What does an infrared thermometer measure?

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

Overview

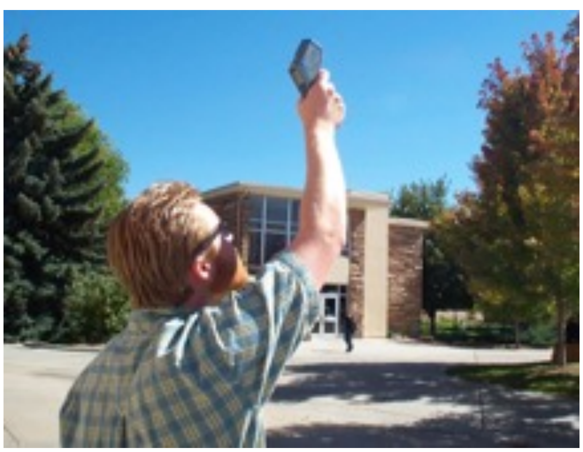
These days, infrared—or "non-contact" thermometers are popular items in hardware stores, auto parts stores, and stores that carry high-end cooking equipment. You point a thermometer at an object, and it reads the temperature. You can see how this could be useful in cooking, in working on your car.

But... What does such a thermometer actually measure? If you are cooking a roast, there's a good chance that the reading will correspond to the surface temperature. But the truth is not always so simple, as we'll see!

Theory

All matter is made of atoms, and the atoms are in constant motion; this is the molecular view of thermal energy. And one of the basic tenets of physics is this: When you accelerate a charged particle, it emits electromagnetic waves. Does this mean that all objects will emit electromagnetic waves?

Indeed it does. This *thermal radiation* is emitted by all solids and all liquids; gases are another story that we'll turn to later. Hotter objects emit more, objects at different temperatures emit different wavelengths, and some objects (metals, for instance) are pretty poor emitters. But the ground, clouds (which are made of solid or liquid water), your body, the walls of the room in which you are sitting... All of these emit thermal radiation in measurable and important amounts.



When you aim a thermometer at the sky, you'll measure a temperature. What, exactly, are you measuring?

Necessary materials:

- Infrared thermometer. There are two important properties to look for:
  - ***Wide temperature range.*** The low end is most important, -50°C is good. The radiation emitted from the sky can be minimal, so a low end of the temperature range is important.
  - ***Small area for measurement.*** The thermometers collect radiation from a certain angle. We use a thermometer with a 12:1 distance-to-spot ratio; this means that, at a distance of 1 foot, the spot from which radiation is collected is 1 inch in diameter. This corresponds to an angle of about 5°.
- Mug warmer
- Can of juice or other non-carbonated beverage. Whatever you pick, it should have areas with paint, bare metal, and clear coatings. We will be looking at the difference in emission from different places on the can.

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:

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.

Now, do this...