Overview

Air, like all gases, is made of molecules, and so it has mass. Air may seem insubstantial, and you can’t see it, but it’s real and it has mass. There are several consequences of this that you know about:

• When the wind blows, you feel the force. This force is the mass of the air slamming into you.
• When you ride your bike fast, you feel the air resistance. This is the force you must apply to push the air aside to move forward.
• When airplanes fly they push down on the air, and this leads to an upward force on the plane.

But as real as we know the mass of the air is, it still seems abstract because we just don’t feel it most of the time. Here we present an activity that will let your students truly experience the mass of the air. The trick is to get enough air together... which is why the exercise uses a giant beach ball.

Theory

If you buy a 1-liter bottle of water, the mass of the water in the bottle is 1 kilogram. (Indeed, that’s how the size of the kilogram was chosen!) When you drain the water from the bottle, it’s replaced by air. 1 liter of air, in Colorado, has a mass of about 1 gram, or 0.001 kg. One thousand liters is a cubic meter. One thousand liters (1 cubic meter) of water has a mass of 1000 kg. In Colorado, 1000 liters (1 cubic meter) of air has a mass of 1 kg. (At sea level, the air is denser and so the mass per cubic meter is greater, about 1.2 kg.)

When you fill up a balloon, you are adding mass to the balloon. But if you put the balloon on a scale, the scale won’t read the mass of the air you’ve added because, as the balloon got larger, it displaced more and more air from the area immediately surrounding it. This produces an upward buoyant force on the balloon. The buoyant force is equal to the mass of air displaced, so, if the pressure inside and out are the same (and they are, to a first approximation) the additional weight is canceled by the additional buoyant force. Thus, the reading on the scale — the amount of force the scale has to apply to cancel the weight of the balloon — won’t change from its initial value, since the weight of the additional air within the balloon is canceled by the buoyant force on the balloon.

It’s a different matter when you try to accelerate the air — then you really feel the mass. In this experiment, you’ll work with a 5-foot diameter beach ball. The volume of air in the beach ball is the volume of a sphere of diameter 5.0 ft = 1.52 m, or a diameter of 0.76 m. The volume of the beach ball is the volume of a sphere of radius 0.76 m:

\[ V_{sphere} = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (0.76m)^3 = 1.8m^3 \]
The mass of the air in the ball is thus 1.8 kg, almost 4 pounds. The mass of ball itself (the plastic shell you inflate) is about 2.3 kg, about 5 pounds. This means that the total mass of the ball + the air inside the ball is 4.1 kg, or 9 pounds. You'll need to exert a fair amount of force to rapidly accelerate this much mass — to make quickly speed up, slow down, or change directions.

**Doing the activity**

**Preparation before class:** Choose an area where you’d like to experiment with the beach ball and inflate it there. This could be a grassy area outside or the school gym. The States of Matter kit comes with a powered pump and an extension cord, so you can inflate the beach ball quite quickly. We timed it, and the pump in the kit took about 3 minutes to fill the ball.

Explain to your students that you are going to do an experiment to see if they can feel the weight of air. Take them outside or to the gym and show them the giant 5-foot beach ball. They will be surprised and intrigued to try this!

**With your class:** Gather in a circle and have several of your students join you around the beach ball. Have them gently touch the beach ball and then, all together, lift it up over the group. Ask one student to stand under the middle of the beach ball with their hands in the air. Now explain to the students who are holding up the beach ball that, on the count of 3, they will all push up on the ball at the same time, and then step back. Explain to the person under the ball that the beach ball is going to fall down on them and they will get to feel how heavy it is! (Let this student know that the ball will come down with a fair bit of force, so they’re not too surprised or frightened by the experience.)

Pushing the ball in the air can be tricky if everyone around the ball doesn’t push up at the same time. Remind them that as soon as they hear the number 3, they should push the ball up. Proceed and have the ball drop on the student in the center. Stop, gather your students together, and discuss.

Ask the student that was under the ball how it felt to have the full weight of the ball hit them. (Heavy! It probably pushed them down or sideways.) Ask the students who were standing around the ball if it was difficult to push the ball into the air. (No, it was easy; it felt light, etc.) Encourage them to give reasons why they think it was different for the person in the center and the classmates around the edge. They most likely will say that there was only one person in the center, but a lot more around the edge of the beach ball, so it would feel heavier to one person and light to many. This is a very valid idea! Have students test it out.

Have the same person in the center hold the beach ball up. Students may have to help lift it over the student and hold it until the ball is balanced by the person in the center. The students should back away slightly, but be there to help if the ball moves to one side or the other. Have the student holding the ball focus on how the weight of the ball feels. Now have the students around the ball step in and push the ball up on the count of 3, repeating the experiment. Gather all your students again and have the person in the middle talk about how different it felt just holding the ball, compared to having it dropped on them.

Explain to your students that when they lifted the ball up, the air in the ball pushes the air around it out of the way. Some of the air that was moved out of the way fills in below the beach ball and pushes up on the beach ball above it. As a result, the beach ball doesn’t feel very heavy when the person in the middle is just holding it. But when the beach ball is pushed up, it changes direction due to gravity, and falls faster and faster to the ground. Now the person in the middle doesn’t just have

**Necessary materials:**

- 5-foot diameter beach ball
- large open area with grass, or a smooth floor (such as a gym)
- pump, extension cord, and electrical outlet
to hold the ball still (with an assist from the air around the ball), they have to make the ball and all the air inside it come to a stop from a substantial speed — this requires quite a bit of force!

Everyone is going to want to try this — and should — but we’ll leave how to make this work with your whole class up to your experience as a teacher. Perhaps you could enlist the help of a staff member or volunteer who could lead the rest of your class in a game or activity. while you are working with small groups of students.

When you are done, just uncap the beach ball and let it deflate on its own. When it has deflated, you can fold or roll it up and put it back in the kit for next time.

**Extension:** This is another way to help students in your class experience the mass of the ball. It does feel a bit different, so if possible, let your students experience both versions of the activity.

Ask all of your students to gather in a circle. Roll the beach ball next to a one side of the group, and have these students hit or push the ball with all their might at a group of students on the other side of the circle. Those students on the receiving end, should then push the ball with all their might back. This can go on for quite a while as the ball collides with different students around the circle. This gives them an experience feeling the weight of the air and the beach ball and also is quite fun! Be sure to discuss what they observed and felt and equate it back to the idea that air has mass (that fills up the ball) and it weighs something.

**Summing up**

The idea that air has mass, and therefore weight, is a very abstract concept for students. This activity is a great way to let them feel the weight, and a unique experiment they will remember for a very long time.

**For more information**

Little Shop of Physics: [https://www.lsop.colostate.edu](https://www.lsop.colostate.edu)

Colorado State University College of Natural Sciences: [https://www.natsci.colostate.edu](https://www.natsci.colostate.edu)