

Why does it get colder on clear nights than on cloudy nights?

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



Overview

You know it's true: If there isn't a cloud in the sky, the air temperature will drop much more over night.

Why? It's all about radiation...

Theory

All objects radiate electromagnetic waves. And increasing an objects temperature increases the total amount of energy radiated; hot objects "glow" more brightly.

Increasing the temperature also decreases the peak wavelength of the emitted radiation. The sun gives off visible light. You are cooler than the sun, so you emit energy, and you emit it at a longer wavelength, in the far infrared region of the spectrum.

The sun does glow more brightly than you. But you are still pretty bright! The amount of energy you emit might come as a bit of a surprise.

Here's a remarkable fact: An unclothed human will *emit* a significant amount of electromagnetic energy—about 850 W. Your body's basal metabolic rate is only about 150 W, so something else must be going on. If this was all there was to the story, you'd be losing 700 W more than you generate, so you'd cool off and die.



Taking the temperature of the sky. On this clear Colorado afternoon, it was a frosty -30°C .

Necessary materials:

- Infrared thermometer
- Sheets of plastic, glass, etc.

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. IR thermometers can be found at www.harborfreight.com under "non-contact pocket thermometer".

But there is a piece we left out: The radiated energy that your body absorbs from the environment. An unclothed human in a room at about 20°C will your *absorb* about 750 W of thermal energy that is emitted by the walls, floor and ceiling of the room. The net loss of energy is only 100 W—enough that you will feel chilly, but not so much that you will develop hypothermia.

If the walls of the room you are in are cold, you will radiate just as much, but you will get less back. If the walls are warm, you will get more back. The temperature of the walls, ceiling and floor in a room are every bit as

important to your comfort as the temperature of the air.

Now, let's look at the earth. The only way the earth can gain or lose energy is by radiation. During the day, sunlight warms the earth. At night, the earth radiates—a lot—and it cools. Think about this: The earth, as a whole, stays at about the same temperature from day to day. This means it must be radiating as much energy to space as it receives from the sun. If you were to look at the earth with infrared eyes, it would be really bright.

This emitted infrared carries away energy. But the atmosphere isn't particularly transparent to infrared, so the earth doesn't cool off so much. It ends up being a bit warmer than it would be with no atmosphere. If the earth had no atmosphere, the earth would radiate enough energy to cool off to an average temperature of -18°C . But we do have an atmosphere, and one that blocks infrared. This keeps the earth's temperature at a much more pleasant 15°C . This warming is called The Greenhouse Effect, and it is, undoubtedly, A Good Thing. But as the atmosphere changes, the earth might warm up further... Perhaps catastrophically. This isn't good.

Doing the Experiment

If you point an infrared thermometer at something, it measures the emitted infrared and translates this into a temperature. Some things are transparent to infrared, and some things aren't.

SAFETY NOTE: The thermometers we use have lasers on them. The usual precautions regarding lasers in the eyes should be followed.

EQUIPMENT SAFETY NOTE: The instruments should not be pointed at the sun! This will destroy them.

Here are some things you can try:

- Point the thermometer at your hand, and pull the trigger. You will measure your hand's temperature by the infrared it emits. Try measuring the temperatures of other things.
- Now, put a piece of glass between your hand and the thermometer. Can it measure your hand's infrared through the glass? Nope. Glass is opaque to infrared.
- Try other things between your hand and the thermometer. What things absorb? what things transmit?
- Can you find surfaces from which infrared reflects? How would you measure this?
- Now, go outside and point the thermometer at the sky. If it "saw" all the way to space, it would measure a really, really low temperature. But it doesn't. It "sees" upper levels of the atmosphere, which absorb (and emit) infrared. These upper levels are cold, quite cold, so, at night, the earth will radiate a good deal of energy while getting little back.
- Now, point the thermometer at a cloud. You will see a much higher temperature—the cloud is warmer, but it also reflects infrared from the surface. If you are underneath a cloud at night, you will get more radiation back, and cool down less.

After some experimenting, you students should be ready to answer the central question of this exercise:

How do the observations show us that the earth will cool down more on clear nights than on cloudy nights?

Summing Up

What happens when the atmosphere as a whole transmits less infrared? Think about it!

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>