

Why can warm air “hold” more moisture than cold air?

A laboratory experiment from the Little Shop of Physics at Colorado State University



Overview

In the winter, when you heat cool air to warm your house, the air gets very dry. Why is this? There’s the same amount of moisture, but the relative humidity of the heated air is much less—the warmed air can “hold” a good deal more moisture than the cool air.

Is there some special property of warm air that lets it soak up more water vapor? Not really. It’s just that, at higher temperatures, water molecules are more likely to go into the vapor phase, so there will be more water vapor in the air.

This activity is a good one for helping your students make a connection between a microscopic model and a macroscopic

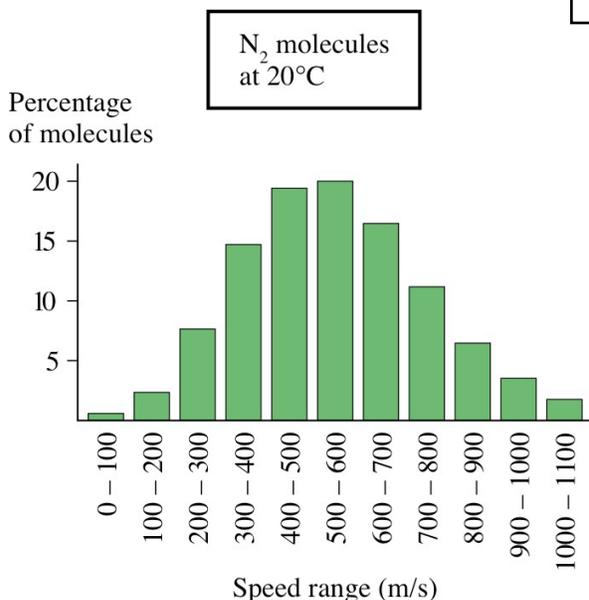


Chart of different energy levels of nitrogen.

Necessary materials:

Activity 1

- Dice (enough for 4 or more per student)
- 2 areas of the classroom, one designated water vapor, 1 for liquid water

Activity 2

- Hand boiler toy
- Ice (optional)

The hand boilers are sold under a variety of names including “hand boiler” or “love meters”. We have found them at many educational sites, including:

Copernicus Toys: www.copernicustoys.com
Educational Innovations: www.teachersource.com.

consequence, much like the “molecules in a box” activity that is part of the “What is pressure?” It also shows the idea of vapor pressure, which can be a tough one to wrap your mind around.

Theory

Temperature is a measure of energy at an atomic level. For a gas, high temperature means that the atoms or molecules move faster—they have more kinetic energy. But the atoms or molecules don’t all have the same speed. The graph at right shows the distribution of speeds for nitrogen molecules at a temperature of 20°C. The molecules are moving at a pretty good clip, but some are much faster than others. Some of the molecules are moving at speeds typical of very fast trains, perhaps 50 m/s. Others are moving at the speed of supersonic aircraft, 1000 m/s. If you raise the

temperature, the whole distribution will shift to the right—the *average* speed will increase—but there will still be a range of speeds.

The same thing holds true in a liquid. At any temperature, the molecules in the liquid will be moving at different speeds. Some of the molecules will be moving fast enough to escape—to go into the gas phase.

This makes sense. You know that water can evaporate—that is, go from a liquid to a gas—at temperatures less than the boiling point of water. Warm water will evaporate more quickly than cold water, because the average speed of the molecules—and thus the chance that the molecules are moving fast enough to “escape”—is higher.

Of course, if there are water molecules in the air, they can be moving slow or fast. If they are moving slowly enough, they might go into the liquid phase—the might condense.

Suppose you have a lake, and above it the air is saturated with water vapor. There’s an equilibrium between these two processes. Water molecules are going from liquid into gas—going from the lake into the air—at the same rate as molecules are going from the gas into a liquid—going from the air into the lake. If you warm up the air, and thus the lake, more molecules will go from the liquid phase to the gas phase. There will be more molecules of water in the air. So the air, in some sense, will “hold” more water vapor, simply because the faster molecules are more likely to be in the gas phase.

More molecules means more pressure, as we’ll see. We often speak of the vapor pressure of the water vapor, that is how much pressure there would be if only water was present. But more on that later.

Doing the Experiment - Activity 1

Explain to your class that they are going to model the variation in molecular speeds by participating in this activity. Each student will play the role of a molecule of water that can change phase if it has more or less energy. Give each student 2 dice. The students will roll the dice to see how much energy they have; a higher roll means more energy. Have students gather in the area of the room designated as liquid water.

The students should use both hands to cup the 2 dice and give them a shake. Have them open their hands and add up the total. If they get a sum of 11 or more, they have enough energy to go to the water vapor area. If they have a sum 10 or less, they should remain in the liquid water area.

Here’s something to notice: Which molecules left? The most energetic ones! So the average energy of the ones that stayed behind is less. That’s why evaporation cools things off.

Have your students shake their dice a few more times, so they can observe people switching from one side to another depending upon the sum of each roll (the molecule’s energy level). Continue play until a trend emerges. How many molecules are leaving the liquid phase for the gas phase? How many are leaving the gas phase for the liquid phase? This is equilibrium—a good point to raise.

Now explain that you are “heating” the water and give each student a third die. Ask your class to predict what will happen if the molecules have more energy. The parameters remain the same: A sum of 10 or less means the molecule goes to or stays in the liquid water phase, a sum of 11 or more means the molecule goes to or stays in the water vapor phase. Continue play until a trend emerges.

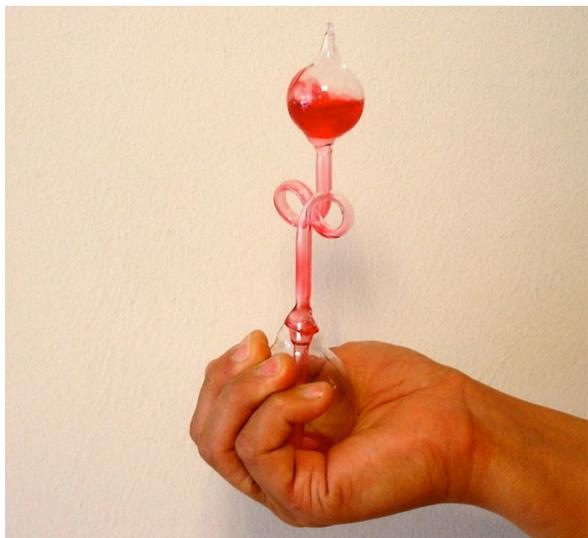
*Notice that there are more molecules in the gas phase now. That means that the gas molecules have more pressure. This is the **vapor pressure** of the water in the gas phase.*

Continue by giving each student a 4th die. The students will quickly spot the trend that emerges.

Ask your students: What would happen to the energy of each molecule if every student had 12 dice to shake each time? If the temperature is high enough, all of the molecules will go to the vapor phase. That’s what happens when water boils.

Doing the Experiment - Activity 2

Show your class the hand boiler device and explain that they will be working with one of these toys in each cooperative group. Explain that this activity also has to do with the question above: Why can warm air “hold” more moisture? Discuss safety issues:



Bubbles of vapor rise through the liquid giving the appearance of boiling.

through the liquid as well, giving the appearance of boiling. Have them talk about how this connects to the activity with the dice.

You might also ask the group what would happen if instead of adding energy, they lowered the energy level of the molecules. Have cold water or ice available for them to experiment. Have them describe how this would look in the dice activity.

Summing Up

These two activities help students visualize some very abstract concepts, the notion that molecules always have some range of energy/speed and the idea of a vapor pressure or a partial pressure.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: <http://cmmmap.colostate.edu>

Little Shop of Physics: <http://littleshop.physics.colostate.edu>

SAFETY NOTE 1: These devices are made of thin glass and are very fragile. Caution students to work very gently with them and avoid knocking them over or dropping them.

SAFETY NOTE 2: There is ethyl alcohol inside the hand boilers. You can use the heat of your hand to work with them. Never heat them with hot plates, mug warmers, or open flames as they will break and the liquid is flammable.

Have a student hold the hand boiler in his/her hand while the other students in the cooperative group observe what is happening. They should see the liquid rise up to the top of the tube and then appear to boil.

Have your students discuss what they are seeing. Have them think about how a person's warm hand leads to more energetic molecules and a higher temperature. This leads to an increase in vapor pressure, which forces the liquid up the tube. Bubbles of vapor escape