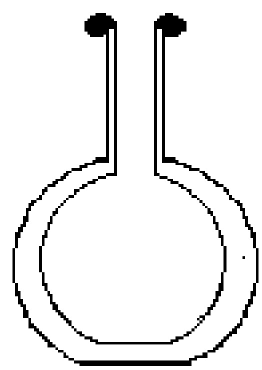
AIR PRESSURE

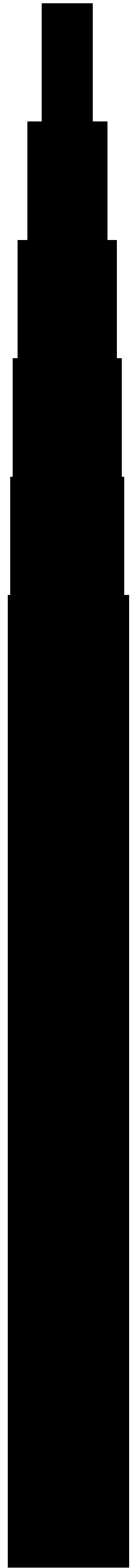
PROBLEM PRESENTATION / EXPLORATION

A. Drinking Straws
   1. Every kid knows how to make a straw work, but does he know why it works?
   2. At the first exploration station have the following setups:
      a.) A straw resting in a paper cup of Kool Aid® or punch.
      b.) A straw with a couple of pin holes punched in halfway up the straw resting in a paper cup of Kool Aid® or punch.
      c.) A straw inserted through a cork or one-holed rubber stopper into a 125 mL Erlenmeyer flask containing Kool Aid® or punch.
      d.) Two straws and a cup of Kool Aid® or punch with a card having instructions to put both straws into your mouth, to place only one of the straws into the liquid, and to suck simultaneously on both straws.
   3. Ask the students to relate what happened or didn't happen in each instance and to explain these observations. Ask them to pay particular attention to what they did with their mouth and jaw as they sucked.
   4. Have them to advance an idea of what caused the liquid to rise.

B. Balloons
   1. At the second exploration station challenge students to reproduce:
      a.). A flask or jar lined with a balloon fitting snugly to the interior surface of the flask or jar. The mouth of the balloon is folded over the mouth of the container.



      b.) Provide for them a balloon and container and indicate that upon their request you will provide for them anything else they think they will need to carry out this challenge. Emphasize that they must first clear their projected activity with you.
   2. At the third exploration station challenge students to reproduce:
      a.) A jar containing a fully inflated balloon filling the entire volume of the jar.

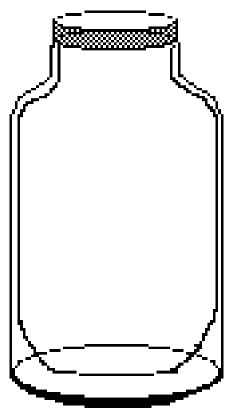


b.) Provide them an empty jar (the jar needs to have a wide mouth, possibly a mayonnaise jar) with a screw-on cap and an inflated balloon. Once again, tell them that you will provide for them anything else they need to carry out this challenge, but they must first clear their projected activity with you.

C. It is very likely that the students will show an understanding of how straws work and that air pressure is involved, but it is highly unlikely that they will be able to complete the balloon challenges. Hopefully, at the completion of the CONCEPT INVENTION phase students will have the appropriate understanding of how air pressure can be utilized to meet these challenges

CLASS RESPONSE / CONCEPT INVENTION

A. Obtain a large mouth jar (a large institutional sized pickle jar from the cafeteria works well). Get a large plastic sandwich bag and invert over the mouth of the jar. Push it into the jar and smooth it out so that it clings to the inside surface. Securely tape the bag to the mouth of the jar



1. Challenge a student to come up and reach into the jar and pull the bag out.
2. They will not be able to do this unless they rip the bag. Why? Point out that there is no glue or other type of adhesive holding the bag to the jar.
3. Quickly, the students will conclude that it must be something **pushing** down on the bag that is causing this action. Try to reinforce this point of view. Undoubtedly, someone will try and explain this phenomenon by saying that there is a suction that is **pulling** the bag down. **This is not what is happening and hopefully will be dispelled as the lesson proceeds**. Definitely it is not a pulling but rather a pushing action that is keeping the bag in the jar.

B. Proceed next to a demonstration that many of the students will have probably already experienced.
1. Place a stick of pine wood (approximate dimensions 0.3 cm x 3 cm x 75 cm) on the demonstration table. Allow about 8 cm of the stick to overhang the table.
2. Ask: "What will happen if I hit this protruding end with my hand?' No doubt the students will indicate that it will go flying up. Do it.
3. Now replace the stick and cover it with one or two full sheets of ordinary newspaper so that the edge of the paper is flush with the edge of the table. Smooth the paper out so that there is no air trapped between the table and paper.
4. Ask: "What do you think will happen if I hit the stick again?" If the students don't offer any answers, suggest that the paper might tear and the stick will fly up again.
5. Hit it sharply with your hand and the stick will instantly break.
6. Remove the paper and replace it with a stack of books at least two feet high

sitting on the stick. Ask: "What will happen if I hit the stick this time?" With no hesitation this time they will predict that the stick will break. Do it.

7. Indicate that both times the stick broke because there was a tremendous weight resting on the stick. The second time it was the weight of the books, but the first time it was the weight of the air above the paper.
8. Introduce the situation of what would happen to a diver standing on the bottom of the ocean if he didn't have on a pressurized diving suit. The weight of all the water above him would crush his lungs.
9. Even though none of us has stood at the bottom of an ocean and felt the weight of the water above us, we all live at the bottom of an ocean of air. This ocean of air rises forty or fifty miles above the surface of the earth. The weight of this air is tremendous on every square centimeter of our body.
10. Draw a square centimeter on the floor, or put a single sugar cube on the floor. The column of air above that cm^2 weighs 1030 g
11. Determine how many square centimeters of stick were covered with the newspaper. If 65 cm x 3 cm is covered by the paper, the weight of air pushing down on the stick is 200850 g or 200.85 kg or 442 pounds!! No wonder the stick broke.
12. Is it now clear why the sandwich bag can't be pulled out of the jar? If the diameter of the bottom of the jar is 25 cm, then the area is πr^2 or 3.14 x (12.5 cm)^2 = 491 cm^2. Now the weight of the air pushing down on the bottom of the jar is 491 x 1030 = 50560 g, or 50,56 kg, or 1114 lb of air!!

C. Barometer

1. The traditional way to talk about how much air pressure is present is to use a barometer. Although students may have aneroid barometers at home, they may never have seen a mercurial barometer. If you have one, show them how it works, if not, a working barometer can be constructed. **This should be done only as a teacher demonstration**. [Mercury is dangerous and students should not be allowed to come into direct contact with it.]
2. Fill a long glass tube (80 cm) with this mercury. To get an 80 cm tube two 40 cm tubes can be connected with a short piece of Tygon® tubing. Only use this type of plastic tubing; do not use regular rubber tubing. You do not want to take any chance of developing a leak at the junction of the two pieces of glass tubing. Seal one end of the glass tubing in the oxidizing part of the flame of a Bunsen burner. Make sure that it is completely sealed. Fill the tube slowly with mercury until all air has been removed. Place a piece of Saran wrap over the open end, Invert the tube so that the sealed end is at the top, and move the tube to the dish of mercury. Lower the bottom of the tube below the surface of the mercury (take care not to put your finger in the mercury) and remove the Saran wrap. **Before removing the Saran Wrap have students predict what will happen when it is removed.**
3. The level of mercury in the tube will fall some but the liquid will not drain out of the tube if the bottom is below the surface of the mercury in the dish. Point out that the weight of mercury is 13.6 times heavier than if the tube was filled with water. Why doesn't the heavy mercury fall all the way out of the tube?
4. The reason that it falls but not all the way has nothing to do with a partial vacuum above the liquid pulling up the liquid (it is true that a partial vacuum is created), but the reason the liquid stays up in the tube is that the pressure of the air pushing down on the liquid in the dish supports the column of mercury.
5. Now by using a meter stick to measure how high the column of mercury is above the surface of the liquid in the dish is a measure of the air pressure. The normal air pressure is a column of mercury 760 mm high. Students may be more familiar with the barometric pressure given in inches of mercury but in science we prefer to use mm of Hg. [760 mm of mercury is equal to 29.92 inches of mercury.]
6. Would the atmospheric pressure be higher or lower than 760 mm Hg on top

of Mt. Everest? Why? [Because the column of air above you when standing on top of Mt. Everest is shorter and contains a smaller amount of air, the pressure pushing down on the barometer would be less than 760 mm Hg.

7. What would be the atmospheric pressure if you were standing on the canyon floor of Death Valley? [More than 760 mm Hg.]

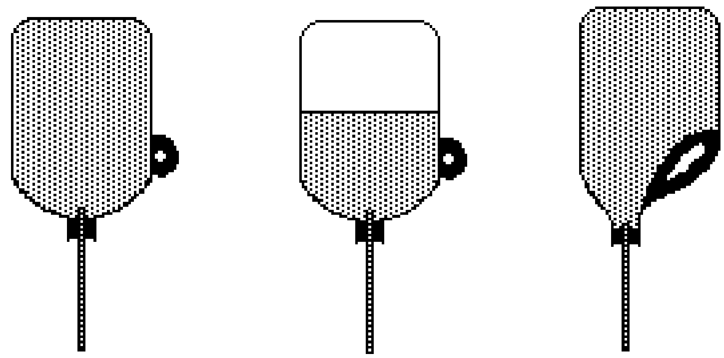
D. Rubber Plungers

1. Have two students come up and get two rubber plungers (the type you would use to unplug a sink) and push them against each other.
2. Ask them now to pull them apart. They will come apart very easily.
3. Tell the students that whether they know it or not you have secretly been exercising for today's lesson. Tell them that you have developed fingers that are exceptionally powerful, and to prove it you want them to reattach the plungers and with your two fingers you will hold the plungers together so that they cannot pull them apart.
4. Naturally there is something funny going on here. One of the plungers has a small hole it. When you put your fingers on the plungers to hold them together make sure that you cover the hole with your thumb. It works even better if your thumb is wet.
5. Now when they pull on the plungers the rubber plungers will stick together and most likely the wooden handle will come off before the plungers come apart.
6. After having some fun with this try to determine why it was so easy to pull the plungers apart before you held them. Because there was a hole in one of them air was allowed to come into the gap. This meant that the pressure on the inside and on the outside was the same. Pulling them apart was relatively easy.
7. The pushing together of the plungers rapidly forced air out. When you plugged the hole with your thumb, air was prevented from coming into the gap and equalizing the pressure. Now when the plungers are pulled apart the volume of the air trapped inside increases, lowering the pressure.
8. Because all of the outside air pressure pushing on the outside of the plungers is many times greater than the small pressure on the inside, the plungers are not easily separated.
9. The total force that was holding them together can be calculated from the total surface area of the two circles multiplied by 1030 g. If the plungers have a 10 cm diameter there is about 150000 g, or 150 kg, or 330 lb of pressure holding them together.

E. Predict which jug of water will drain the fastest

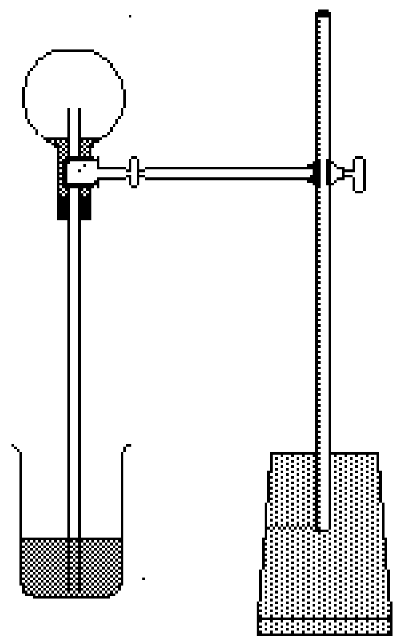
1. Prepare three jugs of water, 1 one gallon plastic milk jug, and 2 one gallon glass jugs. Fill the plastic and one of the glass jugs with water. To the other glass jug add water to the half way mark. Prepare identical one-holed rubber stoppers for each jug. Insert one end of a short piece of glass tubing into the stopper and attach to the other end some rubber tubing.
2. Run water through the tubing to remove all the air and pinch off the end of the tubing with your fingers so that water doesn't fall out the end with the rubber stopper. Now insert the stoppers into the three jugs still pinching the rubber hose.
3. Ask the students to predict from which jug the water will drain out the fastest when the jugs are elevated above the sink so that the rubber tubing is hanging down and you unpinch the tubing.
4. Have three students carry out the actual draining process. Question the class as to why the water drained out of the plastic jug but not out of either of the glass jugs. [The atmospheric pressure is pressing on all sides of the jugs equally. In the plastic jug the pushing of the air on the outside of the jug in addition to the weight of the water in the jug overcome the pushing in of the air experienced at the mouth of the jug. Consequently the water can drain out. Only because the plastic collapsed in response to the air pressure can we have enough downward force to overcome the upward force and have

the water flow.



In the case of the glass jugs the solid container does not allow the outside air pressure to be transmitted to the water. The upward air pressure is greater than the downward weight of the water and no draining from the full jug takes place. A small amount of water may drain from the half-filled glass jug. Turning the jug upside down forces a little of the water in the tube to drain out. Because no air entered, as some water drained out of the flask it lowered the pressure above the water (remember, when volume increases, pressure decreases) in the jug low enough that after a few seconds the upward air pressure is greater than the combined air pressure and water pressure in the jug, and the draining ceases.

F. Magic Fountain



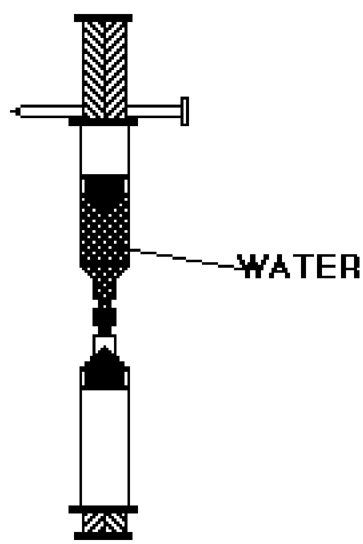
1. Pour 50 mL of water into a 1000 mL Florence flask. Add a small amount of vinegar and a few drops of phenolphthalein.
2. Fill a large beaker with water and add a some sodium hydroxide.
3. Insert a 40 cm piece of glass tubing into a one holed rubber stopper that will fit snugly into the flask. Make sure that the glass tubing extends through the rubber stopper about 10 cm.
4. Turn the flask at right angle to the table so that the 50 mL of liquid rests in the curved portion of the flask. Now insert the rubber stopper with the short end of glass tubing protruding into the flask. Take care that no liquid gets into the tube. Push the rubber stopper in so that there is a snug fit. Slowly

rotate the flask 90 degrees so that the long end of the tube is pointing down and the flat portion of the flask is pointing up The short piece of glass tubing should be situated about 7 or 8 cm above the surface of the liquid which has now fallen into the neck of the flask.

5. Take an iron ring and support the flask by putting the neck of the flask through the ring. Attach the ring to a ring stand.
6. With a Bunsen burner heat the flask. Shortly you should see air bubbles come out the bottom of the long glass tube into the liquid in the beaker. Continue until the liquid in the flask boils. **Be sure and use safety glasses for this demonstration**. Remove the heat. Shortly thereafter, as the liquid begins to condense, liquid should rise up the tube and rapidly spray into the flask. After a few mL of the liquid has entered the flask the entire contents should turn bright pink. The sodium hydroxide entering the flask neutralizes the vinegar creating a basic solution and is indicated by the phenolphthalein turning the whole solution pink.) The liquid should continue to rise until the beaker has been emptied.
7. Did the atmospheric pressure ever change on the surface of the liquid in the beaker? NO. Therefore, since there was upward movement and this requires a difference in pressure, the pressure inside the flask must have become lower. That is exactly what happened when the vapor in the flask condensed. As it changed back to liquid its volume decreased drastically. There are not enough vapor molecules trapped in the flask to counteract the outside air pressure, and the liquid moves in to fill up the extra space.

G. Pulling or Pushing?

1. Students still may think that liquids are drawn up by suction rather than this rise being explained by the pushing force of air pressure. This last demonstration should show that suction does not work.
2. Obtain two 50 mL plastic syringes. In one of these with a hot nail make a hole in the middle of the plunger of the syringe. This insures that when pulled back to the point where the nail can be inserted into the hole that the volume of the cavity created will remain fixed.
3. Cut a small piece of Tygon® tubing and attach it to the first syringe. Now draw water up into the syringe by moving the piston up. Insert the nail so that the piston can no longer move and that the water remains in the barrel of the syringe.
4. Attach the second syringe with its piston fully closed to the first syringe by means of the piece of Tygon® tubing. Make sure there are no leaks.



5. Now, have the students explain how we can move water from the first

syringe into the second. The obvious answer will be to pull the plunger of the second syringe out to suck the water out of the first syringe. It will become quickly clear that pulling the moveable plunger does not do the job. **Suction does not work**. The only way that liquid can be moved into the second syringe is to remove the nail and **push** the water.

H. Reexamination of the Drinking Straw Problem

1. The straw with the holes in it would not allow the liquid to rise. Why? Lets review what we know about air pressure and rising liquids. Ordinarily when you drink through a straw your jar lowers with the volume in your mouth becoming larger, hence the pressure gets lower. Since this is lower than the outside atmospheric pressure, the liquid can be pushed up through the straw. Using the straw with pin holes in it constantly repressurizes your mouth making it the same as the outside atmospheric pressure. Consequently you can never draw the liquid up into your mouth.
2. The soda did not come up the straw that was stuck in the rubber stopper. Why? Since there is no way for the atmospheric pressure to come in contact with the liquid's surface and push it up the straw, you may suck on the straw forever without quenching your thirst. Remember, it is the pushing of the air not the sucking that raises the liquid up the straw.
3. Drinking through two straws simultaneously produced the same problem encountered with the straw having pin holes. Since the pressure in your mouth is constantly being made equal to the outside atmospheric pressure, the outside pressure is pressing against itself.

I. Reexamination of the Unsealed Balloon Problem

1. Do you think the balloon was sucked in or pushed in?
2. We know that the atmospheric pressure could push the balloon in if the pressure on the top side of the balloon was less than the under side. What ways of reducing the pressure have we seen? The best way has been to have a change of state from vapor into liquid.
3. Take the empty flask and add about 20 mL of water. Heat it to boiling until all the air has been forced from the flask. It will now contain only water, some in the gaseous phase and some in the liquid phase.
4. Carefully (the flask is hot) lower the balloon into the flask and fold the lip of the balloon over the mouth of the flask. Allow it to cool. As the vapor turns to liquid the pressure is reduced tremendously inside the flask. Since the atmospheric pressure remains great it pushes in through the mouth of the balloon and forces the balloon firmly against the inside of the flask or jar. How would you remove the balloon from the flask? [By heating it the pressure of the water trapped between the balloon and the wall of the container will increase. When the inside and outside pressure on the balloon are the same the balloon can easily be removed.]

J. Reexamination of the Sealed Balloon Problem

1. If the balloon is going to inflate this time, it does not seem likely that the outside atmospheric pressure is going to be able to do the pushing. Instead, it seem reasonable that the pressure inside the balloon must be doing the pushing. That would mean that the outside pressure will have to be decreased to allow the inside pressure of the balloon be larger.
2. Students should be encouraged to figure this out before you give them help. Tell them to consider the solution to the first balloon challenge and see how this might be changed to achieve our desired outcome in this challenge.
3. Because mayonnaise jars can't be heated with Bunsen burners our heat source will be a pan of boiling water.
4. Add a small amount of water to the jar. Introduce the sealed balloon into the jar. Transfer the jar and its contents to the pan of hot water. After a few minutes use oven mitts or other types of protection to remove the jar from the water. Quickly screw on the lid.
5. Transfer the jar and contents to a container of cold water and roll it around quickly so that it is cooled off evenly on all sides.

6. Observe the balloon inside. It has expanded to fill the entire volume of the jar.
7. The small amount of water vaporized driving out all the air in the jar. Screwing on the lid keeps any additional air from entering the system. When the jar is placed in the cold water the gaseous water changes into liquid water with a drastic drop in pressure. The pressure inside the balloon now is greater that the pressure in the jar and the balloon expands because the trapped air is pushing against the lower outside water pressure.

CONCEPT EXTENSION

A. Upside-down Glass
1. Obtain two 8 ounce plastic drinking glasses. With a hot nail or ice pick melt a small hole through one of the gasses at the bottom edge. Try not to make the hole obvious to the casual glance.
2. Have a student volunteer come up to join you in a demonstration. Give the student the glass with the hole at the bottom. Do the following demo over a large sink or use a large pan or aquarium to catch any water that spills.
3. Indicate to the student that we will do this demo together. Say, "Watch and do as I do."
   a.) Fill the glass with water.
   b.) Place a 3 x 5 notecard on the mouth of the glass so that it covers all the opening.
   c.) Quickly turn the glass and card upside down while keeping your hand on the card which is now in contact with the water. Ask the students what will happen when the hands are taken away.
   d.) Your card will stay on with all the water trapped in the glass. There is enough air pressure to support the weight of the water. The student's card will fall off and the water will pour out.
   e.) Tell the student that your glass was a special anti-gravity glass and that you are willing to switch glasses. When the demo is repeated water does not pour out of either glass. When they inquire why water didn't come out of your glass, tell them that you have been developing special anti-gravity "mind-over-matter" powers.
   f.) When you use the glass with the hole in it casually cover the hole with your finger and everything will work well and the water won't come out.
   g.) Try to solicit explanations from the class. If they are not forthcoming quickly, tell the students that you can turn gravity off or on at will. Give them some crazy story such as if they close one eye and hold their mouth open that you have found that you can temporarily turn off gravity. Even if you can't get them to enter in, you do it. At just the right moment remove your finger from the hole and the card and water will come falling down.
   h.) Try and liken this to what happens if you have a straw full of water and you put your finger over the top end. As every student knows, the water will stay up in the straw, but when your finger is removed it streams out. Removing the finger allows the atmospheric pressure to be the same on the top and bottom of the straw. By this time some curious student will have found the hole in the bottom of the glass. If not, by all means **don't tell them what was happening**. Make them figure it out.

B. Diet vs. Classic Coke® Cans (See Gas Law Lesson, p. 114-115)
1. When the students enter the room have two Coke® cans heating on the hot plate. Using tongs pick up the Classic Coke® can, rapidly turn it upside down, and thrust it into a pan of ice water. Instantly, it will be crushed.
2. Repeat using the Diet Coke® can. This time there will be only a slight implosion of the can.

3. Students should have a good appreciation for what happens here. In the Classic Coke® can a few mL of water had been added to the can and the heating had filled the can with gaseous water. In the Diet Coke® can no water had been added, and only hot air filled the can
4. Upon rapid cooling the gaseous water changed to liquid water (the volume changed by a factor of 70) reducing the pressure inside the can drastically. The air pressure pushing in on the can and down on the water in the pan immediately crushed the can and forced water inside. In the Diet Coke® can the cold water merely cooled the hot air down with very little decrease in volume.
5. This can be demonstrated in a less dramatic way by using a plastic milk jug instead of an aluminum can. Fill the jug with hot water and let sit for a couple of minutes. Pour the water out and cap the plastic jug. In a short time the jug will start to collapse because the warm air inside is cooling which reduces the pressure, allowing the outside atmospheric pressure to push in on the walls of the jug.

C. This activity is patterned after the "old" egg in the milk bottle demonstration. In recent years it has been almost impossible to find a milk bottle, and for those of you who have done this you might also remember that sometimes the egg takes a beating and gets messy. The demo that follows is the modern day version.

1. Obtain a glass bottle (Ocean Spray® juice bottles work well).
2. Our modern day version of the egg is a water balloon having a diameter of about 10 cm. You might have to adjust this size to your specific bottle.
3. Have students try to push the balloon into the bottle. It should be large enough so that they cannot put it into the bottle by merely pushing.
4. Challenge them to get the balloon in the bottle without removing any water from the balloon.
5. It is possible that they will want to add a small amount of water, heat it, put the balloon in the mouth of the jar, and cool the jar by pouring cold water on it. I am sure that they could make this work this way, and this does show the carry-over from the CONCEPT INVENTION phase.
6. Ask them if they could do it without using additional water in this way.
7. As we remember from the old egg in the milk bottle version, a small strip of paper can be set on fire and dropped into the bottle. If the balloon is quickly put into the mouth of the bottle, the air cools in the bottle in just a few seconds which reduces its volume and the balloon is pushed in the by the greater outside air pressure.
8. How can the balloon be removed from the bottle without puncturing the balloon?
9. For those who added water to the bottle and cooled it to get the balloon in, maybe heating it would increase the pressure in the bottle enough to push it out. This is worth trying. Be careful when heating the bottle. It is not made out of Pyrex® glass and won't take a direct heat. It would probably be safer to place it in a pan of boiling water.
10. Probably an easier way is to insert a straw into the bottle, turn it upside down so that the narrow end of the bottle is pointing down, and push the straw in between the glass and rubber. A few sharp puffs of air through the straw should dislodge the balloon nicely.

D. How Tall Can a Straw Be?

1. Ask students to predict what would be the tallest straw that they could build that would allow them to drink a soda.
2. Indicate to them that they can join two, three, or more straws together to make a super straw. A short slit in one straw will allow the joining together of two straws. A tight strip of tape to prevent leakage is also recommended.
3. Have teams work on this problem. Eventually they will want to drink from the second or third stories of the school. Let them try to work it out and overcome the engineering problems.

4. The maximum height that they will be able to draw the liquid up is about 33 ft. This is equivalent to a pressure of 760 mm of mercury. In other words, the outside air pressure can only push up water to a height of about 33 feet. No matter how hard they suck, air pressure will only push water up 33 feet.
5. Because Coke® has all that sugar in it and its density is greater than pure water, they may not even be able to get it to rise 33 feet.
6. Essentially, the students have demonstrated how a water barometer could be constructed. After this activity it should be obvious why we use mercury in our barometers instead of water.

E. Ask students to research why their ears pop when ascending in an airplane?
1. When a quick and drastic change in altitude occurs a difference in pressure is created between the air in the middle ear and the air outside the body.
2. This difference is equalized either by air rushing into the Eustachian tube or escaping from it by way of a valve-like flap, and causing the eardrum to bend inward (if the plane is descending) or outward (if the plane is ascending).
3. This is why many people chew gum when flying since this type of activity keeps the Eustachian tube open and the air pressure equalized.

F. Ask students to research what causes their knuckles to crack or pop when they pull on their fingers. Ask them to crack the same knuckle twice within five minutes. They will not be able to do it!
1. Physicians have discovered that the noise we hear is caused by exploding gas bubbles.
2. Joints have fluid in them containing dissolved gases. When the joint is stretched, the pressure is reduced because the volume is increased and the gas bubbles pop out of the solution. (Same thing happens when a bottle of soda is opened.) Since the gas can't escape from the joint, in about fifteen minutes it is reabsorbed by the joint fluid. Only then can the knuckle be cracked again.