LITTLE SHOP of PHYSICS

# How does the atmosphere keep the earth warmer?

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## Overview

The earth cools by radiation — it's the only way that the earth can exchange energy with space (since space is a vacuum, it's not possible for the earth to transmit energy to it via conduction or convection). But our atmosphere is not transparent to the thermal radiation that the earth emits, so the earth is warmer than it would be without an atmosphere.

## Theory

We can simulate the energy exchange of the earth and the atmosphere with space by using a stack of glass plates for this simple reason: Glass is transparent to the visible light and the near infrared emitted by the sun (and the lamp!), but opaque to the thermal radiation emitted by the earth. So energy gets in, but it can't get out — at least, not easily. The Earth's atmosphere is functionally similar: It contains molecules of certain gases, known as *greenhouse gases*, that do not interact with visible and near infrared light but do interact with thermal radiation.

Glass is opaque to thermal radiation; it is a good absorber (and thus a good emitter) of thermal radiation. Greenhouse gases do the same thing—greenhouse gas molecules absorb thermal radiation, taking energy in. The greenhouse gas molecules then emit thermal radiation, sending the energy back out. This direction in which the thermal radiation is re-emitted is random — the thermal radiation may return to the earth, but it's just as likely to end up heading for space. The net result is that the surface of the earth is at a higher temperature than it would otherwise be, due to the thermal radiation coming down from the atmosphere. A temperature profile develops in the atmosphere, which warmer air near the surface, cooler air above. Energy is transported up and out by thermal radiation, across the temperature gradient. The same amount of energy goes out as comes in, but the earth is at a higher temperature than it would otherwise be.

## Doing the experiment

We'll start with a simple experiment that shows how the atmosphere keeps the earth warmer. This can be done as a demo, but is more effective when small cooperative groups work to collect data and then compare with others. Once you set the experiment up, you'll need to let the lamp shine on the stack of plates for 20 minutes.

- ⋆ **SAFETY NOTE I: The desk lamp with the incandescent or halogen bulb can get very hot. Be sure students are careful when working around the lamp.**
- ⋆ **SAFETY NOTE II: The glass plates have sharp edges, so students need to be especially careful when moving and lifting the plates. You may want to keep the picture frames on each glass plate and put the rubber feet on the frames.**

1) Have your students make a stack with the 4 glass

**Necessary materials:**

- 4 identical pieces of clear glass (you can use glass from picture frames — we found ours at a dollar store)
- 4 clear rubber feet for the bottom of each piece of glass (to act as spacers)
- flat black paint (use this to evenly and completely cover one side of one glass plate)
- thermal radiation sensor ("infrared thermometer")
- desk lamp with an incandescent bulb

Thermal radiation sensors ("infrared thermometers") can be found at www.harborfreight.com under "non-contact pocket thermometer."

Make sure your desk lamp has an incandescent bulb–these give off much more thermal radiation than a compact fluorescent bulb.

plates. They should put the black painted glass plate at the bottom of the stack. Place the desk lamp over the stack of glass plates and discuss how close you want the light bulb to be to the top of the stack.Turn the desk lamp on and let it shine on the stack of plates for approximately 20 minutes.

2) While you are waiting for the experiment to be ready, model for your class what they will be doing once they begin. Explain to your students that they are setting up a model of layers of the atmosphere. Show them how they will have to work as a group to conduct this experiment. There will be four jobs per group. One student will turn off the desk lamp and turn it away so that it doesn't keep warming the plates with infrared radiation. The second student uses a thermal radiation sensor* to immediately measure the temperature of the top plate, while the third student records that temperature, while the fourth student pulls the top plate off. The process is repeated by students 2, 3, and 4 until they have measured the temperature of all the plates in the stack.
   - We recommend that you have a group of students practice this, so they all realize how quickly they have to complete the tasks. The plates start cooling immediately, so the quicker the students work, the better.
3) While you are still waiting for the experiment to be ready, have students predict what they think will happen with the temperatures. Which plate do they think will be the warmest, the coolest, and why?
4) Conduct the experiment and have students report and compare their data. Discuss what they think is happening. They will probably find that the bottom plate is the warmest, the one above a little cooler, and the one above that cooler yet. How about the very top plate? This will depend on the light source. Why might this be?
5) This will be a great place to explain how the glass plates are like layers of the atmosphere. The visible and near infrared radiation from the lamp (sun) can pass through the layers, but once this energy is absorbed by the earth (the black plate) the radiation emitted is thermal radiation of a longer wavelength. It cannot pass through the layers as easily, so the earth gets warmer.

*Thermal radiation sensors are generally sold as "infrared thermometers" or "non-contact thermometers." We prefer the "sensor" terminology because it more accurately describes what these devices actually do — they sense thermal radiation, then make some assumptions to use this measure as a proxy for temperature.

<u>Activity variation 1</u>

1) Put the four glass plates on the table with the black plate at the top and the 3 clear plates below it. Put a desk lamp over them.
2) Turn on the desk lamp and leave it on for at least 15 minutes.
3) As in the experiment above, turn off the desk lamp and use the thermal radiation sensor to take a temperature of the top black plate and then the clear plates below it. Be sure to do this quickly.
4) Compare your results to the first experiment. Did anything surprise you about this? The black plate is absorbing the energy as it did in the experiment above and then is reemitting thermal radiation in both directions, warming the plates below it. It radiates to the closest clear plate, and then this plate absorbs the thermal radiation and re-emits it to the black plate above it, and also, to the clear plate below it, and so on. The black plate will be the warmest and each plate will be a little cooler to the bottom of the stack. The net result is this: It's easy for energy to get in, because the radiant energy (mostly) goes right through the glass, but it's hard for it to get out. It has to go through a "cascade," the black plate heating the glass plate below it, this plate transferring energy to the plate below it, and so on.

<u>Activity variation 2</u>

1) Put two glass plates painted black on a table. Put a desk lamp over them.
2) Turn the desk lamp on and leave it on for at least 5 minutes.
3) Turn the desk lamp off and move it away from the glass plates. Quickly use the thermal radiation sensor to take the temperatures of both black plates and record.
4) Immediately place a clear glass plate over one of the black plates.

5) Wait one minute, remove the extra frame, and then take the temperature of both black plates again and record.
6) Quickly put the extra frame back on the black frame and repeat the procedure again.

Activity variation 3

1) Have one student hold up his/her hand. Take the temperature of the hand and record.
2) Have another student hold a glass plate in front of the student's hand. Use the infrared thermometer to take the temperature again and record. The temperature reading of the hand with the glass plate in front should be much cooler.
3) Discuss what the students think is happening.

## Summing up

This is a good simulation that can show how the layers of the atmosphere keep the earth warmer than it would otherwise be, and is easily adaptable to permit exploration of various characteristics of thermal radiation.

## For more information

Colorado State University College of Natural Sciences: http://www.natsci.colostate.edu

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