervision is required.

Let's review how the standard Cartesian diver works: When you squeeze the plastic soda bottle, the pocket of air inside the diver is compressed allowing water to be forced up inside the pipette. The diver sinks because the increased amount of water in the pipette increases the mass of the diver, which also increases the density of the diver. Would the diver still work if the opening of the pipette was sealed shut and no water could be forced inside the pipette? Wait to answer the question until you have completed this activity.

ASSEMBLY STEPS
1. You can use the standard diver that you made in Activity #1 or you can make a new diver. If you are making a new diver, screw a hex nut onto the base a pipette. Several turns of the hex nut should be sufficient to hold it in place. Cut off all but 1/4 of an inch of the pipette stem.

2. Place the diver in the cup of water, making sure that the water in the cup is at least four inches deep. Squeeze the pipette to draw water up into the bulb. Continue adding or subtracting water until you get the diver to just barely float in the cup of water. (The pipette should be about half full of water.)

3. Remove the diver from the cup of water, being careful not to squeeze out any of the water. Turn the diver upside down so that the opening of the stem is pointing up. There may be a drop or two of water trapped in the stem of the pipette. Hold the opening of the pipette up to your mouth and blow into the stem to force the water out.

4. Keeping the diver inverted, cover the opening of the pipette with one drop of hot-melt glue. If you slightly squeeze the pipette and hold the squeeze while you are putting the glue on the opening, the glue will be drawn up into the stem when you release the squeeze. Place the diver in the cup of water so that the glue can cool down. Note: The diver should float in the cup of water -- if the diver sinks, you will have to remove the glue and re-adjust the water level.
5. If you sealed the diver properly, you should be able to squeeze the pipette and none of the water will leak out. This is your sealed Cartesian diver.

6. Place the sealed diver in the bottle of water and replace the cap. Make sure the soda bottle is filled completely to the brim with water. Squeeze the bottle and watch what happens. Does the diver sink? Why?

HOW DOES THE SEALED DIVER WORK?

This version of the Cartesian diver has been known to fool many science teachers. If water cannot enter the pipette, how will the mass change to make the diver sink? The reason the diver sinks when you squeeze the bottle is because the pressure exerted on the water collapses the sides of the pipette. Squeeze the bottle and watch how the sides of the pipette cave inward. This decreases the volume of the diver. Remember that density = mass/volume. The decrease in volume increases the density and causes the diver to sink. TRICKY!

MATERIALS

- Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
- Five pipettes
- Five hex nuts
- Scissors
- Permanent felt tip marker
- 8 ounce or larger, clear, plastic cup
- Special soda bottle pump (found in the kit)

Fool your friends into thinking that you have a bottle of trained Cartesian divers with this clever activity while at the same time learning 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.

ASSEMBLY STEPS

1. Screw the hex nut onto the base of the pipette. Several turns of the hex nut should be sufficient to hold it in place. Cut off all but 1/4 of an inch of the pipette stem. Do this with all five pipettes.

2. Number the divers “1” through “5” using a permanent ink marker.
3. 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.

4. 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 water and diver #5 should have the least amount of water in its bulb.

5. 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.

**HAVING A LITTLE COUNTING FUN**

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 quite a bit of fun with this just in the way you present it to your friends.

"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?
**DIVER ACTIVITY #5:**

**SQUIDY™**

**MATERIALS**

- You will find a SQUIDY™ diver packaged separately in your kit.

Watch closely as a mysterious squid-like creature sinks and swims inside the plastic soda bottle. What is it? It's SQUIDY™!

SQUIDY is a novelty diver that I created in 1991 after encountering a problem during a taping of a science segment on NBC's NEWS FOR KIDS - a Saturday morning children's television program. The theme of this particular week's segment was building Cartesian divers. Unfortunately, the television director complained that she could not easily see the clear plastic diver ascending and descending in the bottle. I needed to find a way to make the diver more visible to the television cameras, so I set out in search of a disguise for the diver.

SQUIDY is actually a specially designed rubber cap that fits snugly over the pipette. You will also notice that the pipette and hex nut are different than the others in the kit. The idea for SQUIDY came from a trip that I took to the local tackle shop. Unfortunately, I could not find a fishing lure that would easily fit over the bulb of the pipette. So, I used a squid-like lure as a prototype and had a new rubber cap designed and manufactured to fit over the pipette. The whole idea seems a little silly, but SQUIDY never fails to capture a child's attention.

Since the rubber squid hides the inner workings of the Cartesian diver, challenge your friends to squeeze the bottle and figure out how the diving squid works. Teachers are using SQUIDY as a way to stimulate scientific inquiry in their classrooms. Students are challenged to explain in scientific terms how the squid floats and sinks in the bottle. It's a great way to get children turned on to Cartesian divers.

All of the materials and directions for assembling SQUIDY are contained within the kit.

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**DIVER ACTIVITY #6:**

**HOOK™**

**MATERIALS**

- Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
- Two pipettes
- Two hex nuts
- One red wire (10 inches) and one blue wire (6 inches)
- Scissors
- 12 ounce or larger, clear, plastic cup

You're bound to get "hooked" on Cartesian divers after you make HOOK™. For this activity you will construct two divers: A wire is attached to one diver in the shape of a HOOK, and the other diver, called the SINKER, has a loop of wire extending over the top. The object of the game is to HOOK the SINKER in the bottle.

**ASSEMBLY STEPS**

1. Screw one hex nut onto the base of each pipette. Several turns of the hex nut should be sufficient to hold it in place. Cut off all but 1/4 of an inch of each pipette stem.

2. Wrap one end of the short piece of blue wire around the base of one of the divers several times. Form the other end into a hook as shown below. This is the HOOK.
3. 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 as shown to the right. **This is the Sinker.**

4. 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 HOOK so that it just barely floats. Adjust the water level in the SINKER so that it just barely sinks.

5. Carefully transfer the pipettes 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.

**Here's the challenge:** HOOK the SINKER by squeezing and tipping the bottle from side to side, trying to maneuver the HOOK around the loop of the SINKER. Be careful... once you start playing with this science toy you won't be able to put it down!
DIVER ACTIVITY #8: Cartesian Helicopter

MATERIALS
- Plastic soda bottle with a cap (1, 1.5, or 2 liter bottle)
- One pipette
- One hex nut
- Cartesian Helicopter template (plastic sheet with circles)
- Scissors
- Hole punch
- 8 ounce or larger, clear, plastic cup

Can you guess what the Cartesian Helicopter does? The diver has a plastic propeller attached to its base. When you squeeze the bottle, the diver spins as it rises and falls.

ASSEMBLY STEPS

1. You will find a Cartesian Helicopter template in the Super Diver Kit. It's a plastic sheet with six printed circles that look like this:

2. Cut out one of the circles. The template includes enough circles to make six Cartesian Helicopters.

3. Punch out the small center circle with a hole punch.

4. There are six lines that extend outward from the center circle. Cut along these six lines, but stop when you get to the printed circle. Do not cut all of the way through to the punched out circle.

5. Notice that the letters "U" and "D" are printed on the corners of the flaps. Fold the corners of the flaps marked with a "U" up and fold down the corners marked with the letter "D". You should end up with a symmetrical looking propeller.

6. Push the stem of the pipette through the punched out hole in the center of the propeller. Secure the propeller in place with a hex nut. Several turns of the hex nut should be sufficient. Cut off all but 1/4 of an inch of the stem.

7. Place the Cartesian Helicopter in the cup of water. Adjust the water level in the diver so that it barely floats. Carefully transfer the diver to the soda bottle that is full to the brim with water. Be careful not to accidentally squeeze out any of the water in the pipette when you transfer it to the soda bottle. Screw on the cap.
1. Screw the nut onto the end of the bulb as shown. Several turns of the nut should be sufficient. See figure 1.

2. Cut off all but 1/4 of an inch of the stem. Wrap one end of the short piece of wire around the stem of the bulb several times. Form the other end into a hook as shown. This is the basic Cartesian Diver called the HOOK. See figure 1.

3. Place the HOOK in a tall glass of water. It floats because air is trapped in the bulb. Squeeze the bulb and fill it a little less than 1/4 full with water. The HOOK should just barely float in the glass of water. Too much water in the bulb will cause the HOOK to sink. See figure 3.

4. Building the Sinker: Repeat step 1 using the second bulb and nut, and cut off all but 1/4 of an inch of the stem. Wrap one end of the long piece of wire around the stem, form a large loop over the bulb, and wrap the other end of the wire around the stem as shown. See figure 4.

5. Fill the Sinker half full with water. The Sinker should just barely sink to the bottom of the glass of water. Place the Sinker in a clean soda bottle that is full of water (it's fine to bend the wire). The Sinker should sink to the bottom.

6. Place the HOOK in the soda bottle being careful not to squeeze out any of the water in the bulb. Make sure the bottle is filled to the brim with water. The diver will not function properly if there is any air in the bottle. Screw on the cap and squeeze the sides of the bottle. The HOOK will dive to the bottom. The object of the game is to HOOK the Sinker. If the HOOK does not float, remove it and squeeze some of the water out of the bulb. As an option, you may want to seal the air and water inside the divers using cool melt glue.

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**Try These Fun Ideas!**

1. Bend the wires into new shapes to make the game more challenging.

2. Rapidly tap the side of the bottle to make the Sinker climb up to meet the HOOK. How does this work?

3. After properly adjusting the water level in both the HOOK and Sinker, seal the open end of the diver with a drop of hot-melt glue. Observe how the sealed diver works.

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**Steve Spangler SCIENCE**
The Cartesian Diver is an experiment in the properties of air: Air occupies space, has weight, and exerts pressure. The Cartesian diver, consisting of a plastic medicine dropper and a metal nut, will float or sink in the bottle of water depending on the water level in the bulb of the dropper. When pressure is applied to the outside of the bottle, the water level inside of the diver rises because the pressure squeezes the air into a smaller space. The more water that is inside the diver, the less buoyant it becomes and the diver sinks. When the pressure on the outside of the bottle is released, the water level inside of the diver drops and the diver floats to the top.

The Cartesian diver is a classic science experiment named after René Descartes (1596–1650), a French scientist and philosopher who used the diver to demonstrate the laws of buoyancy, or the tendency of an object to float in a fluid.