What is the opposite of sweating?

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

Overview

When you sweat, liquid water on your skin turns to vapor. This phase changes takes away energy, cooling you. And when water vapor turns to liquid water, it releases energy. When water vapor condenses on a surface, it warms it—by quite a bit!

The transport of energy by such phases changes in the atmosphere is very important to understanding weather and climate, but it can be abstract and difficult for students to grasp. In this activity, your students will actually see chocolate melting due to the release of energy as water vapor changes from a gas to a liquid.

Necessary materials:

- 2 hot plates
- 2 miniature chocolate bars
- 2 large metal serving spoons
- 2 double boiler pans
- Water
- 2 chef hats (optional)

Water in the lower pan boils. The resulting water vapor condenses on the upper pan, releasing heat energy. The warming of the upper pan is almost entirely due to the energy released when the water condenses.

Theory

Imagine heating water in a pan on your stove. When you turn on the burner, you are adding heat energy to the water, and its temperature will rise. If you have 1 kg of water at 0°C, you will need about 420 kJ to raise it to the boiling point at 100°C.

Now, imagine that you keep the burner going. The temperature won't rise anymore; instead, the heat energy that you put in is used to convert the liquid water to water vapor—you are boiling the water away. To completely boil away 1 kg of water takes 2260 kJ—much more energy than it took to heat the water up. This **latent heat** is responsible for most of the warming and cooling that water does in the environment, as we will see.

Water will evaporate at lower temperatures than that at which it boils. Evaporation is still the change of liquid water to water vapor, so heat energy is needed. If you sit outside on a hot summer day, you sweat. Water on your skin evaporates, cooling your skin as it does. The evaporation of 1 kg of water at normal skin temperature of 30°C carries away even more energy than boiling—2400 kJ. This is A Good Thing; it means that your body can keep itself cool by evaporating modest amounts of water.

When water evaporates, it carries away thermal energy. This is something most folks know and understand. But the opposite is also true: *When water condenses, it gives up thermal energy.*

Air cools when it rises and expands, but the rate of cooling decreases for moist air, because as it cools water vapor condenses, releasing energy as it does. Condensing water vapor to liquid water means that small droplets of water form—a cloud. Making a cloud reduces the cooling of the rising air. Dry air cools by about 10°C for a rise of 1000 m; moist air (that is, air containing water vapor) cools by about 5°C for a rise of 1000 m.

Summing up: **Sweating keeps you cool, and making clouds keeps the air warm.** The consequences of evaporation for biology are dramatic, and the consequences of the condensation heating are no less dramatic for the atmosphere. Water vapor is one of the key elements that the atmosphere uses to move energy around

Doing the Experiment

This is a teaching demonstration we like to call *Cooking with Condensation*. It's great fun and the results are quite memorable.

> **SAFETY NOTE: The hot plates, double boilers, and boiling water can get very hot. Warn students to be careful and avoid touching these items, before, during, and after the demonstration. You will want to use 2 reliable adult volunteers to demonstrate.**

- Before you begin, set up the two cooking stations identically. Turn both hot plates to high. The only variable in the experiment will be that one double boiler pan is dry and the other one has water boiling in it.
- Explain to your students that you are going to explore the question: Do things get warmer or colder when water vapor condenses? As a class, brainstorm examples of this happening such as: mirrors or windows getting misty when you take a shower, droplets forming on the outside of a cold glass of lemonade on a warm summer day, dew on grass blades in the early morning, etc.
- Tell them that you are going have a competition to test the question above. Ask each of your students to make a prediction before you begin.
- Choose two volunteers to compete in the contest: *Cooking with Condensation.* The goal is to see which cook can start melting a chocolate bar before the other. The two volunteers should put a chocolate bar into the bowl of the spoon. They should hold the spoons equidistance above the double boiler they are using. We suggest 2 to 3 inches above.
- Comment on what is happening to the spoons. The one above the boiling water is getting foggy looking. Occasionally have the two cooks hold up the spoons at an angle. The one cooking over the boiling water will start showing some chocolate melting around the edges of the bar.
- Discuss what they think is happening to melt the chocolate in the spoon. The water vapor changed to a liquid phase releasing energy as it condensed on the spoon. Return to the examples the class brainstormed at the beginning of the activity. Review what is happening with each example as the water vapor changes phase during condensation.

Summing Up

When students observe this demo, they see the results of water molecules going from a gas to a liquid phase, releasing heat energy as they condense. The solid chocolate bar absorbs this energy and begins melting, changing phase to a liquid.

Check out the following activities to explore more about this concept: *How can clouds keep the air warmer?* and *How can freezing make something warmer?* Your students will never look at phase changes quite the same again!

For More Information

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

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

How can clouds help keep the air warmer?

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

Overview

When air rises, it cools. But if the air contains water vapor,the cooling can bring the air below its dew point—the water vapor will condense. This has dramatic consequences for the air temperature.

Necessary materials:

- Latex or nitrile glove

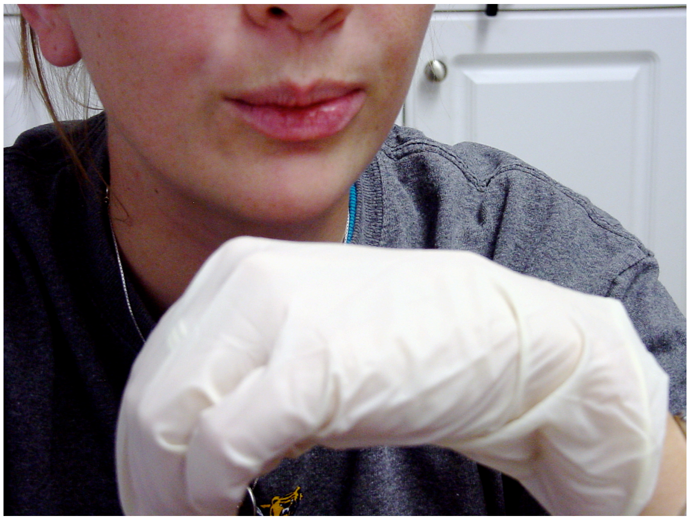
The glove isn't strictly necessary for this experiment, but it does heighten the effect. We've found it makes a good tool to help folks better sense the thermal energies involved in evaporating and condensing water.

Theory

Imagine heating water in a pan on your stove. If you turn on the burner, you are adding heat energy to the water, and its temperature will rise. If you have 1 kg of water at 0°C, you will need about 420 kJ to raise it to the boiling point at 100°C.

Now, imagine that you keep the burner going. The temperature won't rise anymore; instead, the heat energy that you put in is used to convert the liquid water to water vapor—making it boil. To completely boil away 1 kg of water takes 2260 kJ—much more energy than it took to heat the water up. This **latent heat** is responsible for most of the warming and cooling that water does in the environment, as we will see.

Water will evaporate at lower temperatures than it boils. Evaporation is still the change of liquid water to water vapor, so heat energy is needed as well. Suppose you were to sit outside on a hot summer day and douse yourself with water; the water would evaporate, cooling your skin as it did. The evaporation of 1 kg of water at normal skin temperature of 30°C carries away even more energy than boiling—2400 kJ. This is A Good Thing; it means that your body can keep itself cool by evaporating modest amounts of water.



Your breath is always the same temperature, whether you blow hard or easy—which you can tell by wearing a rubber glove.

So, as we have seen, when water evaporates, it carries away thermal energy. This is something most folks know and understand. But the reverse is also true: *When water condenses, it gives up thermal energy.*

Your body keeps itself cool by evaporating liquid water. But the air can keep itself warm by condensing water vapor—it's the opposite of sweating. This makes a difference in the atmosphere!

Air cools when it rises and expands, but it can reduce its rate of cooling quite dramatically by condensing water vapor. Each kilogram of water vapor that condenses to form droplets of water releases 2400 kJ. That's a lot of energy!

When air rises, it cools. And when it cools, water vapor may condense—a cloud will form. Making a cloud actually keeps the air from cooling so much as it rises. Dry air will cool by about 10°C for every 1000 m it rises, but moist air (that is, air containing water vapor) will only cool by about 5°C for every 1000 m it rises. The difference is due to condensation of water vapor.

So, to sum up: **Sweating keeps you cool, and making clouds keeps the air warm.** The consequences of evaporation for biology are dramatic, and the consequences of the condensation heating are no less dramatic for the atmosphere. Water vapor is one of the key elements that the atmosphere uses to move energy around.

Doing the Experiment

It's hard to make a cloud and show how this keeps the air warm, but it's easy to show that evaporation (liquid turning into a gas) cools things and condensation (gas turning into a liquid) warms them. And all you need is your hand and your breath!

Here's a fact you need to know: your breath is always the same temperature, whether you blow in a tight stream or in a soft puff. We've measured this, and it's true. The air comes from the same place—your lungs—and so it's warm and it's moist.

The experiment goes like this:

- Blow on your hand with a tight stream. Your hand will cool.
- Now, blow on your hand with a soft, open-mouth puff. Your hand will warm.

If you are doing this with your class, pause and discuss what's happening. Your breath is the same temperature in both cases, but it feels quite different. The difference in evaporation and condensation. When you blow a fast stream of air, it makes water evaporate from your skin, cooling it. When you blow a soft puff, moisture condenses on your skin, warming it. The temperature is the same, but there is a different amount of heat transferred.

You can prove this by doing the same process while wearing a tight rubber glove.

- Put on a rubber glove.
- Blow on your hand with a tight stream of air. Your breath will now feel warm! There's no evaporation, because the glove is dry, so there is no cooling.
- Blow on your hand with a soft puff. It will feel warm as well, as moisture condenses.
- Now, blow with a tight stream again. It will probably feel cool... now, the glove has some moisture on it, so it will evaporate!

Talk this over with your students to be sure they get a feeling for what is going on. The key question is:

When a cloud forms, why does this keep the air warmer?

It's just like sweating to keep yourself cool. But backwards!

Summing Up

This experiment is largely qualitative, but it does make a key point about energy transformations in air, one with good connections to the science of the atmosphere.

For More Information

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

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

How can freezing make something warmer?

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

Overview

We normally think of water as freezing at 0° C (32 °F). But this is an oversimplification. Liquid water can be cooled to a temperature as low as -40 °C (-40 °F) without freezing. Water, or any other liquid, that is still liquid at a temperature below its freezing point is *supercooled*.

Once a supercooled liquid begins to freeze, it will freeze quickly. And as it freezes it gives off heat energy. This experiment uses a heat pack as the central element. Once you create one solid crystal, the rest of the liquid will quickly turn solid—it will freeze. As it does so, it gives off heat energy. This *freezing* makes the heat packs *warmer!* A freezing liquid keeps your hands warm!

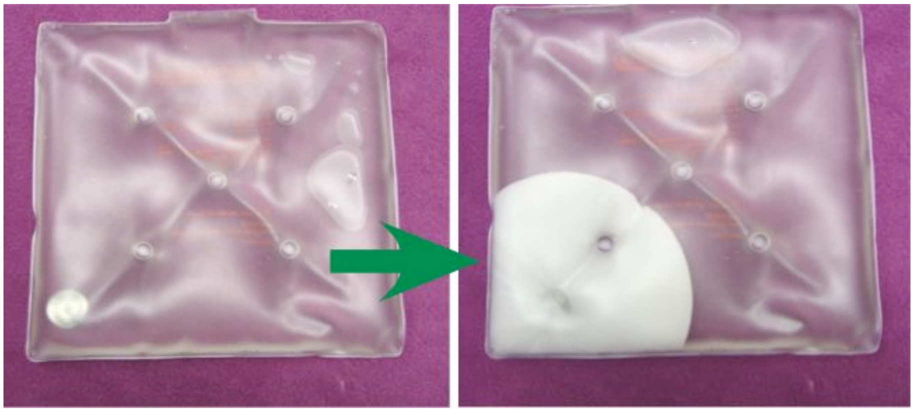
Necessary materials:

- Sodium acetate reusable heat pack
- Thermometer

The heat pack is the key element. These are pretty easy to find; look for "reusable heat pack." The pack is filled with a solution of sodium acetate. When you pop the disk in the pack, the solution freezes, releasing heat. But you can melt the resulting solid by adding heat. This is a simple matter of placing the pack in a pan on the stove and boiling it for 20 minutes.

Theory

You know that an ice cube will cool your drink. As the ice cube melts, it absorbs heat energy from its surroundings. Water molecules frozen in the form of ice are tightly bound. Water molecules in the form of liquid aren't. So to turn a solid into a liquid means breaking bonds, and that takes energy. As the ice melts, it cools off its surroundings.



Once the disk is popped, the heat pack freezes.

Now, think about freezing. When you make ice cubes, you put liquid water in the freezer. The freezer cools the water, taking energy out. When ice melts, it takes in energy; when it freezes, it must release energy.

This taking in and releasing of energy is a very important process for the earth. Ice can melt in one place (taking in heat) then the resulting water can flow to another place and freeze there (giving off heat). Not only has water moved from one place to another, so has the heat energy.

The heat packs for this experiment contain a sodium acetate solution that freezes at 60 °C, but that can be easily supercooled. If you boil the packs in water, the sodium acetate melts. As the packs cool, it stays liquid; at room temperature, it is well below its freezing point, but it is still liquid. When you "pop" the metal disk, you create a small region of rapid expansion and cooling, forming a single crystal of frozen sodium acetate which "seeds" the rest of the pack, which will quickly begin to freeze.

The key thing to notice is this: As the pack freezes, it gives off heat, as it must. Some of the liquid freezes, warming the pack to 60 °C. Now the freezing continues; the pack will stay at 60 °C, the freezing point, as this happens, giving up heat as the freezing proceeds. The pack will stay at 60 °C until it is all frozen.

You can melt the solid sodium acetate again by boiling a heat pack on the stove. When you do this, you put heat in. This heat is released when the pack freezes again. The packs thus move heat from one place to another. You put heat in using the stove in your kitchen; the liquid stores this heat which is then released when the pack freezes. *The heat that warms your hand ultimately came from someone's stove!*

Doing the Experiment

This can be done as a very short activity, in which students simply induce freezing and then watch the process, or you could do a more involved experiment involving detailed measurements.

We'll start with the simple version. First, the usual safety note:

> **SAFETY NOTE: The contents of the packet aren't toxic; this is food-grade sodium acetate. But when the packet freezes, it gets quite hot. (It is a heat pack, after all!) It can be hot enough to be uncomfortable, and may cause minor burns if you aren't careful.**

The short version of the experiment goes like this:

- Pass out the heat packs. Ask your students to tell you what phase of matter is in the packs. Have them note the temperature.
- Now have them watch the packs closely and pop the disk. Let them observe for a few minutes.
- Have your students explain what they see.

Here's the crucial piece:

> **The packs are freezing, but they warm up and give off heat energy as they do so.**

This can be the basis for a good discussion of supercooling, phase transitions and energy.

If you want to do more, measure the temperature as a function of time. And then try this with an insulate pack. As the packs freeze, they stay at the freezing point. If you insulate a pack, it will stay warm for a longer time. To freeze the pack, all of the heat released in the freezing must be released. If there is insulation, this takes longer!

Summing Up

This is a quick and dramatic experiment that you can use as a springboard from some great discussions of the physics behind the transport of energy in the atmosphere.

For More Information

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

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

Do plants “sweat”?

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

Overview

Years ago, I attended a workshop in Las Cruces, New Mexico in the middle of July. I would do a morning run with some of the locals, who told me their rule of thumb for the temperatures: 60 degrees at 6, 70 degrees at 7, 80 degrees at 8, 90 degrees at 9, 100 degrees at 10. They were more or less correct. Once the sun came up, the cool desert mornings rapidly turned hot. By mid morning, it was too hot to be outside.

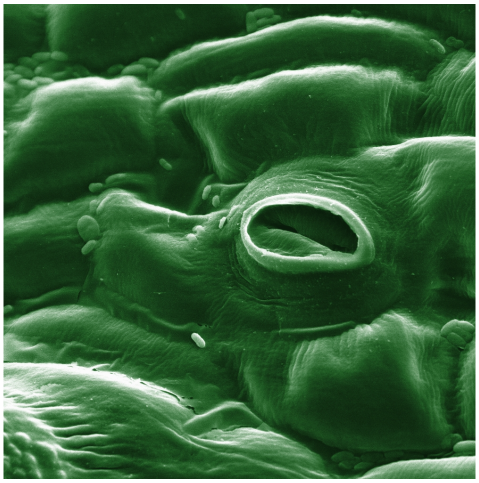
In the green rolling hills of east Texas, at a similar latitude, the sun is just as hot, but the temperature rise is much less extreme. The days start much warmer, but then rise much more slowly, so that temperatures in the middle of the day are about the same as in New Mexico.

You know that sweating keeps you cool—the conversion of liquid water to water vapor requires energy. And the difference between these two climates results from the same phase transition. The source of the water? Plants. The green hills are covered with grasses and other plants that *transpire*, converting large amounts of water in the leaves into water vapor into the atmosphere, moderating the temperature rise as they do so.

Necessary materials:

- 1 clear glass bowl or fish tank per group
- Several different types of ground cover: grass, bare dirt, water, etc.
- Source of heat and light—this can be a heat lamp or the sun.

This experiment isn’t picky - any glass container will do the trick. We have successfully used fish tanks as well as dessert bowls from a local department store.



Stomates on a tomato leaf as seen by a scanning electron microscope

Theory

Plants have many pores on their leaf surfaces (and, to some degree, on stems, flowers, and roots) called *stomates* or *stomata*. When the stomates open to admit carbon dioxide for respiration, water vapor can leave through these same openings.

The more big leafy plants populate an area, the more water vapor is expelled into the air. Consider the tropical rain forests of the world. You might bring to mind an image of an explorer pushing aside leaves larger than herself so make way on an adventure. This is an area where the day to night temperatures will very but not nearly as much when compared to areas without this type of vegetation.

Doing the Experiment

There is more condensation on the glass over the grass (right) than over the cup of pure water (left)

Divide your student into small groups and give each a glass bowl or fish tank. Instruct them that they will be using this container to get a qualitative measurement on how much humidity is being produced by the system contained underneath it. Ask them to make predictions about what they might observe. Will there be more or less humidity when the container is placed over grass or water? Students can do this indoors with a heat lamp and containers of the different types of ground cover, or they can do this outside on a sunny day and use whichever types of local ground cover are available. Have students record their data and report to the group.

You may find that although the container becomes foggier when placed over grass than when placed over water. The water will eventually fog up the container but the evaporation process for it to do so is actually slower than the transpiration process exhibited by the grasses—an interesting surprise that illustrates the importance of transpiration.

Summing Up

This experiment illustrates one important aspect of the interaction of the biosphere and the atmosphere. What happens above us is very tightly coupled to what is happening below us.

For More Information

CMMAP, the Center for Multiscale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

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

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 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.

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.

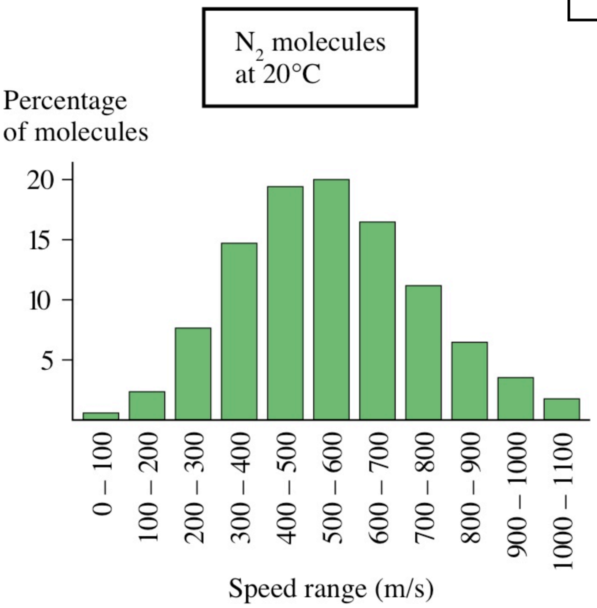


Chart of different energy levels of nitrogen.

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.

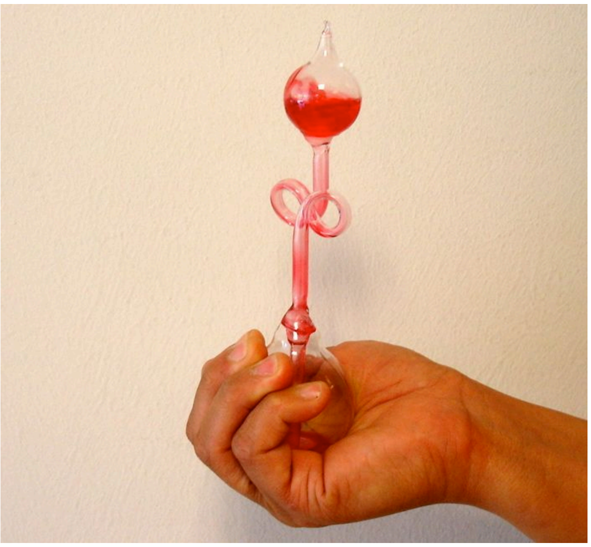
> *Notice that there are more molecules in the gas phase now. That means that the gas molecules have more pressure. This is the* ***vapor pressure*** *of the water in the gas phase.*

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.

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 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://cmmap.colostate.edu

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

Do cities affect the weather?

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

Overview

Clouds reveal the patterns of weather to the keen observer. They are weather stations in the sky, giving us indications of what the weather may bring. They are poetical and a pleasure to watch, taking on shapes and sizes that ignite the imagination. What, however, is within these inspiring shapes, and how do they form?

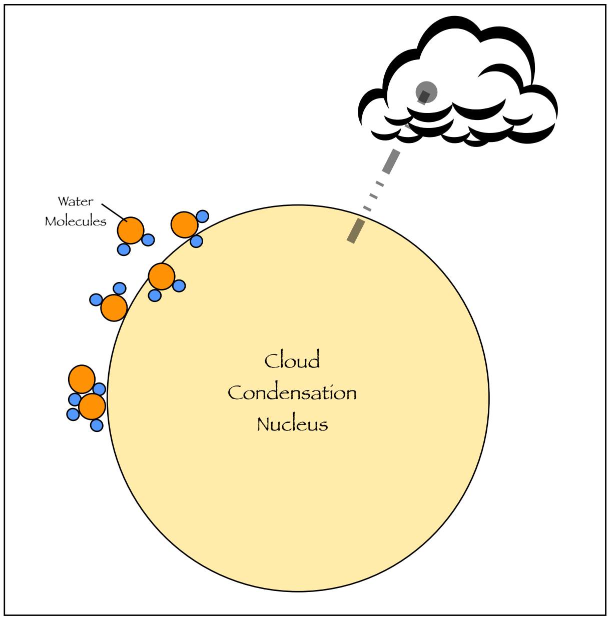
Necessary materials:

- Two 2-liter bottles
- Tire valves to fit in the caps
- Air freshener (Glade Powder Fresh works well.)
- Bike pump with pressure gauge
- Sucker sticks to release air pressure.

The most important element is the tire valve, purchased at an auto parts store. These will fit inside the bottle cap, and allow you to pressurize the bottles. A pump with a gauge is also important, because it will let you pump up the bottles to a known pressure.

Theory

The cloud inside our bottle, as well as clouds in the atmosphere, form when four conditions are present: water vapor, cooled air, supersaturation, and condensation. Water is the only substance in the atmosphere that naturally occurs as a gas, solid, or liquid. The water that makes up clouds is all around us in the gaseous form of water, water vapor. In humid areas, water vapor can account for 4% of the volume of the atmosphere. In dryer areas, less than 1% of the atmosphere is water vapor.



Molecules of water vapor are helped to form a droplet of liquid water by a condensation nucleus.

Water vapor can condense to form liquid water if the air is cooled, because cooler air can hold less water vapor. Air cools as it rises due to **adiabatic cooling**. (Adiabatic, pronounced "a-dE-&-'ba-tik" means that there is no transfer of heat between an air parcel and its surroundings.) When a parcel of air rises, it expands; the expansion requires energy, which comes from the thermal energy of the air, so the air cools. As we noted, cold air holds less water, so when the air rises, as it cools, the water vapor will "want" to condense out of the air—it will want to form droplets. The air can become **supersaturated**, with a relative humidity greater than 100%., but the droplets don't form yet... they need help. Liquid water has surface tension. This means that making a droplet requires energy to create this surface tension. The water molecules can get around this energy barrier by condensing on a surface. In the summer, when a cold glass of ice water meets warm, moist air, water droplets form on the outside of the glass.

In the atmosphere, **condensation nuclei** provide the surfaces on which water vapor can condense. Dust particles will allow water vapor to form a droplet as in the above diagram; alternatively , soluble materials such as salt will dissolve in the condensing water vapor, facilitating droplet formation in a slightly different manner. Without cloud condensation nuclei, the relative humidity must be several hundred percent in order for water vapor molecules to condense freely. Condensation nuclei in the atmosphere range from dust, to volcanic ash, to pollution. With these nuclei, the water vapor in the air can condense to create a cloud made of billions of tiny droplets of liquid water.

Doing the Experiment

***SAFETY NOTES* :**

- **The bottles will easily hold more pressure than the pump can provide as long as they are intact. If a bottle has any defect, replace it.**
- **When you pump the bottles up, they won't explode, but the caps can fly off at high speed if they are released. You should fasten the caps in place to eliminate this possibility. Folks open soda bottles all the time with no ill effects. But these bottle caps have valves in them so a bit of caution is warranted.**

1. Add a small amount of water to both bottles.
2. Spray (just one squirt!) the air freshener into one bottle. Swirl the water around the bottle so all the air freshener has a chance to mix in.
3. Pump up the bottles to a fixed pressure; 30 psi/2 bars is plenty. The air in the bottles will warm as you do this. Students can easily feel where the energy comes from for this increase in thermal energy!
4. Let the bottles cool to room temperature.
5. Let the air out of the valves of both bottles at the same time using the sucker sticks, and observe. Compare the bottle with the condensation nuclei to the bottle without. What differences do you see? Do you think there were some condensation nuclei present in the bottle we did not spray with air freshener? What else could you use for condensation nuclei?

Summing Up:

So, how could cities change the weather? The dust and pollution by cars and industry in cities increase the number of condensation nuclei in the atmosphere. In 2003, NASA provided evidence from satellites, models, and observations that this can affect the local weather. Clouds are more likely to form downwind from cities, but, in some cases, this means that rain is less likely because the droplet size is smaller. These tiny droplets do not condensate into rain droplets instead they remain suspended in the air.

For More Information

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

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

Can you make ice cream in two minutes?

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

Theory

Freezing cream, milk, and sugar with liquid nitrogen is a nice demonstration, and great excuse to eat ice cream. Most of the air we breathe is nitrogen (about 78%), and about 20% is oxygen. Liquid nitrogen is very cold: -320°F or -196°C. While liquid nitrogen is used for many temperature-related applications, it's particularly useful for freezing foods because nitrogen is odorless, colorless and tasteless.

Necessary materials:

- liquid nitrogen
- gloves and goggles
- large stainless steel punch bowl or salad bowl
- 1 quart of heavy cream
- 1 quart of whole mile
- 1 pound of sugar
- flavoring
- wooden spoon

The very cool thing about this demonstration is this: When you add the liquid nitrogen, it boils. This takes heat energy from the ingredients. The ingredients then freeze. So you have two different phase transitions happening in one bowl: boiling and freezing. It's a great way to show the energy exchanges in phase transitions.

The secret to the creamy ice cream is all in the rapid freezing of the mixture. The liquid nitrogen causes the fat and the water particles to stay very small, giving the ice cream it's creamy consistency. The goal is to avoid ice crystals - similar to what you get when you make ice milk.

Doing the Experiment

1. Pour the cream, milk, and sugar in the bowl. You can simply pour the ingredients in; it uses full quantities of all of them, so it's quick to get started! A bit of mixing wouldn't hurt, but isn't crucial.

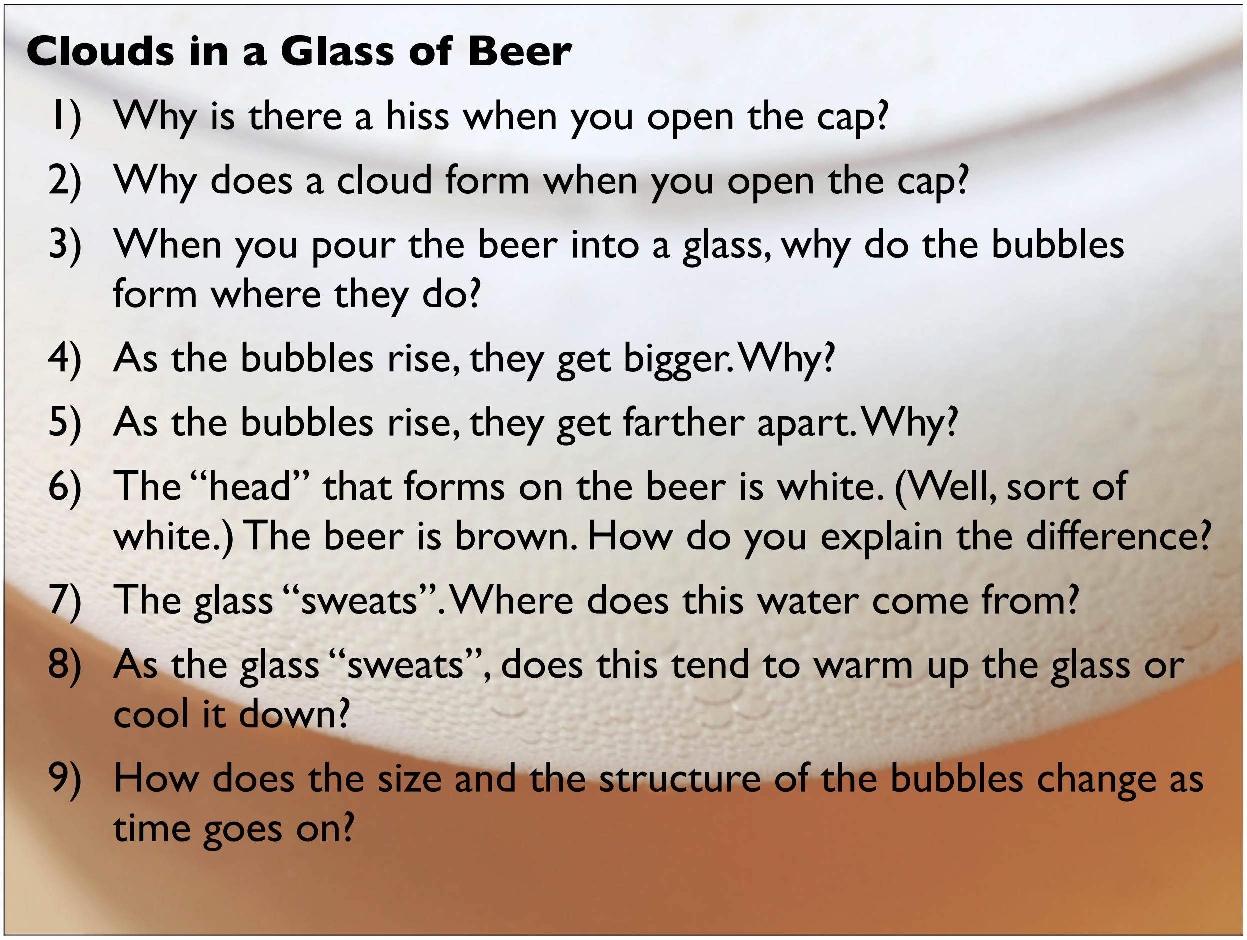
2. If you are making vanilla or chocolate ice cream, whisk in vanilla or chocolate syrup now. Add any other liquid flavorings you might want.

3. Put on your gloves and goggles. Pour a small amount of liquid nitrogen directly into the bowl with the ice cream ingredients. Continue to stir the ice cream, while slowly adding more liquid nitrogen. This is best done by two people. You need to stir, not whip! You want to have pockets of liquid nitrogen mixed with the ingredients so that the necessary heat exchange can take place. But don't whip it up; if you get bubbles, you'll make a frothy mess.

4. Continue to stir the liquid nitrogen and the liquid ingredients. As it hardens more, remove the spoon and just pour the remaining liquid nitrogen onto the ice cream to fully harden it.

5. Allow the excess liquid nitrogen to boil off before serving the ice cream.

SAFETY NOTES:
If you are using a metal container for the liquid nitrogen, be sure to wear gloves.
Don't touch liquid nitrogen or store it in a closed container!



Clouds in a Glass of Beer

1) Why is there a hiss when you open the cap?
2) Why does a cloud form when you open the cap?
3) When you pour the beer into a glass, why do the bubbles form where they do?
4) As the bubbles rise, they get bigger. Why?
5) As the bubbles rise, they get farther apart. Why?
6) The "head" that forms on the beer is white. (Well, sort of white.) The beer is brown. How do you explain the difference?
7) The glass "sweats". Where does this water come from?
8) As the glass "sweats", does this tend to warm up the glass or cool it down?
9) How does the size and the structure of the bubbles change as time goes on?

Clouds in a Glass of Beer

1) Why is there a hiss when you open the cap?

   The bottle is pressurized. When you open the cap, the release of pressure leads to a hiss.

2) Why does a cloud form when you open the cap?

   The release of pressure leads to a rapid cooling of the air inside the bottle. The air is saturated with water vapor, and it has organic molecules floating around as well, which can serve as nucleation sites. Net result: Just like the cloud in a bottle. But tastier.

3) When you pour the beer into a glass, why do the bubbles form where they do?

   The bottle is etched. The rough edges make nucleation sites suitable for bubbles to form.

4) As the bubbles rise, they get bigger. Why?

   They grow! Once you've made a bubble, you've done the hard part, energetically speaking. More molecules of carbon dioxide can now easily add to the bubble, making it grow.

5) As the bubbles rise, they get farther apart. Why?

   There is an upward force on the bubbles, so they accelerate. They move faster as they rise, so spread out.

6) The "head" that forms on the beer is white. (Well, sort of white.) The beer is brown. How do you explain the difference?

   Scattering! It's just like the "Why are Clouds White?" experiment. But tastier.

7) The glass "sweats". Where does this water come from?

   The atmosphere. The cold glass is colder than the dew point for the air in the room. Water vapor thus condenses on the surface of the glass.

8) As the glass "sweats", does this tend to warm up the glass or cool it down?

   Water vapor turning to liquid water...Warms it up!

9) How does the size and the structure of the bubbles in the foam change as time goes on?

   Smaller bubbles merge to make larger bubbles, which subsequently pop. The bubbles "coalesce" just as falling raindrops do, leading to more (and bigger) drops.

How does humidity affect cooling?

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

Overview

When travelers discuss the different climates they have experienced, many will agree that the summers in Texas are much less comfortable than Colorado despite the fact that the summer highs for these regions are very similar - generally within a few degrees of each other. So why the difference? We've all heard that "it's a dry heat" in Colorado but what does that mean? How does the lack of humidity in Colorado make a 32°C day seem more bearable than a 32°C day in Texas?

Necessary materials:

- An indoor/outdoor thermometer
- Small stuffed animal
- Rubber bands
- Water
- Small fan
- Spreadsheet calculator for relative humidity and dew points based on wet bulb/dry bulb temperature differences

Included as a part of the experiment is an spreadsheet to calculate the relative humidity and dew point temperature from the dry bulb/wet bulb temperatures.

Theory

The terms dew point and relative humidity seem like they are interchangeable. They are related, but have different meanings. Dew point is the temperature at which the air becomes saturated and water vapor condenses into liquid forming dew, like dew in the early morning. Relative humidity is the percentage of water that is actually in the air compared to how much water the air could possibly hold at a certain temperature.

$$\mathrm{RH} = \frac{\text{Water the air } \textit{does} \text{ hold}}{\text{Water the air } \textit{could} \text{ hold}} \times 100$$

The indoor/outdoor thermometer takes two readings: one of the "wet" temperature and one of the "dry."

In the vapor pressure dice game we learned hot air can contained more water vapor then cold air. A good analogy for understanding dew point and relative humidity is to think of nesting dolls where each doll is associated with a range of temperatures. The largest doll would be associated with hotter temperatures and be able to contain more water vapor, whereas the smallest doll would associated with colder temperatures and contained the least amount of water vapor. If you are in the smallest doll you are at a cold temperature, the dew point would be low, and you could have any range of relative humidities. A 50% relative humidity in a larger doll would mean more water vapor than a smaller doll with 50% relative humidity. In the Molecules in a Box experiment we learned the more molecules in a box the more pressure it would exert. In the case of a larger nesting doll with 99% relative humidity, the water vapor would exert more pressure than a smaller nesting doll with 99% humidity. Scientist refer to this as partial pressure because there are other molecules in the air, nitrogen and oxygen for example, also exerting different pressures.

In this activity, your students will be measuring relative humidity by constructing a whimsical psychrometer or wet bulb/dry bulb thermometer. The psychrometer was invented by Dr. Adolf Aßmann in the late 19th century and enables atmospheric scientists to measure how much moisture is in the air. In this experiment, one probe of the thermometer will be shielded from radiation and moisture inside the apparatus while the other will be in a humid environment exposed to moving air. This will cause the latter probe to record a lower temperature than the former. When the water in the stuffed animal (or Humidibeast) evaporates, it absorbs energy, lowering the temperature. The amount of water evaporated from the Humidibeast depends on the moisture content of the ambient air. By measuring the two temperatures, we can determine the relative humidity of the air.

Doing the Experiment

Soak the Humidibeast thoroughly with water and use the rubber bands to secure one probe of the indoor/outdoor thermometer to it so the animal's hide covers the sensor*. It is better to use room temperature water to ensure the wet bulb temperature stabilizes quickly. Set up the fan so that it blows across the animal, encouraging evaporation. Have students observe the difference in temperature readings between the wet and dry. Once the two temperatures have reached a stable point, have students record the values and disassemble their equipment. If the two values are very different then the relative humidity is low meaning that more of the water in the Humidibeast could (and did) evaporate. If, however, the values are closer together then we know that the relative humidity was rather high and the air could not hold much more moisture. When students have resumed their seats, have them use the provided chart to determine the relative humidity and dew point temperature. Discuss how this might vary in different parts of the world or other times of the year.

Summing Up

If you are taking a walk in the park on a warm summer day, your body will attempt to thermally regulate itself by sweating. When the sweat evaporates it leaves your skin cooler - you are in essence a Humidibeast yourself in this situation. If, however, the relative humidity is already very high then less of the sweat will be able to evaporate since the air can not hold much more moisture. In this case, your body will not be able to cool itself and you will feel much warmer. This is why the a hot summer day in Colorado doesn't seem as severe as the same temperature day in Texas.

For More Information

CMMAP, the Center for Multiscale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

The spreadsheet calculations were taken from the NOAA website:
http://www.srh.noaa.gov/images/epz/wxcalc/rhTdFromWetBulb.pdf

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

*No Humidibeasts were harmed in the development or execution of this experiment.