

### **How Cartesian Divers Work:**

Take a submerged test tube, mouth-down, and bubble in just enough air to get it to float. You have just made a cartesian diver! To see it in action, it must be transferred into a liquid-filled, compressible container, such as a plastic soda bottle, which in turn must be sealed shut. We know from our study of gases (specifically, Boyle's Law) that the volume of a gas sample varies inversely with the pressure acting on the sample. We know also that liquids, which have molecules much more tightly packed together, are more or less incompressible. Thus any compression of the bottle causes the air pocket inside the test tube to be compressed, and as that air pocket's volume decreases, it reaches a point where it is too small to hold up the test tube, and so the diver sinks. As the squeeze is released, the pocket resumes its original volume, and up to the surface the diver rises.

Aside from tying in so beautifully with Boyle's Law, cartesian divers also serve as a great density-related activity. Best of all, there are two (perhaps more) equally valid ways to explain how they work.

For example, let us consider the diver to be the combination of the test tube and the trapped air pocket inside, but not any of the water inside or outside the test tube. If the diver floats, then this combination must have a density less than that of the water (1.00 g/mL). As the bottle is squeezed, the diver's mass (that is, the mass of the test tube and of the air pocket inside) stays constant. Indeed, since no atoms enter or leave the system, the mass must remain constant (the Law of Conservation of Matter). The volume, however, decreases substantially as the air pocket is compressed. Since density is mass/volume, if the mass stays constant while the volume decreases, the density must increase, and when it surpasses that of the surrounding water, the diver descends.

Another way to explain this phenomenon is to assume the diver to be the test tube and its contents: the trapped air pocket *and the water inside*. As above, if the diver floats, then this combination must have a density less than that of the water. As the bottle is squeezed, the diver's volume remains constant, but its mass increases as more water has been added to the test tube. Since density is mass/volume, if the mass increases while the volume stays constant, then the density must increase, and when it surpasses that of the surrounding water, the diver descends.

Either way you look at it, cartesian divers serve as wonderful hands-on applications of many of the concepts covered in a typical physical science course.

### **Where Cartesian Divers Come From:**

Although named after the 17th century French philosopher and mathematician, Rene Descartes (1596-1650), there is very little evidence linking Descartes to the divers.

<http://www.ed.uiuc.edu/courses/CI241-science-Sp95/resources/philoToy/philoToy.html>

Instead, the first mention of them is found in a short pamphlet written by Raffaello Maggiotti, a student of Galileo in 1648. They also go by the names: "Cartesian devils" and "bottle imps."

## What Works and What Doesn't:

Once students understand the concept of how a cartesian diver works, challenge them to construct working divers out of novel and unusual materials. They might discover that...

\* A packet of soy sauce works fine. The soy sauce has enough salt in it to make it significantly more dense than the water, but the air pocket inside acts to buoy the packet up. Grab a bunch of soy sauce packets and throw them in a basin of water. There is enough variation in the manufacturing of these packets that some will sink, some will float quite high and some will just barely float. Place one that just barely floats in a bottle of water and you've got the simplest possible cartesian diver.

\* A small nail pushed into a candle might float upright like a diver, but it cannot function like one. Candle wax does not float because it has small air pockets inside; it floats because wax is less dense than water. Solids like wax are virtually incompressible, and thus they cannot be used for cartesian divers. There must be one or more air pockets inside that can be compressed by the squeeze of the bottle.

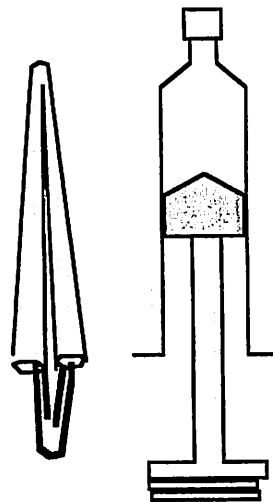
\* A small nail pushed into a piece of styrofoam works well. Insert a nail or screw or tack part way into, for example, a styrofoam packing pellet. Place it in water: it should float quite easily. (If it sinks, find a smaller nail or a bigger pellet!) Now start breaking off small pieces of the pellet until you have something that just barely floats. Transfer it into the bottle of water, and you are good to go. Using a piece of styrofoam cut from a styrofoam cup works too, but it is much less responsive, since the foam has already been substantially compressed in the molding of the cup.

\* A small water-filled glass vial, sealed with a small air bubble inside, might barely float, but it cannot work as a diver. Although it does have the requisite air pocket, the external pressure changes are blocked by the rigid walls of the vial and so they cannot affect the volume of the air pocket. Technically, glass is not completely rigid: it does have some give (**Glass Bottle Divers**). Still, there is not enough give to make for a viable cartesian diver.

\* A plastic straw bent in half and held bent by a large paper clip can work as a fine diver (near right). Either add extra paper clips or cut down the straw to make something that just barely floats.

\* A dime or two glued to a sealed plastic syringe can work quite nicely as a diver. Catheter syringes have air tight caps that can be attached. Either squeeze out air (or draw in water) or add more ballast (coins) to adjust the density until it just barely floats (far right). The nice thing about these divers is that the squeeze of the bottle pushes in the syringe plunger, making the volume change of the air pocket quite visible.

\* A **wadded-up piece of aluminum foil** works well... for a while. Start with a 15 cm x 15 cm sheet of heavy duty foil and wad it up into a ball. The aluminum is considerably



denser than the water (2.70 g/mL compared to 1.00 g/mL), but the air pockets trapped within the ball will act to buoy it up. In fact, they buoy it up too well: simply wadding the foil by hand will make for a ball that is far too buoyant. A pair of pliers or a small hammer is needed to compress this ball to a density that will just barely float. When transferred to a water-filled bottle and squeezed, the ball will dive quite well. This can be used as the basketball in an **Underwater Hoops** set up. The problem is that the air pockets do not all open downward into the water. As such, small air bubbles tend to leak out. Eventually, the ball sinks to the bottom of the bottle and is useless as a cartesian diver.

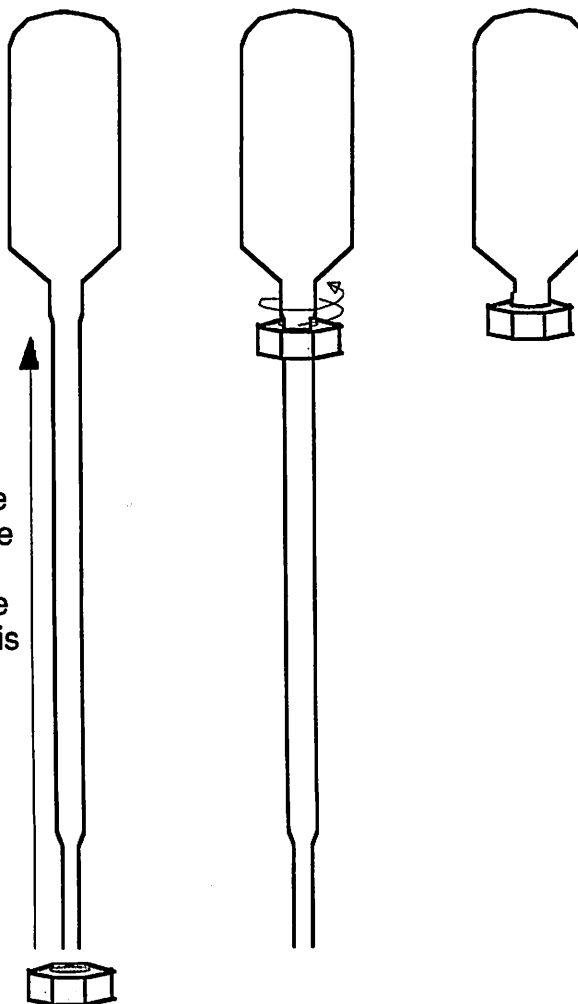
\* A regular eye dropper works well. In fact, this is what many people associate with cartesian divers. The glass portion acts as the weight (ballast) to hold the diver upright, and the air trapped inside the rubber bulb hold it up. The density may be fine-tuned by squeezing out just enough air from the bulb to make the dropper just barely float.

\* A plastic eyedropper (disposable pipet) will not work, unless it has some added weight. For this a small hex nut works perfectly. With enough hunting around, one can find a hex nut that just fits the stem or neck of the pipet. Stainless-steel hex nuts are best to avoid rust and corrosion. This simple, inexpensive, but handsome **Pipet Diver** design is, of course, the basis for this entire DVD. The large bulb provides for a large air pocket, but it also serves as a blank canvas for attaching arms and legs, or mask and snorkel or fins and teeth... The possibilities are truly unlimited.

### Pipet Diver:

Thread a 1/4" stainless steel hex nut over the stem of a graduated plastic pipet. When it reaches the flared "collar," screw the hex nut on, using a twisting-pushing motion (It need not go all the way onto the collar -- just enough to hold it in place.) Snip off the protruding part of the stem, and the construction is complete. It will not work as a diver, however, until its density is adjusted. (**Fine Tuning Density**)

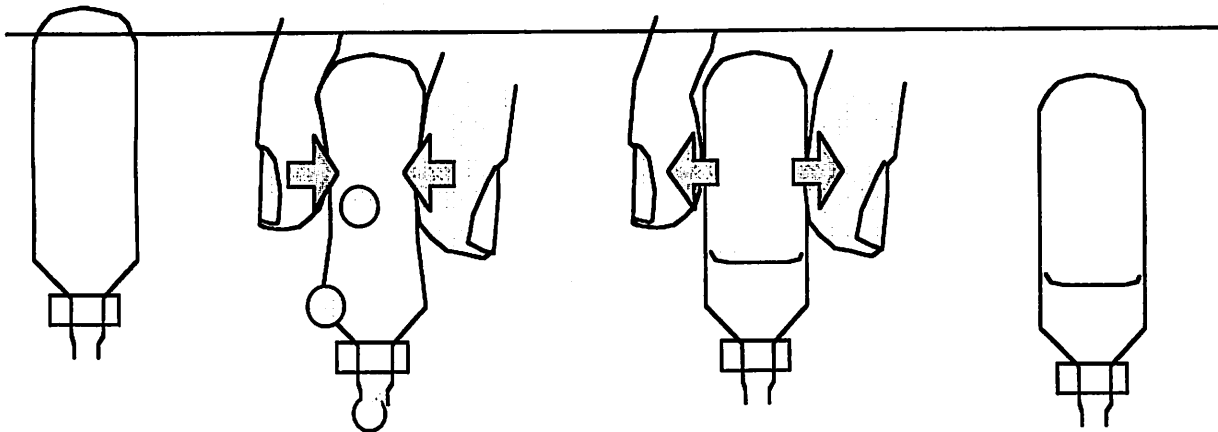
Actually, a hex nut is not required: any dense weight will work. For the **Micro-Diver** and the **Diver Inside a Diver**, copper wire wrapped around the collar of the pipet serves the same purpose. With the exception of a weight that is too massive, generally speaking, the more massive the weight, the bigger the air pocket needed to support it, and the bigger the air pocket, the more responsive the diver is to pressure changes.



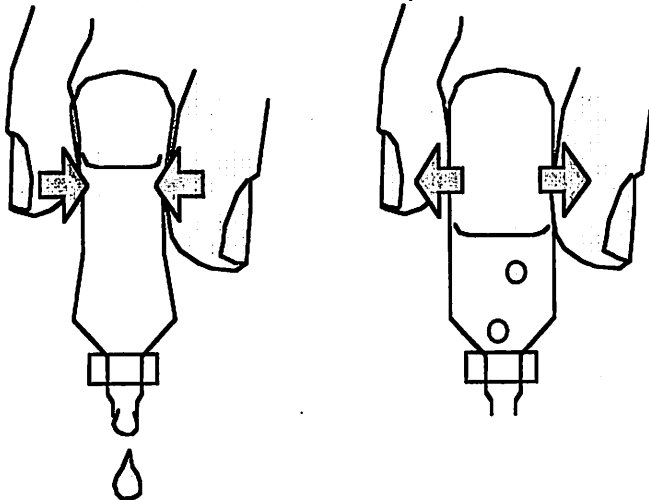
## Fine Tuning Density

Once a diver is constructed, its density must be adjusted to make it just barely less dense than the water in which it is placed. (Note: If **Appendages** or other things are to be attached to the diver, do not adjust the density until you are all finished.)

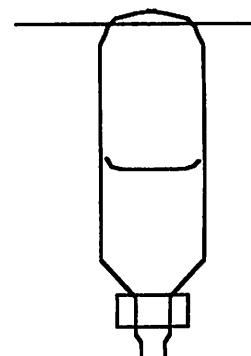
It is easiest to adjust the density in a "testing tank" -- a large wide-mouth container such as a 1000 mL beaker or a 2-L plastic soda bottle with the top cut off. Fill this container 3/4 full of water (If you fill it up too full, you will have it spill out whenever you reach your hand into it.) Place the diver in the "testing tank." Unless it has some fairly heavy attachments, it should float rather high out of the water. Keeping the diver in the tank, squeeze out a few bubbles of air from the the pipet bulb, then release the squeeze to draw water up into the diver. By replacing air with water, you have just increased the diver's density. Check to see whether or not it still floats.



If it still floats rather high, repeat the process above, squeezing out a little few more bubbles, letting in a little additional water and then checking the buoyancy again. If instead, the diver sinks, reverse the process: lift the diver out of the tank, squeeze out a few drops of water, and release the squeeze to draw in a few bubbles of air.



Then, again return the diver to the tank to check its buoyancy. The goal is to fine tune the density to the point where the diver floats with only a 2-3 mm of its bulb protruding above the water level (as shown at right).\* This may take a bit of practice back and forth the first time, but after a few attempts, adjusting the density will become second nature.



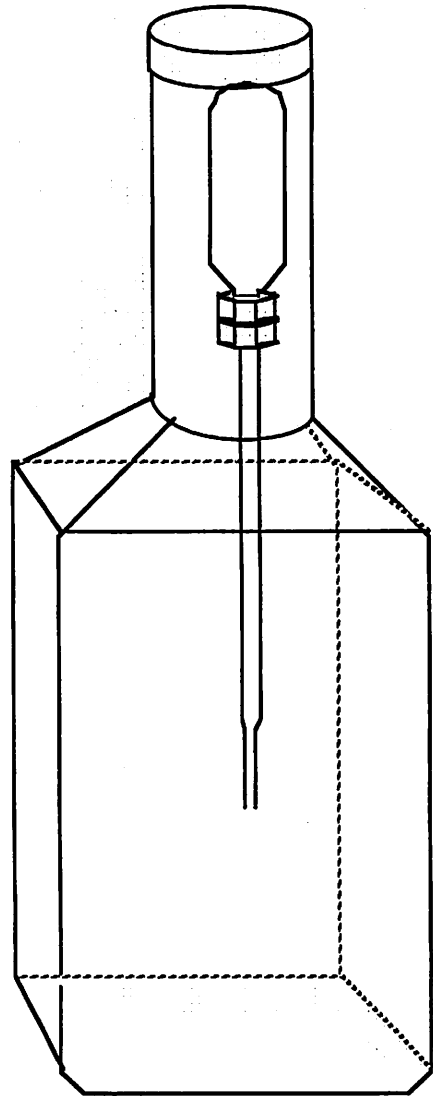
Note: Sometimes squeezing the diver is not an option: there may be appendages that might get broken off, or there may be a beautifully drawn face that shouldn't get smudged... In these situations, rather than squeeze the diver, turn it upside down and use a thin stem pipet to add water to or remove water from the diver.

\*Of course, if you want to make a diver that is tough to sink, then keep the density well below that of water. This can be used to make **Counting Divers** or **Strength Testing Divers**.

### What about the bottle?

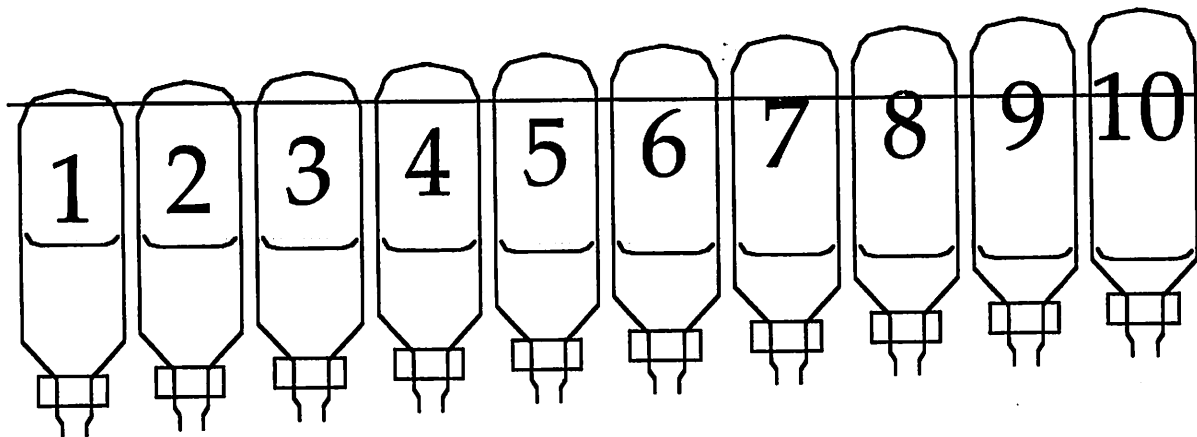
Does any container work? Doesn't it have to be flexible? In the days before plastic soda bottles, cartesian divers were placed in tall glass cylinders, filled with water and covered with some flexible membrane tied tightly over the top. Rather than squeezing the container, the membrane on top was simply pushed down. A variation on that setup is to use a rubber stopper on a glass wine bottle.

Although the stopper, firmly inserted, may not appear to move when being pressed down, it does move enough to sink a diver, provided the diver is set sensitive enough (**Fine Tuning Density**). But can the glass bottle itself be squeezed with enough force to sink a diver? Even though we think of it as being completely rigid, it turns out that glass is somewhat flexible, and a glass bottle can be squeezed enough to sink a *very* sensitive diver. It is best to use a squared off bottle -- the kind gin or tequila is often sold in (Be sure to remove the label -- so the students don't get the wrong idea!). A round bottle would work too, theoretically, but it might require more force than is humanly possible! As mentioned above (**Pipet Diver**), the more massive the weight, the bigger the air pocket needed to support it, and the bigger the air pocket, the more responsive the diver is to pressure changes. With this in mind, try placing two hex nuts on the same pipet, and do not cut off the pipet. This set up should just barely float as is. If needed add a tiny bit of water. If it sinks, remove one hex nut and wrap enough wire around the collar to have the diver just barely float. An added benefit of this set up is that even the slightest compression of the air pocket is visible in the narrow stem. Also, since the diver is so long, it does not have as much latitude to move up and down. This is good, for a diver that is set this sensitive would otherwise keep getting stuck on the bottom due to the extra hydrostatic pressure as discussed in **The Fickle Diver**.



### Counting Divers:

Most students will understand right away how to make ten divers (numbered #1-#10) dive in order. Just leave more and more air in each successive diver. Although this is easy in theory, in practice it can be a real challenge. One way might involve counting the bubbles that are expelled while you are adjust the densities (**Fine Tuning Density**) of the ten divers. #1 might have twenty bubbles squeezed out, #2 might only have eighteen bubbles squeezed, and so forth. Variations in bubble size, however, can present problems with this technique. Another way to accomplish this task might involve having them float at different levels which can be measured with a ruler or simply eyeballed as shown below:



Perhaps the easiest way is just to make a whole series of divers of a variety of densities, put them in the bottle, squeeze, and note the order that they descend. Then fish them out and put the numbers 1-10 on them after the fact, as it were!

#### Variations:

Rather than have the divers count numbers, have them spell out a word or phrase, or have each one show a word to complete a sentence, or perhaps tell a joke, as shown in the video.

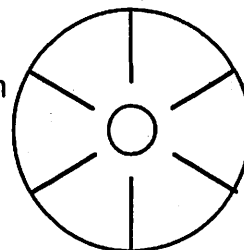
### **Strength Testing Divers**

Construct a series of divers as described in **Counting Divers**, but have each diver bearing a different strength rating: "wimp," "mama's boy," "showing potential," "hunk," "stud muffin." Students seem to get a real kick out of seeing how they rate.

## Whirligig Diver:

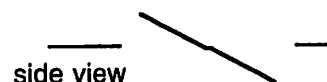
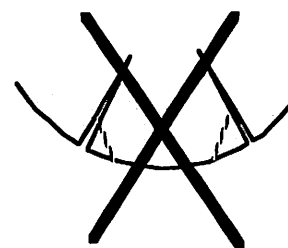
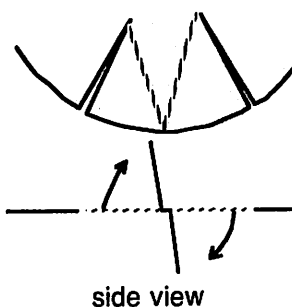
Note: The plastic used to make the propeller should be of a type that cuts easily but does not tear, and that maintains a crease well.

1) Cut out a circle of plastic 2-3 cm in diameter and use a hole punch to make a hole in the center (a standard hole punch makes a hole just large enough to fit over the neck of the pipet).



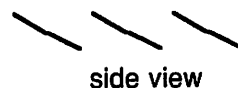
2) Make 4-8 evenly spaced radial incisions extending from the edge of the circle to within 2-3 mm of the center hole. The circle will now be like a flat flower with 4-8 petals.

3) Take one of the petals and bend one corner up toward you and the other corner down away from you. To get the most rotation out of the propeller, it is best to use as much of each corner as possible, so that the bends effectively meet in the middle as shown at right. Using only the very tips of each corner leads to wasted area and poor rotation.



4) Now open up the creases you just made and press the entire petal between your thumb and forefinger to flatten out the bends and make them into a gently sloped propeller blade as shown at right.\*  
\*A 30-45 degree angle works well: the optimum angle for these propeller blades is open for investigation.

5) Repeat steps 3 and 4 with the rest of the petals, making sure that each propeller blade slopes the same direction. (You certainly do not want the blades working against one another!)



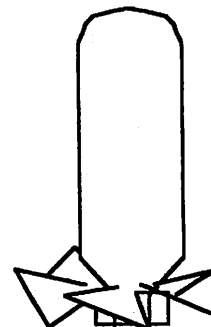
6. Now slide the completed propeller over the stem of a **Pipet Diver** and screw the hex nut on to hold the propeller in place.

### Additional notes and ideas:

- The propeller can be made significantly bigger than the opening that it must fit through. Generally the plastic will be flexible and resilient enough squeeze through the mouth of the bottle and then spring back into shape once inside.

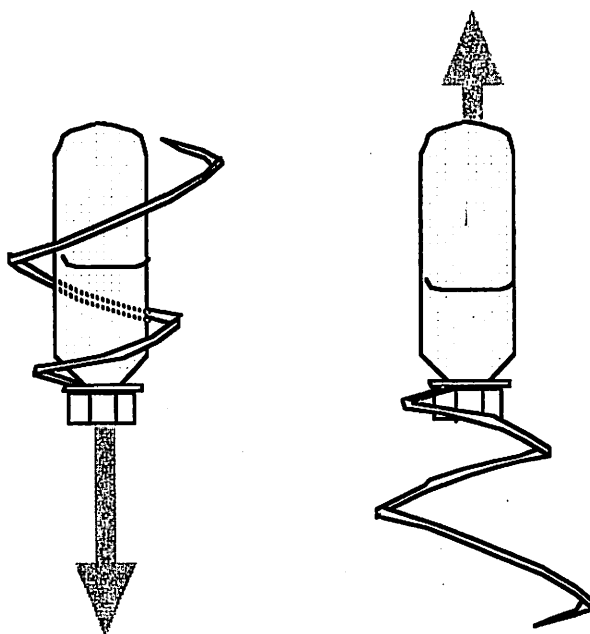
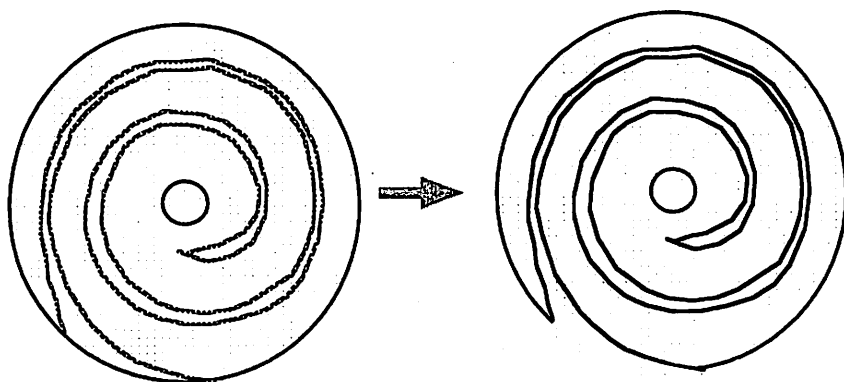
- Rather than place the propeller on the bottom of the diver, use hot melt glue to attach it on top.

- Challenge the students to build a helicopter diver: one in which the propeller turns,



but the diver itself does not. (This would involve some type of pivot connection).

•The whirligig diver spins one way when diving and then back the other way when returning back to the top. Challenge the students to construct a diver that keeps spinning in the same direction whether it's diving or ascending. One solution to this challenge would involve a flexible screw type propeller. Cut out the spiral pattern shown below and slide it over the pipet stem. As it dives, the water will push it upward into a spiral that rotates the diver clockwise (as viewed from above), and then as it ascends, the spiral will invert itself. Since both the spiral and the flow of water are reversed, the diver will again spin clockwise as it rises.



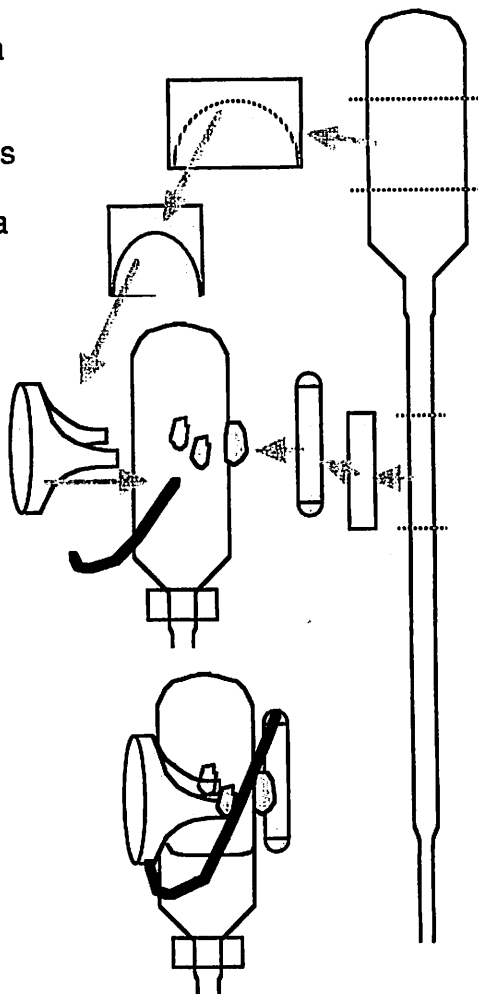
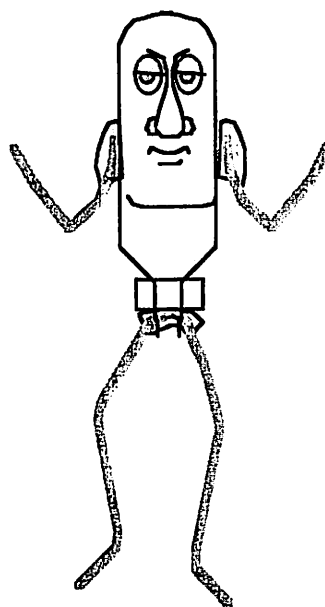
## Appendages:

Appendages can really be constructed out of a wide variety of materials: wire, plastic, string, foam, coffee stirrers, pipe cleaners. Keep in mind that any appendage will alter the density of the diver. For this reason, it is always best to adjust the density (**Fine Tuning Density**) in the testing tank after all appendages have been attached. For bent arms and legs, insulated hook-up wire works well (24 gauge, for example; solid wire holds its shape better than stranded). For attaching arms, it is most effective to place a drop of hot melt glue on the pipet and then lay the end of the wire in the glue and roll it around to coat all sides as shown at right. Simply placing the tip of the wire in the glue drop makes for a rather weak connection. Legs are best made from one continuous length of wire glued in the middle to the portion of the pipet that protrudes past the hex nut. Again, roll the wire back and forth to ensure a good connection:

For hats, shoes, flippers or fish fins, colorful pieces craft foam work well. Avoid using too much foam, though, since the added buoyancy can make for a diver that is practically unsinkable.

Diving masks and scuba tanks can be cut from the same type of plastic pipets that the divers themselves are made from. For the mask, cut a 12-15 mm cylindrical section out of the bulb of the pipet, hold it flat and make a large semicircular cut across it as shown at right. This mask can be attached to a **Pipet Diver** by placing a small drop of hot melt glue on either side of the bulb and sliding the straps of the mask over them. (Hint: Be sure to make the mask jut out no more than 2-3 mm: if it protrudes too much, the diver will be difficult to pass through the mouth of the bottle.)

A scuba tank can be cut from a section of the pipet stem. Use small drops of glue to seal each end, then attach the tank to the back side of the diver. A short length of wire can be used for the hose to connect the mouth of the diver to the tank as shown.



**Octopus Diver:**

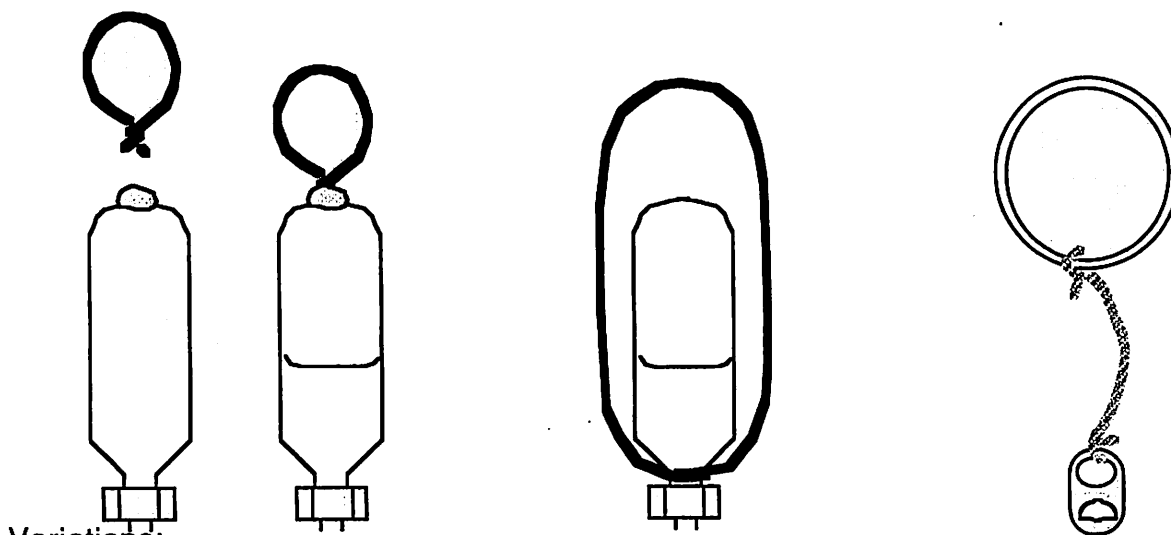
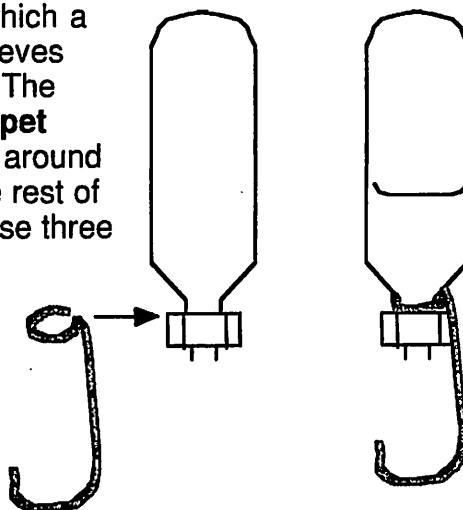
There really is nothing to this diver: it is just a rubber fishing lure slipped over a **Pipet Diver**.

### Hook and Treasure:

A very challenging game can be constructed in which a diver, equipped with a hook, dives down and retrieves some object (treasure) off the bottom of the bottle. The hook is rather easy to construct. Simply build a **Pipet Diver** and wrap the end of a 5-7 cm length of wire around the collar just above the hex nut. Then fashion the rest of the wire into a hook as shown at right. If desired, use three wires and fashion them into a treble hook (this certainly makes the task easier!).

The treasure can also be fashioned out of a **Pipet Diver** and 5-7 cm length of wire, but it requires a drop of hot-melt glue. Twist the ends of the wire together to make an open loop -- the smaller the loop, the more challenging the task.

Place a drop of glue on the top of the diver and insert the loop as shown at left below. Roll the loop back and forth to get good contact with the glue. If hot melt glue is not available, just use a longer length of wire, wrap it around the collar of the diver and make it into a large handle as shown below, middle. Or, for an even easier and more economical treasure simply use a 8-10 cm length of kite string or thread, tie one end to the plastic cap ring that can be pried off the top of the 2-L soda bottle (use a flat head screwdriver), and tie the other end to the pull tab off an aluminum soda can. This assembly is shown at right below. The plastic ring floats, the pull tab sinks, and together they barely sink -- making the assembly ideal for a treasure. (Note: the treasure does not need to function as a diver: it just needs to sink and have a loop or handle that remains upright and accessible to the hook.) The pipet treasures depicted below need to have the densities adjusted (**Fine-Tuning Density**) so that they just barely sink. If they are too dense, the hook diver will not be able to lift them to the surface.



Variations:

1) Make several treasures with different sized loops, and write different point values on each one: large loop = 50 pts, medium loop = 100 pts, small loop = 200 pts. Perhaps make a large hook hanging down from the top of the bottle (hot melt glued to the inside of the cap). The object is to retrieve as many treasures as you can and deposit them on the large hook within a five minute time period. Your score is the sum of the points you have hung on the big hook.

2) Make two treasures, one regular and one with both a loop on top and a hook on bottom: the diver must pick up the hook treasure first and then use that to pick up the second treasure.

3) Make three divers: one colored blue, one yellow and one red, and make three corresponding treasures. This can be done with colored permanent markers or by making **Closed Divers** with different colored water inside. The object is to retrieve each treasure with its matching diver. Once one is hooked, however, be careful not to break them apart while trying to hook the next one!

4) Come up with a cute theme: perhaps the diver is made-up to look like a cat (with the hook being her tail, and the treasure is a mouse she is trying to catch (perhaps with two hoops on top to serve as ears).

5) Rather than using hooks and loops, try gluing small magnets to the divers. This should prove much easier! Or perhaps try velcro!

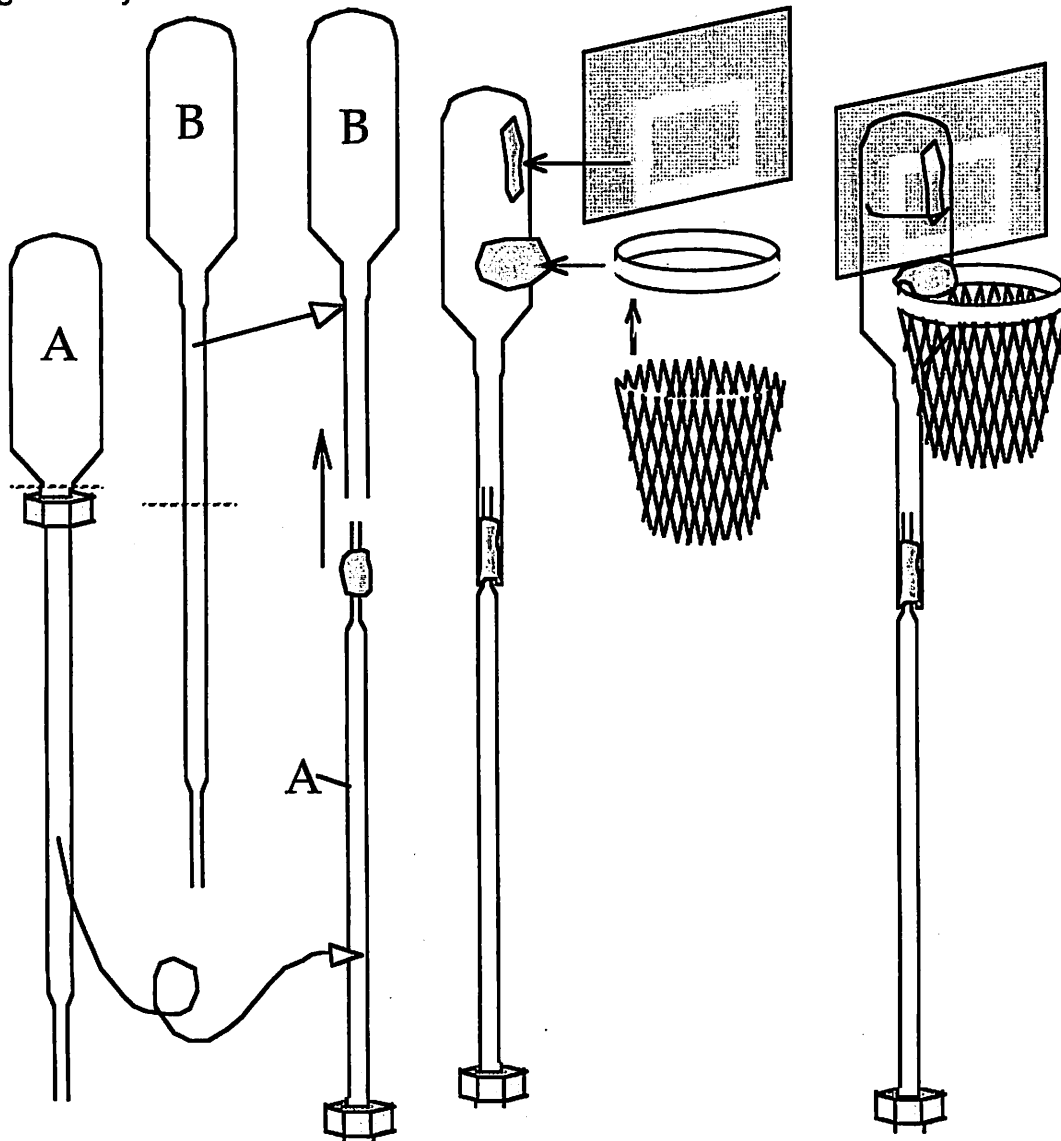
### **Ballerina Diver:**

A cute ballerina diver can be made simply by making a **Whirligig Diver** and attaching the appropriate **Appendages**. The whirligig serves as the tutu and allows the diver to pirouette gracefully as she descends. String hair and wire arms and legs add to the effect, but be careful not to overdo it: every appendage you attach adds to the drag, and thus detracts from the rotation as the diver descends. If you wish to have the hands touching overhead (like the one shown in the video) make both arms out of one continuous piece of wire. This will make them far less likely to get broken off. Shoes and or hands can be made from small pieces of colored foam or from drops of hot melt glue, placed on and then sculpted to the right shape with a pair of scissors.



### Underwater Hoops:

Aside from the **Hook and Treasure**, another fun cartesian diver game is basketball. A fairly simple basket (complete with backboard and net) can be made completely out of plastic: Take a pipet (A) and screw a hex nut onto the collar (as described in **Pipet Diver**) but this time cut the bulb off just above the hex nut as shown below, far left. Take a second pipet (B, no hex nut on this one) and cut about half of the stem off. Place a small bead of hot melt glue on the tapered tip of A and insert it into the cut-off stem of B. The hoop is best made out of the plastic cap ring that can be pried off the top of the 2-L soda bottle (use a flat head screwdriver). A generous drop of glue should be used to attach it to the bulb, moving it around to get a complete seal around the hoop as shown below, far right. A rectangular piece of plastic can serve as a backboard. The net (not shown in the video) can be made from the plastic protective netting used by florists to hold some blossoms closed.

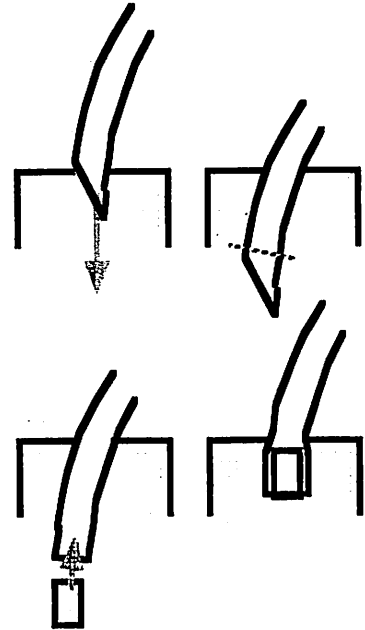


The basket must be filled with enough water so that it sinks, but be sure to leave a big

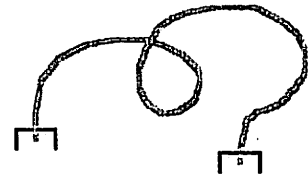
enough air pocket to keep the bulb upright. Inserting the basket into the bottle is a bit tricky. It is best to wrap the backboard back around the bulb and to lift and pinch the hoop as it's passing through the narrow neck of the bottle. If everything is well-attached and as flexible as it should be, the whole assembly should spring back into shape once inside the bottle. The basket ball may be a simple **Pipet Diver**, colored orange with black stripes, or it may be a **wadded-up piece of aluminum foil**.

### Remote-Control Diver:

Cartesian divers are quite effective at illustrating how pressure is transferred through a fluid. You can squeeze the bottle at the bottom, but a diver at the top immediately responds. This effect can be emphasized even further by connecting two soda bottles together by stringing plastic tubing through their caps. To do this, drill a hole through each cap slightly smaller than the outer diameter of the tubing. Cut the end of the tubing at a sharp angle so that the point can be threaded through the hole from the top side of the cap as shown at right; use a pliers and a twisting action to pull the tubing securely in place. Then cut the angled tip off square and take a small section of smaller tubing (a piece of the pipet stem works well with aquarium tubing) and wedge it up into the end of the tubing to flare it out slightly. Finally pull the tubing back out until the flared end wedges itself into the hole. This should make for a good leak-proof fit.



The tube can be as long or as short as one wishes. And just as it is advisable to fill the bottles as full as possible with water, it is also a good idea to fill the tubing itself with water. Otherwise, a long, air-filled tube would represent a significant volume of air that must be compressed along with the air pocket inside the diver. To fill the tubing, simply fill a bottle up completely with water, screw one of the connected caps on,\* and place the other cap in a basin of water. Squeeze the bottle to expel all the air from the tubing, then release the squeeze and allow the water in the basin to be drawn back into the tubing. (It helps to have the basin elevated somewhat relative to the bottle.) Then connect the open cap to the other water-filled bottle.\*



\*In connecting the caps to the bottle, it helps to hold the cap in place and turn the bottle. This keeps the tubing from getting all twisted.

Some Remote-control variations:

Try connecting four or five bottles all to the same central bottle. (This will involve drilling 4-5 holes all in one cap.) Place a set of **Counting Divers** in the central bottle and challenge 4-5 students to come up and see if they can collectively sink all ten. Rather than having the pressures add together and make this a simple task, the pressures seem to average out and make this nearly impossible to accomplish. This is interesting because forces do add together and five students working together could certainly lift something that no one individual could have lifted. When the surrounding bottles are being squeezed, however, the areas over which those forces are being applied also add together: the total force divided by the total area would give the total pressure, but that total would really be no more than just an average.

Another variation on the remote control diver is to have a gas-producing reaction in a separate bottle, and to use this reaction to increase the pressure and force the diver down in the main bottle. Such reactions could include the sublimation of dry ice (careful not to build up too much pressure!), baking soda and vinegar, Alka Seltzer and water or simply the effervescing of soda. It is interesting, and somewhat humbling to note that even a small bottle of soda can be used to sink the most buoyant of divers -- divers that no ordinary human grip could ever sink. That a small bottle of soda can generate more pressure than a typical human is surprising at first, but then think about it: who do you know that is capable of gripping an unopened plastic soda bottle with enough pressure to cause even the slightest indentation!?

As for using a chemical reaction to drive the diver down, especially a reaction as rapid as baking soda and vinegar, a problem presents itself: as soon as the reactants are placed in the bottle, the reaction starts, and by the time the cap is screwed on, the reaction has pretty much run its course. There is, however, an easy means around this obstacle: one that allows you to keep the two reactants from coming together until after you have the cap in place.

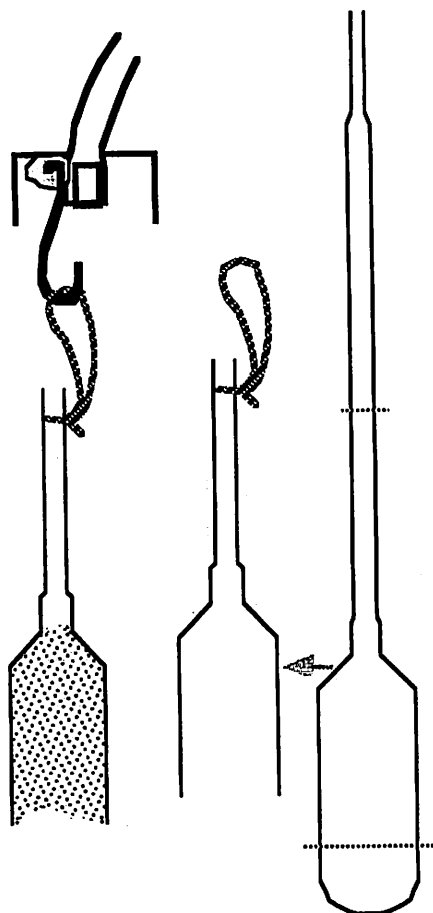
1) First pour 100-200 mL of vinegar in the reaction bottle.

2) Inside the cap that fits the reaction bottle, glue a small wire hook as shown at right.

3) Cut out the midsection of a plastic pipet and attach a string or wire loop to it. Using this cut-off pipet as a plunger, pack it full of baking soda, then carefully hang the loop on the hook.

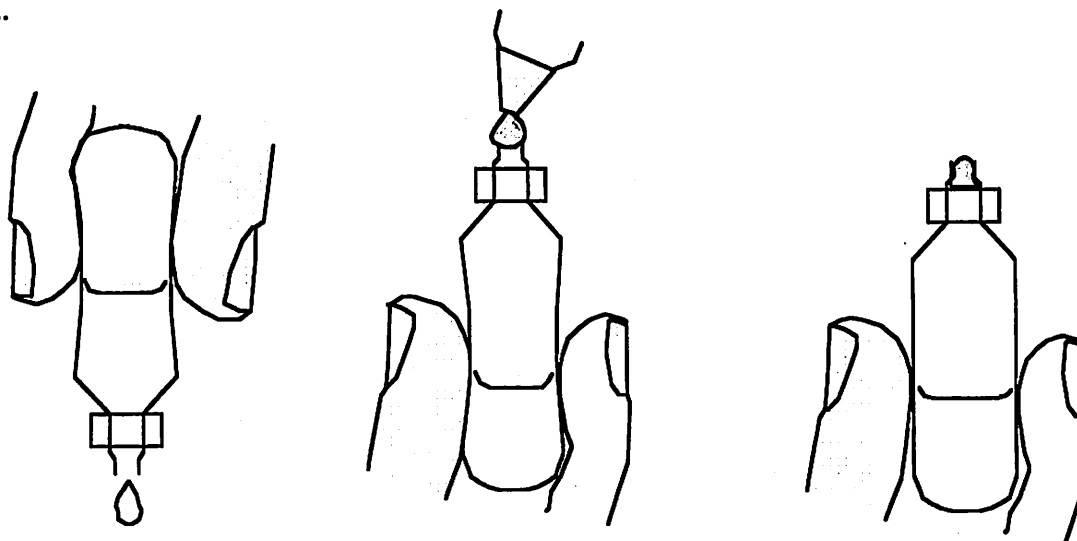
4) Carefully screw the lid onto the reaction bottle. (Again, this is best done by holding the cap in place and gently turning the bottle.)

5) Once the cap is securely in place, give the reaction bottle a quick shake or two to dislodge the baking soda from the plunger. As the baking soda reacts with the vinegar, the carbon dioxide produced drives the divers quickly down in the connected bottle.



### Closed Diver:

Based on all that is discussed in **How Cartesian Divers Work**, one could easily conclude that a closed diver -- that is, one with something blocking its opening -- would not work. If no water can enter or leave, then it would seem that the density of the diver could not be affected by the surrounding pressure. But it turns out that closed divers do work, provided that they are made from a fairly flexible material. Simply make a regular **Pipet Diver**, adjust the density so that it barely floats and then squeeze the pipet just enough to expel one small drop of water. Then, still squeezing the diver slightly, flip it over so that it is open end up and place a drop of hot melt glue over the opening. Then slowly release the squeeze to draw the glue slightly into the stem.



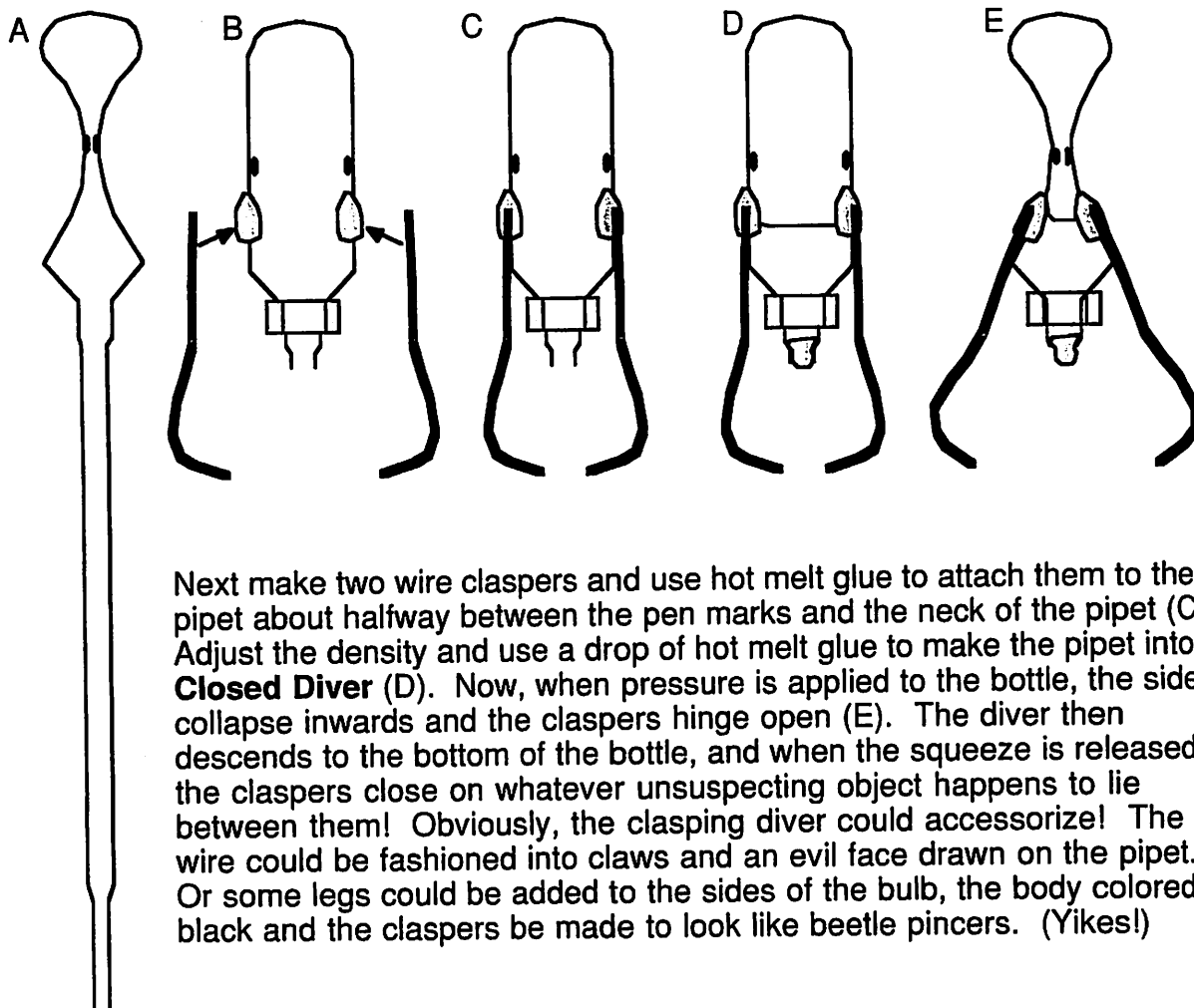
Allow it to cool, check the density again,\* transfer the diver into a water-filled bottle, screw the cap on, and observe what happens as the bottle is squeezed. Rather than the water level rising inside the diver, now the sides pinch inward as it descends.

Of the two explanations offered above (**How Cartesian Divers Work**), the only one that applies to closed divers would be the first one: that their mass remains constant while their volume decreases. It is worth noting that a closed cartesian diver is considerably less sensitive than an open diver of equal density. (This is taken advantage of below in **Seesaw Diver**.) Perhaps this is because of the additional pressure required to distort the plastic (?). Whatever the cause, having a diver with sides that collapse inward opens up a whole new realm of divers as exemplified by the some of the divers described below (**Clasping Diver**, **Jaws**, **Rudolph the Red-Nosed Diver**)

\* If a closed diver tests too heavy or too light, you have two choices: 1) Use a pin or needle that has been heated (in a candle flame, for example) to melt a hole through the hot melt glue plug, draw in or squeeze out some water, and then reseal it -- just rubbing the hot glue gun tip across the hole should seal it up. 2) Add some small appendage -- wire to increase the density, foam to decrease it.

### Clasping Diver:

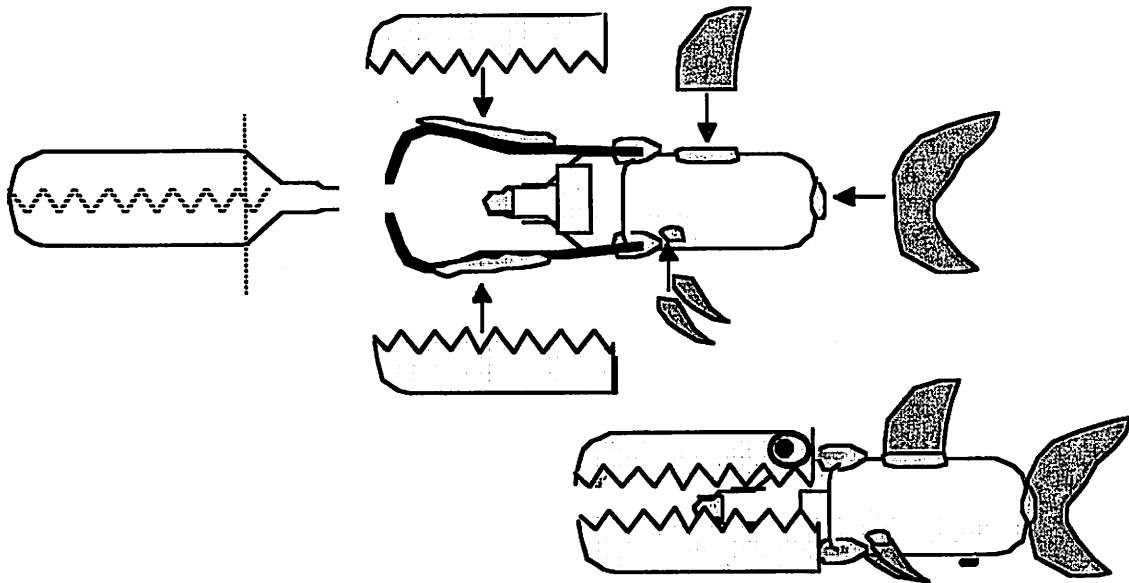
We discussed above how the sides of a **Closed Diver** pucker inward as the diver descends. This physical action can be utilized to open and close a clasping mechanism to allow a diver to actually grab hold of an object underwater. First, we need to determine exactly what sides of the pipet tend to collapse inward under pressure. This varies from one pipet to the next. The simplest way to determine how the sides bend inward is simply to suck on the tip of the pipet. (CAUTION: You must only do this with pipets that are fresh from the box and which you are certain have never been used!) Mark with a pen the sides that collapse inward (A). Then make a regular **Pipet Diver**, by screwing on the hex nut and clipping off the stem (B).



Next make two wire claspers and use hot melt glue to attach them to the pipet about halfway between the pen marks and the neck of the pipet (C). Adjust the density and use a drop of hot melt glue to make the pipet into a **Closed Diver** (D). Now, when pressure is applied to the bottle, the sides collapse inwards and the claspers hinge open (E). The diver then descends to the bottom of the bottle, and when the squeeze is released, the claspers close on whatever unsuspecting object happens to lie between them! Obviously, the clasping diver could accessorize! The wire could be fashioned into claws and an evil face drawn on the pipet. Or some legs could be added to the sides of the bulb, the body colored black and the claspers be made to look like beetle pincers. (Yikes!)

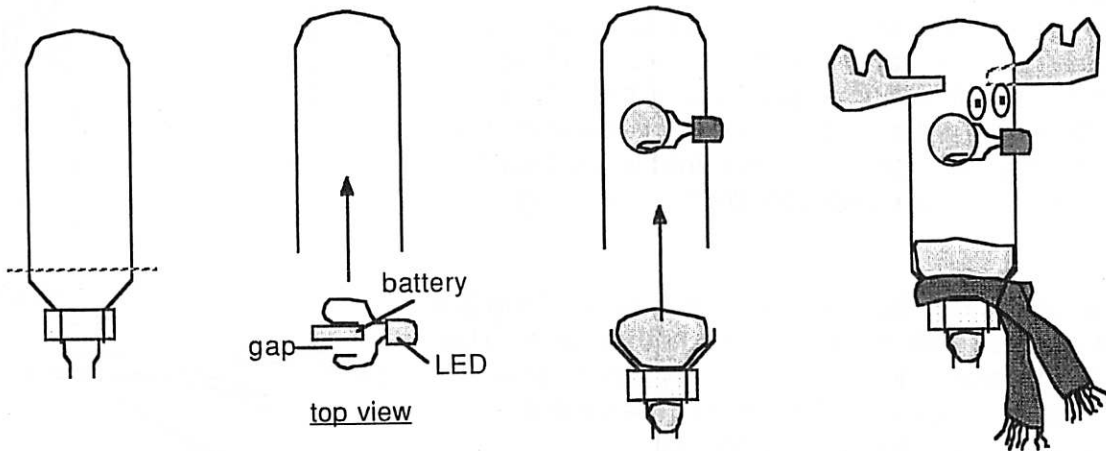
## Jaws:

Just when you thought it was safe to go swimming in a 2-L soda bottle. (Cue the music...) Featured in the video is a ferocious denizen of the deep (and famed movie star): Jaws. Jaws is simply a **Clasping Diver** as described above, with a monstrous set of chompers! These chompers can be made from the bulb of a pipet as illustrated below. Add a tail, some fins and a couple of evil eyes, hot melt glue everything in place, and you're good to go.



### Rudolph the Red-Nosed Diver:

The video featured a second, somewhat less ferocious movie star: Rudolph. Rudolph is unquestionably the hardest of all the divers to build. He requires a red LED and a 1.5 V watch battery to be connected in an open circuit all inside a closed diver! As the bottle is squeezed and the sides of the diver are forced inward, they push together the open ends of the circuit and the LED lights up. So how is all that circuitry made to fit through the little tiny pipet opening? It is not. Nor is it constructed piece at a time inside the pipet like some tiny ship in a bottle. Instead, the entire bottom of the pipet is cut off (as shown at right), the circuitry is positioned inside and held in place with a few strategic drops of hot melt glue. Then the bottom portion is reattached to the top by filling the bottom with hot-melt glue, and then reconnecting it to the upper half! Add some antlers and a scarf and the look is complete! (Way easier said than done!!)



## Glitter Fountain Diver:

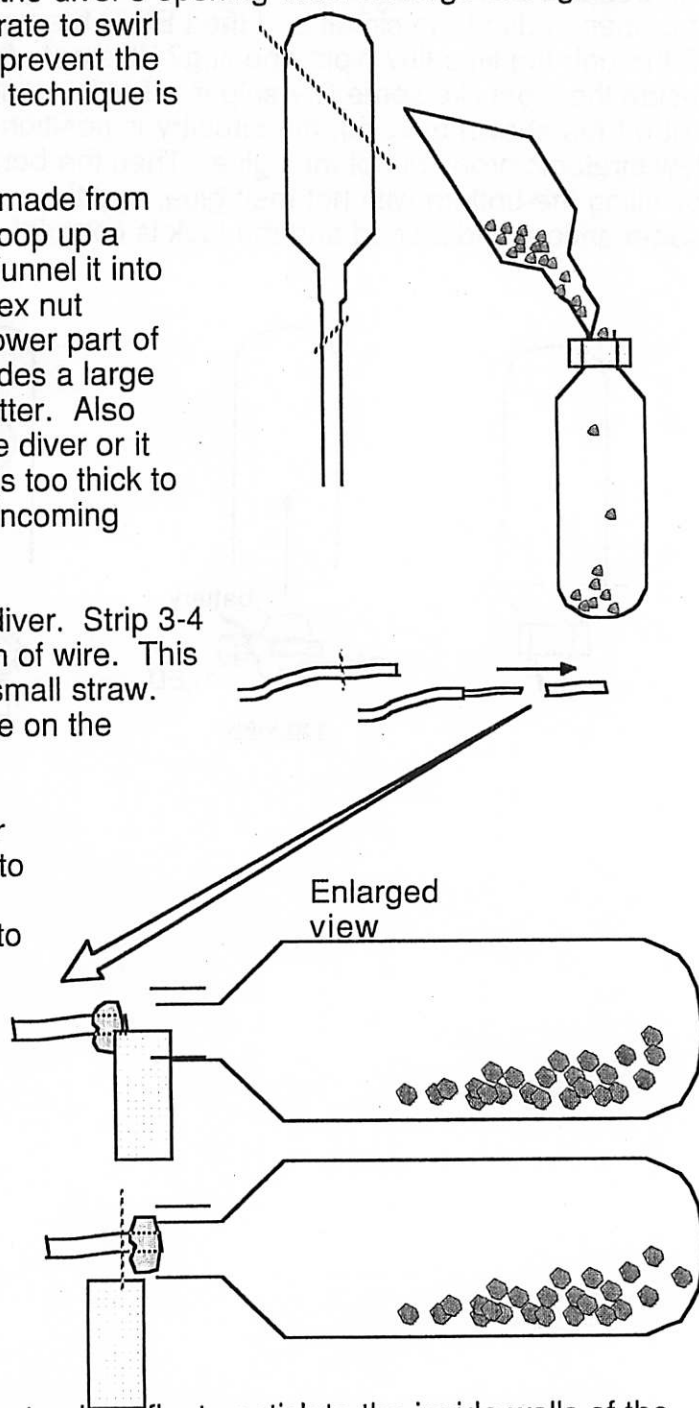
Aside from producing a very beautiful fountain of swirling color, the glitter diver also serves as a vivid demonstration of how the flow of water into and out of the pipet is ultimately what causes the diver to increase and decrease its density. It also provides a bit of an engineering challenge for the diver's opening must be large enough to let the water pass through at a sufficient rate to swirl the glitter inside, but small enough to prevent the glitter from leaking out. The following technique is one solution to that challenge:

1) First, a glitter scoop/funnel can be made from a pipet as shown at right. Use it to scoop up a small amount (~0.1 mL) of glitter and funnel it into a **Pipet Diver**. (It helps to have the hex nut screwed on all the way, and the narrower part of the stem cut completely off: this provides a large opening through which to pour the glitter. Also note: Do not put too much glitter in the diver or it might form a layer on the bottom that is too thick to be swirled around effectively by the incoming water.)

2) Now to restrict the opening of the diver. Strip 3-4 cm of insulation off the end of a length of wire. This insulation piece will serve as a very small straw. Carefully place a drop of hot melt glue on the section of the straw close to, but not covering, the end. Place this just barely inside the opening of the diver and move it around to allow the glue to make good contact with the inside edge of the opening. Allow the glue to cool. If there are any gaps between the tiny straw and the rim of the pipet opening, seal them up with additional glue, then snip the protruding straw off flush with the glue plug.

3) Stir a few drops of dish detergent (Joy or Dawn) into the testing tank and then adjust the density so that the diver just barely floats (**Fine Tuning Density**).

Note: Without the detergent, the glitter tends to float or stick to the inside walls of the pipet. The detergent helps to overcome these surface tension effects and keeps the



glitter from clumping inside the diver. Note also that because of the restricted opening, it takes a little extra time for the water to enter and exit the diver, so there is a bit of a time delay for both descending and ascending.

### Smile/Frown Diver:

The smile/frown diver takes advantage of the rising water level inside the diver. It is a fairly tricky one to make.

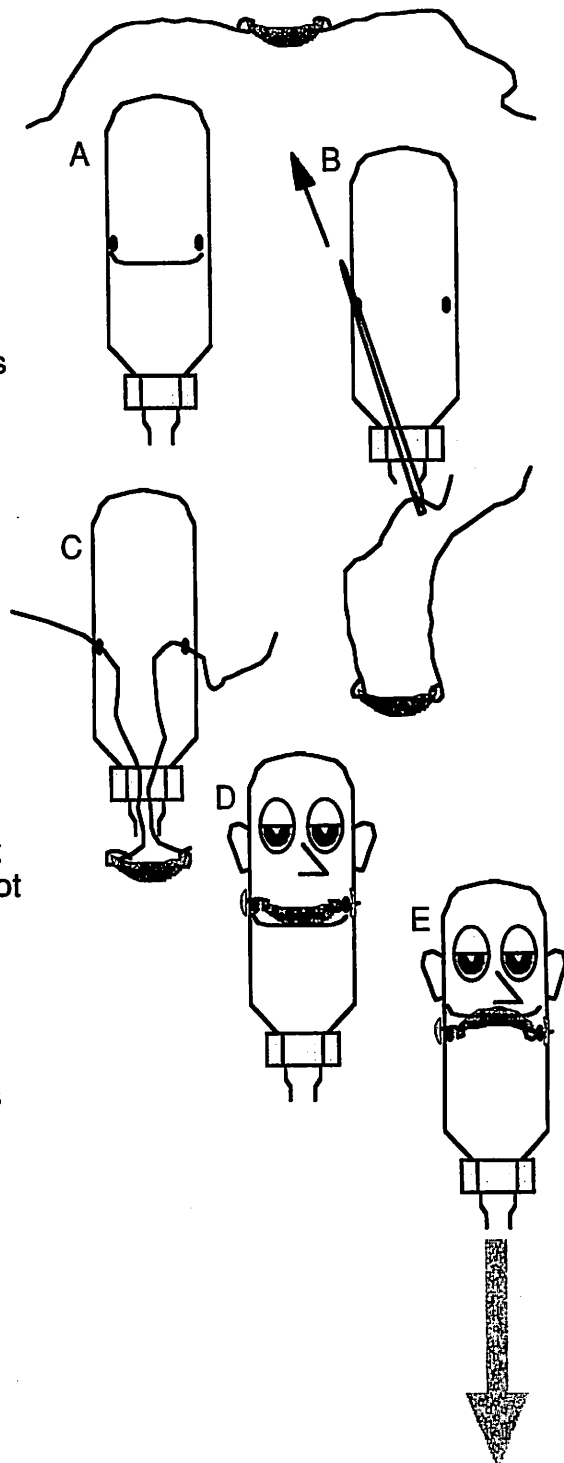
1) Cut a small crescent shaped smile out of a piece of colored craft foam. Use a needle to attach 7-8 cm of very fine thread to each corner of the smile.

2) Make a regular Pipet Diver and adjust the density (**Fine Tuning Density**) to make it just barely float. Remove it from the testing tank, dry it off and mark two spots on opposite sides of the diver just slightly above the surface of the water inside (A). Then squeeze out the water.

3) Place one end of the thread back through the needle and, passing the needle through the pipet opening, poke the point through the inside wall of the pipet at one of the marked spots (B). Pull the thread all the way through. Repeat this process with the thread on the other end (C).

4) Now carefully pull on the two threads (one at a time) to position the smile inside the pipet between the two marks. Use small drops of hot melt glue to hold the threads -- and seal the needle holes. Trim away the extra thread.

5) Readjust the density. The water level should be pretty much where it was before. The smile should be dangling down, perhaps just barely touching the water surface. Add some eyes, nose and even ears (D). Now when the diver is put in the bottle and squeezed, the rising water level inside the diver should flip the smile over and make it appear as a frown (E).



### Micro-Diver:

There is really no limit as to how big a cartesian diver can be, so long as you have a large enough container with a sufficient opening, but is there a limit as to how *small* a diver can be? Challenge the students to build the world's smallest working cartesian diver. Here is one solution:

1) Cut out a section near the tip of a pipet as shown at right (A). Place a small drop of glue in the wide end to seal it over (B).

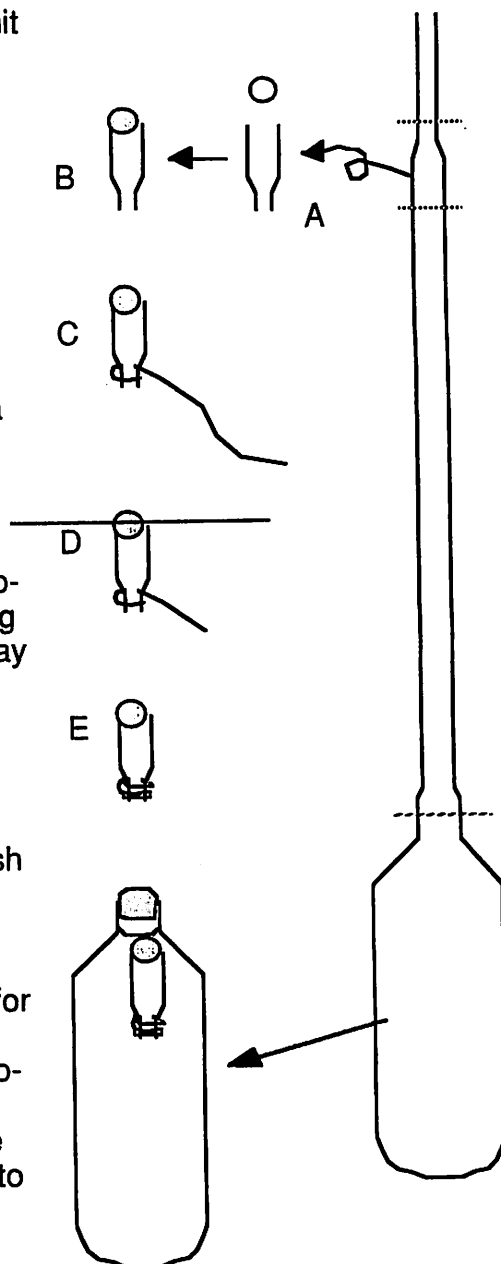
2) Cut a 3-4 cm length of fine copper wire and wrap the end once around the tapered tip (C). Place this in a testing tank. It should sink. (If it does not, use a longer length of wire and try again.)

3) Adjust the density, not by adding water, but by removing some of the ballast. Do this by cutting away the wire one millimeter at a time until the micro-diver just barely floats (D). Then wrap the remaining wire tightly around the pipet tip to get it out of the way and to keep it from falling off (E). The micro-diver is ready for action!

As with the **Glitter Fountain Diver**, the tiny diver tends to get caught up on the surface (surface tension). As mentioned before, a tiny amount of dish detergent stirred into the bottle should help overcome this surface effect.]

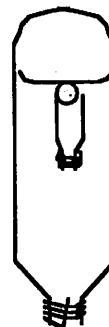
The bulb of the same pipet can serve as the bottle for the micro-diver. Simply cut off the stem right at the flared collar, fill the bulb with water, insert the micro-diver and then glue the bulb shut (as was done in **Closed Diver**). [This assembly can even be made into a necklace pendant, to be worn always close to your heart!!!]

Note: Should a micro-diver ever need to have its density reset (for reasons discussed in **What Do You Do With a Sunken Diver?**), simply take the diver out of its container and tap it gently against a table top to shake loose any water that may have gotten inside.



### Diver Inside a Diver:

Can a micro-diver work inside a regular diver? You bet. Simply make a **Micro-Diver**, and place it inside a cut off pipet bulb, just as described above, but this time leave a little air pocket inside (about one fifth of the total volume of the bulb). Now make this bulb into a diver the same way you did the micro-pipet. Wrap the end of a 15 cm length of wire around the collar of the pipet bulb, place it in a testing tank (it should sink). Then cut it down to the point where it just barely floats. Wrap the rest of the wire around the collar, and take the last few millimeters and bend them up into the opening of the pipet. [This is intended to keep the micro-diver from falling out.]



[Note: a hex nut could be used for ballast here, but it would require a much larger air pocket to support it. This would mean the micro-diver inside would have far less room to move up and down. Although the smaller air pocket does sacrifice some of the sensitivity of the big diver, it gives the micro-diver the extra vertical space it should have. Also, as with the **Glitter Fountain Diver**, the tiny diver tends to get caught up on the surface (surface tension). As mentioned before, a few drops of dish detergent stirred into the bottle should help overcome this surface effect.]

### Oil and Water Diver:

The oil and water diver can make for a beautiful addition to your diver collection. Simply fill the soda bottle up half way with water, add a drop or two of blue food coloring, and then top the bottle off with vegetable oil. A **Pipet Diver** that is made to just barely float in water (**Fine Tuning Density**) will probably sink through the oil, and come to rest at the water-oil interface. To get a diver to float on the oil, set its density a little lower -- so perhaps 5-6 mm of the pipet bulb stick out above the water level in the testing tank. Although it is filled with water, this will quickly be replaced with oil as the bottle is squeezed and released. This exchange will obviously make the diver lighter still. (Note: you could simply use a testing tank filled with vegetable oil to set the density of the oil-floating diver, but that might get a little messy!)

Once it is made, some fun effects can be demonstrated with an oil-water diver. One involves squeezing the bottle enough to bring the oil-floating diver down to the oil-water interface, then giving it a quick, hard squeeze to pump some water up inside it. Then let the diver ascend back into the oil layer and give the bottle little squeezes to expel perfectly spherical droplets of water down through the oil. (It looks very much like the diver is laying beautiful blue eggs, which is why the divers in the video were decorated to look like birds...)

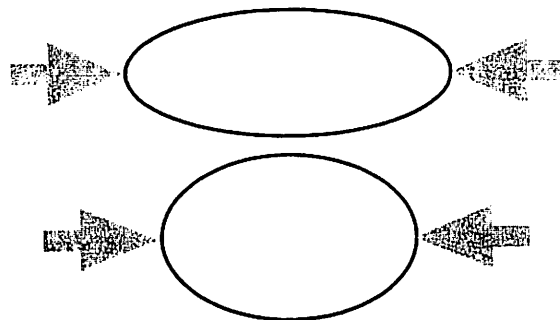
### The Fickle Diver:

If a diver's density has been adjusted (**Fine-Tuning the Density**) to be very close to that of the surrounding water, an interesting paradox presents itself: The diver floats -- just barely -- and when squeezed, it sinks quite easily, but once the squeeze is released, rather than ascend back to the top, the diver stays decisively on the bottom. Tapping the bottle lightly on a table top raises the diver a few centimeters, but it then drops back down. Tapping it somewhat more abruptly brings the diver into the upper half of the bottle and then it gradually ascends the rest of the way to the top. In other words, the diver is less dense than the water when it is in the upper portion of bottle, and yet it is more dense than the water when it is in the lower portion of the bottle! Challenge the students to figure out why it does this. Perhaps those who have gone snorkeling or scuba diving will be familiar with hydrostatic pressure: the deeper one is in a fluid, the more pressure. In fact every 10 m (34 feet) depth of water adds an extra atmosphere of pressure (14.7 psi). That means the 20 cm of water that separates the bottom of the bottle from the top represents an additional 0.02 atm or 2% greater pressure at the bottom. For most divers, that 2% extra pressure does not make much difference, but for those set sensitive enough -- with densities very close to that of water -- that extra 0.3 psi can make the difference between floating and sinking. But what about in the middle? Is there a depth at which the diver would be what is called neutrally buoyant -- neither floating nor sinking, but just hovering indefinitely? Theoretically there would be a precise depth at which this would occur, but trying to position the diver at this depth is like trying to balance one billiard ball on top of another! Any slight deviation from that point, either too high or too low, and the diver will gradually float or sink, respectively, away from the middle.

I once considered constructing a display for a local science center in which several divers are placed in a large (20 cm diameter) clear vertical tube -- perhaps 3 m tall, and connecting it with tubing to a few small soda bottles, as described above under **Remote Control Divers**. Fortunately I realized the problem this would present before making any large investment in the project. A depth of 3 m would cause a 30% increase in pressure at the bottom of the tube. In order to keep the divers from getting stuck at the bottom, they would have to have such large air pockets that only the strongest grips would be capable of getting them to dive in the first place. What a pity, though: I think that squeezing a small bottle and watching as it causes a diver to descend gracefully from the ceiling to the floor, and then back up again when the squeeze is released -- would make for a wonderful, interactive display.

### The Inverse Diver:

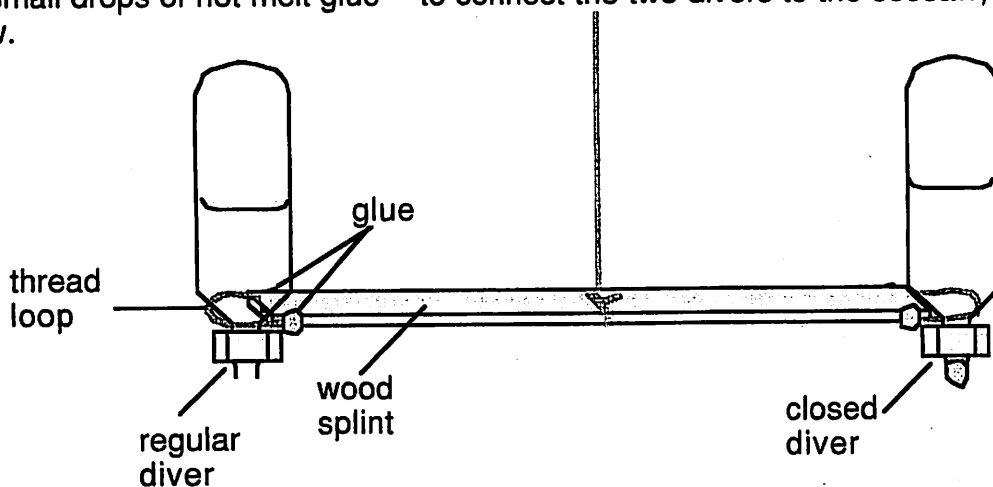
Challenge the students to construct a backwards diver: that is, one that ascends when the bottle is squeezed, and then dives back down when the squeeze is released. The trick here is not in the design of the diver, but in the shape of the bottle. Simply construct a **Pipet Diver** and adjust its density so that it *barely sinks* in water. Then find an plastic bottle (like a clear shampoo or mouth wash bottle -- one with an oblong (oval) cross-section). The diver will sink to the bottom. But when the cap is screwed on and the bottle is squeezed edgewise (as shown at right), the diver ascends to the top! When the squeeze is released, the diver returns to the bottom -- just the opposite of a regular cartesian diver. The reason for this reversal is that squeezing an oblong bottle edgewise actually increases its volume (because it is being made more cylindrical) and this actually decreases the pressure inside. The same effect can be observed when you accidentally put too much toothpaste on your tooth brush. Squeezing the toothpaste tube edgewise can help draw the excess toothpaste back into the tube -- perhaps not the most sanitary experiment, but cool nonetheless!



### Seesaw Diver:

A colleague who was familiar with the **Inverse Diver** gave me the following challenge: make a pair of divers together in the same bottle such that when you squeeze the bottle, one floats to the top while the other sinks to the bottom. "Impossible!" was my first reaction... but then again, she never said they couldn't be connected... And this is where the idea for the seesaw divers originated.

- 1) Construct a **Closed Diver** with a density somewhat *greater* than that of water.
- 2) Construct a regular **Pipet Diver** with a density just *slightly* greater than that of water.
- 3) Use a wood splint or flat plastic coffee stirrer (6-8 cm shorter than the diameter of the bottle) as the seesaw. Find the midpoint of the splint and tie a long thread (30 cm) tightly around it. Then use small loops of thread at each end -- attached to the seesaw with small drops of hot melt glue -- to connect the two divers to the seesaw, as shown below.



- 4) Holding it by the long thread, lower the entire assembly into a testing tank. It should completely sink and come to rest with the closed diver lower than the regular diver. If not, adjust the densities again so that it does.
- 5) Remove the assembly from the testing tank and lower it carefully into a filled bottle. The thread can be hung from a wire hook glued to the inside of the cap. Have the thread long enough so that the seesaw hangs about halfway down inside the bottle. Screw the cap on and squeeze the bottle. Since the regular diver is more sensitive -- that is, its density is more influenced by the added pressure -- the squeeze should increase the regular diver's density by a greater extent than it does the closed diver. As the regular diver's density surpasses that of the closed diver, the seesaw will tip toward the regular diver. When the squeeze is released, of course, the see saw tips back toward the closed diver.

In essence then, the challenge was met: one squeeze of the bottle causes one diver to sink downward and the other to rise upward.

### **The Inverse Air Diver:**

Though I do not believe one has ever been constructed, it seems that it should be theoretically possible to build a rigid, closed diver that is surrounded by air, and which functions exactly the opposite of a regular cartesian diver. If one could construct a 1-L rigid, airtight container that weighed only 1.00 gram and fill it with 0.30 g of helium, then the object would have a combined density of 1.30 g/L -- just slightly more dense than air (1.29 g/L), and so the object would sink. If this were placed in a *large* bottle of air, and the cap were screwed on tight and then the bottle were squeezed, it would increase the density of the surrounding air (remember gases are compressible), but it should not have any impact on the rigid diver). Thus squeezing the bottle should cause the diver to ascend, and releasing the squeeze should allow it to sink back to the bottom! This would make for a neat effect.

## What Do You Do With a Sunken Diver?

It is somewhat of a let down when a student builds a diver, carefully adjusts the density, gets it working just right, only to find the diver stuck on the bottom the next day. What happened? How can it be fixed? There are a number of reasons why a diver may end up on the bottom of the bottle:

1) Water taken straight from the tap usually has an excess of dissolved gases in it -- mostly nitrogen and oxygen -- the main components in air. In the pipes, the water is under pressure, so the dissolved gases stay dissolved. But once in the bottle, the water is essentially at room pressure (about 1 atm), and so the dissolved gases tend to come out of solution, forming little bubbles around the perimeter of the bottle, and perhaps on the diver as well. This undissolving of a gas is known as out-gasing. Though the bubbles clinging to the diver will act to buoy it up, the bubbles on the inside walls of the bottle are displacing water and creating a little extra pressure. This can be enough to force the diver to the bottom. If this is the case, simply unscrewing the cap will relieve this extra pressure and allow the diver to float back up to the top. Tapping the sides of the bottle is usually sufficient to knock loose any bubbles adhering to the inside walls or to the diver. The cap can be screwed on and the diver will be back in business.

2) The diver bottle is set on a shelf and forgotten about. Then, three months later, it is taken down and once again, the diver is found to be too dense to float... and this time unscrewing the cap does not fix the problem. Two things could have happened: someone accidentally dropped the diver, and a little bubble of air was knocked out of it by the sudden impact with the floor. This "getting the wind knocked out of a diver" does happen, but it is fairly uncommon. More likely, a portion of the air pocket that was serving to buoy up the diver dissolved into the water and then undissolved back out at the top of the bottle. Either way, if the diver has lost air, it must be fished out and its density readjusted as described above (**Fine-Tuning the Density**) before it can resume its normal activities. It is interesting to note that even if the level of dissolved gases has stabilized inside the bottle, it is a dynamic equilibrium that exists with dissolving and outgasing going on all the time. And since the level of water inside the floating diver is slightly lower than the water level outside the diver, it stands to reason that the gas inside the diver will dissolve at a slightly greater rate than the gas at the top of the bottle. Although this is a very slight difference, over time it can have enough of an impact to sink the diver. Most remarkable perhaps is that this even happens with a **Closed Diver**. Even though it is completely enclosed, the gas molecules inside the pipet can pass through the polyethylene walls of the pipet, and end up causing a closed diver to collapse inward and sink hopelessly to the bottom. This usually takes several months to occur, but it is still disconcerting -- especially because readjusting the density of a closed diver (as mentioned above) is considerably more involved than it is for an open one.

A good follow-up discussion for the day after the lab is to show the class a sunken diver and have them brainstorm as many ways as they can think of for how to get the diver to the top of the bottle. Here are some solutions that my classes have come up with over the years:

\*Take off the cap, use a long hook to retrieve the diver off the bottom, readjust the density so that it floats. (not too creative but it works).

\*Take off the cap, use a long narrow straw to blow a few extra bubbles into the diver.

\*Take off the cap and place the diver in a low pressure environment -- such as a partially evacuated bell jar. (This works great, but once the pressure is restored, the diver will again sink.)

\*Take off the cap and place the diver in a high temperature environment -- such as an oven. As the gas pocket heats up, it expands and decreases the density. (It's neat to consider that the water is also expanding as it heats up, and its density is also decreasing, but not nearly to the same extent that the air pocket is. If it were to the same extent, then heating the bottle wouldn't work.)

[These last three suggestions make for a good connection to the gas laws ( $PV = nRT$ ) -  
- adding more moles of gas, decreasing the pressure, increasing the temperature --  
these are all good ways of increasing the volume of the air pocket to make it more buoyant.

\*Take off the cap and add some sugar or salt. Stir this in and as it dissolves, the density of the surrounding water increases. This should act to buoy up the sunken diver. (It takes a truly divergent thinker come up with this one!)

\*Take off the cap and add some strong acid -- or something that might eat away some of the hex nut. (This too would work in theory, but stainless steel is not very reactive...)

\*Take off the cap, squeeze the bottle slightly, then while still squeezing, screw the cap back on and release the squeeze. (This unsqueezing of the bottle does reduce the pressure slightly and does bring a sunken diver to the top, provided it's density is not too much greater than water's.)

\*Simply turn the bottle upside down! This does bring the diver to the "top" of the bottle -- or at least what was the top. (There's one in every crowd!)

### How to Set up the Lab:

Although there is no one right way to do this lab with students, the following might give you ideas:

1) A week or two ahead of time, the students are told to bring in with them on the day of the lab two undented, rinsed-out, colorless 1-L or 2-L soda bottles with caps on and labels removed. (I tell them it is worth 10 pts if done correctly!) Having them bring in two each will compensate for the half of the class that forgets! And should more than half remember, you simply collect the extra bottles for some future projects.

2) The day before the lab, I spend the last 10-15 minutes of class showing the cartesian diversions video -- to get their creative juices flowing, and to encourage them to bring in various knickknacks from home that they think might somehow prove useful. We also discuss the theory behind the lab: what causes the divers to dive. Richard Frasier describes in his superb website (<http://www.ed.uiuc.edu/courses/C1241-science-Sp95/resources/philoToy/philoToy.html>) how he has his middle school students develop and then test their own theories as to how the diver descends... This could easily become an entire teaching unit onto itself, for it is ripe with potential for open-ended investigations and hands-on research.

3) One the day of the lab, I place 5-6 hot-melt glue guns around the room, and I caution students about how to use them. Also at each lab station are one or two large testing tanks (cutoff 2-L soda bottles) for use as described above in **Fine Tuning Density**. Stations also include a few pairs of scissors, some colored permanent markers and a long hook, made from a coat hanger. This hook is good for fishing divers out of the bottle in order to make adjustments. (Better to hook a diver out than to empty out the bottle and then have to refill it.)

4) At a central table I will have a few boxes of pipets, a few boxes of hex nuts, some plastic scraps, some strips of hook-up wire, foam pieces, spools of different colored yarn and string, as well as some hot-melt glue sticks, some pliers, a few hole punches and some heavy-duty scissors for cutting the wire. I tell the students to limit themselves to three pipets and three hex nuts per person, just so they don't go through the supply too quickly.

5) While they are making their divers, I'll hold little mini-sessions on how to make the **Whirligig Diver**, the **Hook and Treasure** and various **Appendages**, such as the scuba mask and tanks. Those who are interested crowd around to learn.

6) I tell the students that there are three separate contests they can enter their divers in: Most Beautiful Diver, Most Creative Diver, and Most Spirited Diver. The winners (as judged by a impartial colleague in the science department) receive bonus points.

7) Some reminders I find myself espousing every class period:

a) The diver you construct can be as elaborate as you want, but it must be able to pass through the mouth of the bottle they are using.

- b) Wait until after you have added all appendages before adjusting the density.
- c) Fill the bottles up to the very top with water  
... and my personal favorite:
- d) Don't forget to screw the cap on before squeezing the bottle!!

8) When they are finished with the activity, I have them answer a bunch of follow-up questions:

## **Cartesian Diver Lab Follow-Up Questions**

Name: \_\_\_\_\_

After you complete the lab, answer the following questions:

1. Explain using text and diagrams precisely how the cartesian diver works. Your explanation should include the words: "pressure," "air pocket," "density," "compressible," "volume," "mass," etc. Why does squeezing the bottle make the diver sink? Why does releasing the squeeze make the diver float back up?
2. Your explanation above of how a diver works probably depends on the diver being open on the bottom. Yet in the movie, you saw a closed diver. Describe how it behaves differently than a regular open-ended diver. Explain using diagrams why it still works.
3. How does the diver depend on the fact that gases are compressible and that liquids are not?
4. Does the diver work better when there is a big air pocket in the top of the bottle or a small one? Explain.
5. If you wanted to make a series of divers that spelled out the word "H-E-L-L-O," how would you do it? Use diagrams.
6. In the movie, you also saw a diver with glitter fountaining inside. Explain, using diagrams how it was made. Was it an open diver or a closed one?
7. In the movie, you also saw a Jaws diver whose mouth opened up when it dived. Explain, using diagrams how it was made. Was it an open diver or a closed one?

8. In the movie, you also saw a Rudolf the red nose diver whose nose lit up when it dived. Explain, using diagrams how it was made. Was it an open diver or a closed one?

9. You also saw a wadded-up piece of aluminum foil work as a diver. Explain how that would work.

10. A nail is pushed into a piece of styrofoam packing material. Do you think that would work as a diver? Explain.

11. A candle (which floats) is tied to a paper clip. Do you think that would work as a diver? Explain.

12. What, if anything, would you have had to do differently in the diver lab if you had used...

- a) ...oil instead of water?
- b) ...a heavier hex nut?
- c) ...a small pipet?
- d) ...a larger bottle?
- e) ...helium instead of air?

13. A Cartesian diver is stuck on the bottom, with not quite enough air to get it to the top. List seven different ways to get the sunken diver to the top of the bottle, and

explain why you think each work. (Hint: Think of the different factors you've learned about that affect a gas's volume.)

would

1)

2)

3)

4)

5)

6)

7)

14. Sometimes, if a diver is set to be very sensitive, so it is just barely less dense than water, it will sink just fine, but then when the squeeze is released, it does not float back up, even though no air has been lost out of it. Explain why that happens.