Stubborn Ping-Pong Ball

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Stubborn Ping-Pong Ball

Concepts Illustrated: Air pressure, air current, Bernoulli's principle, Coanda effect, fluid dynamics, mass, volume, aerodynamics, airplane flight, dynamics of tornadoes, molecular motion of gases.

Several construction designs and demonstration variations of this demonstration offer a range of equipment and presentation choices to suit available resources.

Paradox:

No matter how hard they try, students discover they are unable to blow a ping pong ball farther than a couple of inches into the air!

Equipment:

Each student should use their own device. For sanitary reasons, they should not share them.

1) A bendable or flex straw.
2) A 1 or 2L plastic soda bottle and its cap.
3) A ping-pong ball.
4) Ruler.
5) Timer is optional.
6) Long-stem funnel is optional.
7) Tubing is optional.

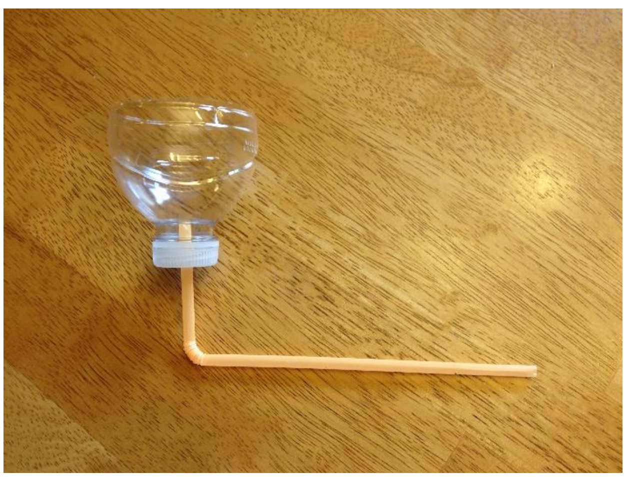
Preparation:

Three construction designs will be described here. The first is the model that will be used for the *Lesson Procedure* explanation.

1. The device is constructed by first drilling a hole in the bottle cap. A hammer and nail can also be used to make this hole. The diameter of this hole should be the same as the straw. When pushed into this hole, the straw should fit as snugly as possible. Push the short end of the bent straw into the hole. It should be pushed in far enough so that when the ping-pong ball rests in the cap, the straw contacts it. To determine the most accurate position, hold the long end of the straw horizontally with the short end bent vertically. Place the ping-pong ball in the cap and blow through the long end of the straw. If the straw is not pushed into the cap far enough, the ball will spin but not lift into the air. If this occurs, push the straw up a bit into the cap. If the ball falls off the cap when you blow into the straw, the straw is pushed in too far. If this occurs, pull the straw out of the cap a bit. When the ping-pong ball hovers over the bottle cap when you blow into the straw, it is in the desired position. Now using a hot glue gun, put a bead of glue around the straw at the hole in the bottle cap.

Be sure to practice this demonstration several times before you present to the class. Blow a slow, steady stream of air. If you blow with too much force, the ball will fly out of the stream of air and away from the device.

2. This simplistic design involves just a straight straw. Using a hole puncher, make a hole in one end of the straw, about two inches from the end. There will be a hole through both sides of the straw. Put a piece of tape over a hole on one side. Now pinch that end of the straw and tape the end shut. Blow into the opposite end of the straw with the open hole on top and the sealed hole underneath. Place the ping-pong ball in the air stream above the straw and it will be held in place.
3. With practice, the ball will hover in mid-air using just a flex-straw. Bend the short end up, blow into the long end and place the ball in the upward stream.
4. The device can also be constructed by cutting off the top of a plastic water bottle or soda bottle. Using a box cutter or utility knife, cut the bottle where the sloped top meets the straight side wall. Drill a hole, or drive a nail, into the center of the plastic bottle cap. Screw the cap onto the bottle top and insert the short end of the straw into the cap. Match the nail to the width of the straw and it will form a fairly tight seal. That's it! Using this model, place the ball on the stream of air after you have begun blowing into the straw. Blow as hard as you can. The ball remains firmly in the stream of air.



Construction of the device.

With ping-pong ball in place.

The Lesson:

Show the device and hold it in position with the long end of the straw horizontally and the cap upright. Now place the ping-pong ball into the cap. Explain that you are going to blow into the straw. You will use a ruler to measure how high the ping-pong ball will lift into the air, away from the cap. Hold the ruler at the cap, vertically. When the ball lifts off the cap it will rise along the ruler. There will be many different predictions. Now, blow into the straw while holding the ruler in place at the cap. Students will be quite surprised that their teacher cannot blow the ping-pong ball more than a few inches from the cap. They will be very surprised to find that the ball hovers in mid-air over the cap without being blown away from it! Students will be excited to try this for themselves, to prove they can blow hard enough to blow the ball completely away from the cap.

The demonstration can be extended, if you choose. Still holding the straw horizontally, rotate the cap so that it is now facing downward. Explain that while holding the straw 12 inches above the desk, you will hold the ping-pong ball in the cap. You will blow into the straw and then release the ball. Ask students to predict how long it will take for the ball to hit the desk. Charge one student to be the timekeeper, giving her a timer or asking her to watch the clock. Again, there will be many different predictions. But no one will predict what actually occurs. Hold the ball in place and begin to blow into the straw. Slowly release the ball. The ball will hover just under the cap, remaining suspended in the air without falling! This is rather startling to observe!

Lesson Variation:

This variation of the demonstration is conducted in the same manner as the previously described procedure, except that it employs a funnel in place of a straw. It should be unused and clean. Display the funnel and a ping-pong ball. Now place the ping-pong ball into the funnel, with the stem down. Lift the funnel up into the air, above your head, and blow into the stem. Hold the ruler in position to measure the height that the ball is thrown into the air. But, the ping-pong ball remains firmly in place!

Now invert the funnel so that the stem is upright. Place the ping-pong ball in the funnel, holding it in place so that it doesn't fall out. Explain that you will begin to blow into the stem and then release the ball. As in the previous demonstration, ask students to predict the time it takes for the ball to hit the desk once you begin blowing into the funnel. Once they've predicted, blow into the stem. Release the ball to show that it remains in place and does not fall out of the funnel!

A straw that slides over the stem of the funnel could also be used to blow into.

Flexible plastic tubing could also be pushed onto the stem of the funnel. This would allow for the length of the stem to be manipulated. It would also allow for the shape of the stem to be tested. Finally, it would allow students to use different funnels while simply reusing their plastic tubing.

Finally, a balloon could be used by students who do not want to blow into the tube or stem. Blow up the balloon and clip its neck to prevent the air from being released. Then, attach the neck of the balloon to the stem of the funnel. Remove the clip, allowing the balloon to deflate and the air inside to blow through the stem.

Possible Variables:

1. The length of the horizontal section of the straw.
2. The length of the vertical section of the straw.
3. The diameter of the straw. This can be investigated with balls of different diameters, as well.
4. The volume of the ball.
5. Balls with holes in them. The number of holes can also be investigated.

6. Balls of varying mass and density. The mass of the ping-pong ball can be adjusted by poking a hole in it, filling it with sand or water, and plugging it with a small bead of putty, clay, or wax.
7. Replacing the ping-pong ball with a ball of another substance, such as a cork, Styrofoam ball, or cotton ball. Students might also use different diameters of these balls. They can also investigate Styrofoam balls of various shapes.
8. Using the straw without a cap.
9. The number of balls placed into the stream of air.
10. Length of funnel stem. This can be adjusted by attaching tubing or a straw to the stem.
11. Angle that the device is held.

Phenomenon Explained:

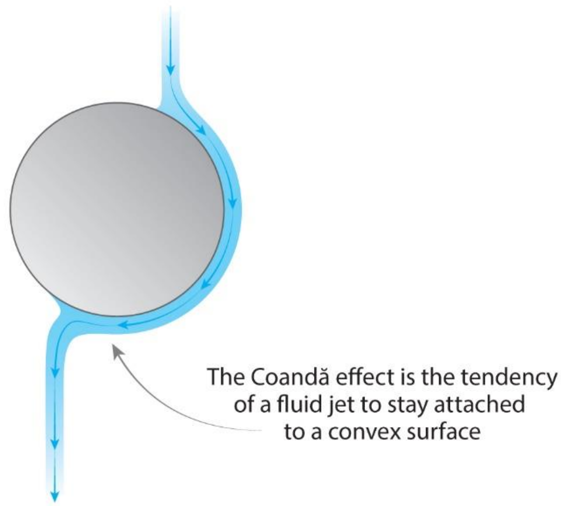
This demonstration is a rather startling method of presenting Bernoulli's principle, which describes a phenomenon observed in moving fluids, either liquid or gas. It states that as the speed of a fluid increases, the pressure within it decreases. Fast moving air essentially creates a region of low pressure. The faster a fluid, whether gas or liquid, moves over a surface, the less air pressure it exerts on that surface.

When the ball is initially placed into the cap used in the original demonstration, gravity holds it in place. When you blow into the straw, air pressure pushes the ball against gravity. This is enough pressure to overcome the force of gravity and the ball is lifted. The air is traveling fastest at the cap, where it first contacts the ball. This creates an area of high pressure. After hitting the ball, the air travels around it, evenly distributed. The air curves around the ball, but continues on a straight path on the opposite side. A pocket of low pressure is created on this side of the ball. This creates a pressure gradient with more air pressure below the ball, and less above it. The atmospheric pressure above the ball is now greater than the air pressure blowing around it. The higher atmospheric pressure "pushes" the ball down, towards the cap, holding it in place. When the force upward is balanced with the force of atmospheric pressure and gravity, the ball will remain rather securely suspended in the stream of air.

When the device is held upside-down, the higher atmospheric pressure exerted on the opposite side of the ball is great enough to oppose the force of gravity, and the ball does not fall.

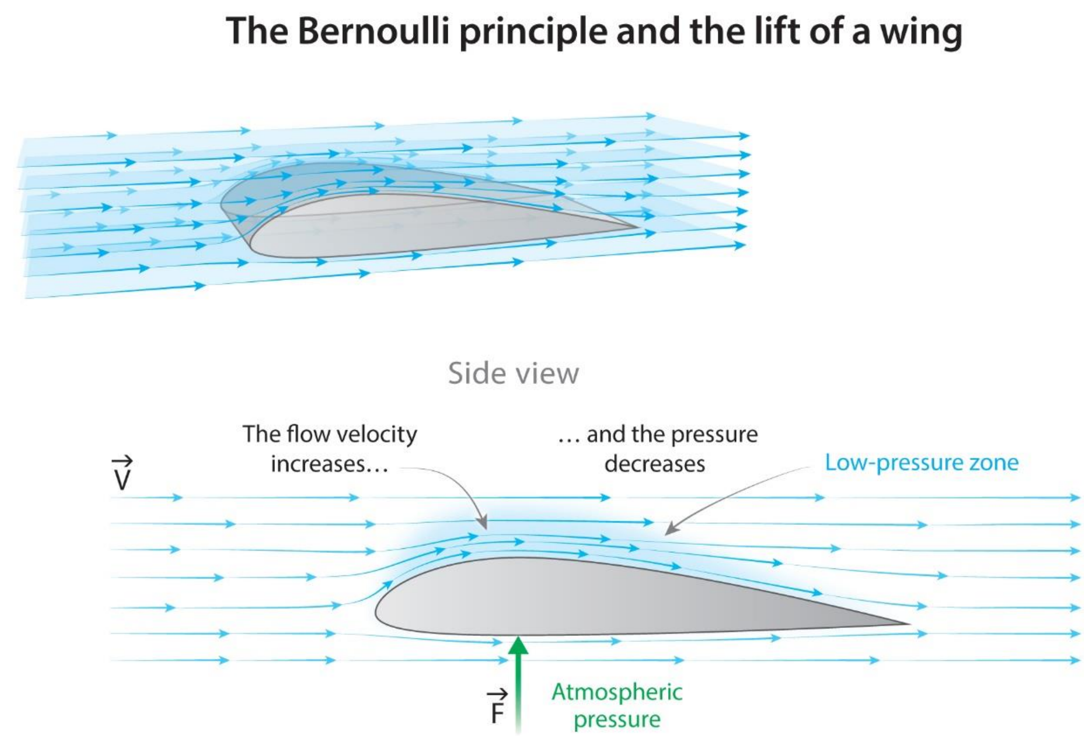
In the lesson variation, a current of fast moving air is created on the side of the ball where the stem meets the funnel. This results in reduced air pressure at that point and lower pressure on the opposite side of the ball, where the higher atmospheric pressure prevents the ball from being ejected from the funnel. In fact, the harder one blows into the stem, the lower the pressure, and the more difficult it becomes to blow the ping-pong ball out of the funnel.

The Coandă effect



The behavior of the air blown into the funnel also exhibits the properties of the Coanda effect. It describes the tendency of a streaming fluid to follow along a curved surface it encounters, given the angle of the curvature is not too sharp. When the air hits the ping-pong ball, the current divides, wraps around the ball, and converges on the other side.

Bernoulli's principle and the Coanda Effect explain, in part, how airplanes fly. Air flows over the upper surface of the wings faster than under them. This creates a reduced air pressure above the wings and a higher pressure under them. This generates lift. In addition, when the wing is tilted, air is deflected downward by both its upper and lower surface. Air flowing across the wing glides along the tilted direction of its surface. The air is entrained from the surroundings, resulting in a region of lower pressure above the wing. This also generates lift.



Counterintuitively, the faster the flow of air, the lower the pressure it exerts. This explains the massive destruction caused by tornadoes. The incredible speed movement of air creates a tremendous decrease in pressure within a tornado. The stronger air pressure around the tornado throws nearby objects into it.

Standards Alignment:

Next Generation Science Standards (NGSS, Lead States 2013)

Disciplinary Core Ideas in Physical Science

PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter

Disciplinary Core Ideas in Earth and Space Science

ESS3: Earth and Human Activity

ESS3.B: Natural Hazards