

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.

Theory

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 . Water has a high heat capacity; it takes much less energy to raise the temperature of 1 kg of, say, copper by this much.

But if you take this 1 kg of water at 100°C and boil it away, turning the liquid water into water vapor, you will need to add 2260 kJ—much more energy.

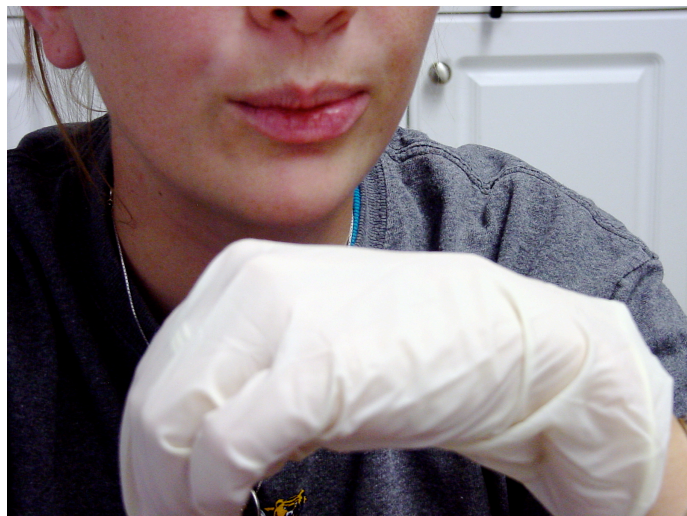
Of course, water will also evaporate at lower temperatures. The evaporation of 1 kg of water at normal skin temperature of 30°C carries away even more energy—2400 kJ. This is A Good Thing; it means that

your body can keep itself cool by evaporating relatively modest amounts of water.

When water evaporates, it carries away thermal energy. But the reverse is also true: When water condenses, it gives up thermal energy.

Your body keeps itself cool by evaporating 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.



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

Necessary materials:

- Two liter bottle
- Tire valve to fit in cap of bottle (Ace Hardware)
- Bike pump with pressure gauge
- LCD aquarium thermometer (Petco)
- Air freshener or incense

The most crucial piece is the tire valve. We found metal tire valves that can fit inside the cap of a two liter bottle. Having a bike pump with a gauge is also crucial; with the pump's gauge, we can inflate the bottle to a known pressure.

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.

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 final bit is to explain:

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://cmmmap.colostate.edu>

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