

What is the “greenhouse effect”?

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



Overview

You know that putting on another layer of clothing helps keep you warm on a chilly day. The same thing is true for the earth—the layers of the atmosphere keep the earth from losing so much energy to space, keeping us nice and toasty.

Theory

If the earth was bare rock, with no atmosphere, like the moon, the average surface temperature would be about -18°C , about 0°F .

We know that the earth is warmer than this—quite a bit warmer, as it turns out. The average surface temperature on the earth is about 15°C , or about 60°F . The earth is kept warmer by the insulation of the atmosphere; this is known as the **greenhouse effect**. It's easy to do a simple experiment that gives clues as to how the atmosphere works this magic.

The key, just like the key to keeping warm in the winter, is layers.

If you take your warm hand and place it in a cup of cold water, heat will flow from your hand to the water. If you put your hand in a cup of hot water, heat will flow from the water to your hand. That's thermodynamics, specifically the second law of thermodynamics: heat flows from hot to cold. The amount of heat that flows depends on the temperature difference; more heat flows if the temperature difference is large, less if it is small. If you swim in a cool river, you'll get chilly after a while; if you swim in the ocean in the Arctic, you will quickly get hypothermia.



Layers keep you warm. As you “step down” from body temperature to outside temperature, the more steps there are, the smaller the steps.

Necessary materials:

- Infrared thermometer
- Cold day
- Students with layers of jackets, sweaters and other warm clothes

The crucial piece is the infrared thermometer. You need one that can measure very cold temperatures, and one with a reasonably narrow field of view.

The one that we use is pretty nice:

Mastercool (MAS52224-A) Infrared Thermometer with Laser

This dependence on temperature difference is true for all mechanisms of heat exchange, including **conduction** (direct transfer by two objects in physical contact), **convection** (transport of fluids, like water or air), or **radiation** (transfer of energy by emission of electromagnetic waves.) The earth sits in the vacuum of space, so the only way it can gain or lose energy is by radiation. Understanding energy gain and loss by radiation helps us explain why the earth is warmer than it “should” be.

The atmosphere above us has many layers, and there is a variation in temperature as well. The earth gets radiant energy from the sun, and it gives off radiant energy to space. But there's a

difference in these two types of radiation. The wavelength of the electromagnetic waves that an object emits depends on its temperature. Higher temperature means shorter wavelength. (That's how the thermometers you will use in this experiment work—they measure the radiation that objects emit. Shorter wavelength means a higher temperature.) The incoming radiation, from the sun, with its 6000°C surface temperature, is mostly visible light. The visible light comes right through the atmosphere. The outgoing radiation, from the surface of the earth, at an average temperature of 15°C, is mostly infrared. Infrared doesn't go through the atmosphere so easily; much is absorbed, largely by water vapor and carbon dioxide. There are layers of the atmosphere between the earth and space that absorb most of this radiation. They are warmer than space, and so their presence keeps us warmer—rather than being “next to” the cold of space.

Doing the Experiment

This lesson gives you a good excuse to teach outside—in the winter! You want your (warmly attired) students to be outside long enough that the temperatures of the layers of their clothes have equilibrated. This will take some time, at least 10-15 minutes. After this time, their garments will be warm on the inside, cool on the outside. You'll get the most interesting results from students wearing layers—a shirt, a sweater and a thin jacket would be ideal. We'll assume this set of layers for the following description. We will mea

- Have one student with a good set of layered clothing serve as the test subject. Pick a spot in the middle of her back and use the infrared thermometer to measure the surface temperature of his jacket.
- Now, have him quickly remove his jacket, and measure the surface temperature of his sweater at the same spot.
- Next, have him quickly remove her sweater, and measure the surface temperature of his shirt at this spot.
- Finally, use the thermometer to measure his skin temperature—ideally, in the same spot, but use your judgement here. The inside of the forearm could work as well.

Look at the range of temperatures, from the warm skin to the cool outside of the jacket. There is a big difference in temperature between the inside and the outside, but each layer sits next to another layer which is only slightly different in temperature. Ask your students to explain how this layering, this “stepped” temperature profile, will help them stay warm.

Now, do this:

- Aim the infrared thermometer at the sky. Space is quite cold—deep space is about -270°C, or -455°F. But the thermometer measures a temperature that is much less frosty; it will probably read about 0°C, or perhaps as cool as -10°C or even -20°C. Cold, yes, but not -270°C!

What the thermometer is measuring is the temperature of a layer of the atmosphere that absorbs the earth's emitted radiation. Because the earth is covered by a layer of atmosphere that is cooler than the earth but warmer than space, it keeps the earth warmer. After making both sets of measurements, you can help your students make this connection.

Summing Up

Now, for the obvious question: If the earth is kept warm by the atmosphere, and if carbon dioxide in the atmosphere is responsible for this warming, and if we are increasing the level of carbon dioxide in the atmosphere, won't that cause the earth to warm up? The answer is: Almost certainly. It's like putting on another layer of clothing on a cold winter day, a simple matter of thermodynamics.

Of course, the atmosphere is more complicated than this; there might be other effects. But the fact is that *we are adding carbon dioxide to the air, and that the climate is changing*. There is clear data to show both effects.

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>