

What do “infrared thermometers” measure?



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 the thermometer at an object, and it reads the temperature. You can see how this could be useful to a chef or mechanic.

But... What does such a thermometer actually measure? If you’re baking a potato, there’s a good chance that the reading will correspond to the surface temperature. But the truth is not always so simple — for example, if you’ve wrapped your potato in aluminum foil, you won’t see anything like the temperature of the spud itself!

In the title, we’ve put “infrared thermometer” in quotes because this device doesn’t measure temperature directly; rather, temperature is inferred from a different measurement. So just what does the device measure? This is a good open question that you can ask your students to explore.

Theory

All matter is made of atoms, and all the atoms are in constant random motion. This is the molecular view of thermal energy. Atoms, in turn, are composed of charged particles. And when you accelerate a charged particle (as occurs perpetually in the atomic motion associated with thermal energy), it emits electromagnetic waves. Does this mean that all objects will emit electromagnetic waves?

Indeed it does. (Well, it does for any object with a temperature greater than absolute zero — that is, any object you’re apt to ever encounter.) Hotter objects emit more of this *thermal radiation*, 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. The intensity (I ; in watts per square meter, W/m^2) of the emitted thermal radiation from a source at a temperature T (in Kelvin, K) is:

$$I = e\sigma T^4$$

Sigma (σ) is the Stefan-Boltzmann constant, which has the value $5.67 \times 10^{-8} W/(m^2 \cdot K^4)$. The term e is the emissivity, a measure of the effectiveness of the surface in emitting thermal radiation. The emissivity is dimensionless; different materials can have different values of e , but the value is always between 0 and 1. Most objects that you are apt to measure with an infrared thermometer are good emitters. Your skin has an emissivity of $e = 0.98$, no matter your skin color. Water has $e = 0.98$, paper $e = 0.94$, plastics $e = 0.95$, painted surfaces $e = 0.94$. But metals are very poor emitters; for example, aluminum foil has $e = 0.03$. An infrared thermometer is typically calibrated assuming $e = 0.95$, which is a good average value for most surfaces.



An “infrared thermometer” reads out a temperature. But it actually measures thermal radiation, which complicates matters...

When you aim the thermometer at a surface, a lens and sensor collect emitted thermal radiation. If you aim the thermometer at a warm surface, the sensor heats up. The hotter the surface, the more warming that takes place. The final temperature of the sensor is used to deduce the temperature of the emitting surface.

Most thermometers have an integrated laser, which shows the area of the surface for which emission is being measured. But the laser doesn't work as a "probe"; it has nothing to do with the measurement. And the thermometer measures emitted energy from a large area; a typical thermometer will have a distance to spot ratio of 8:1, meaning that, at a distance of 8 cm, radiation is measured from a spot 1 cm in diameter. If you stand 8 feet from a wall and point the thermometer at it, you are measuring the radiation from an area 1 foot in diameter, and the temperature displayed will be an average of the temperatures over this spot.

The thermometer estimates the temperature of the emitting surface by assuming $e = 0.95$. If you aim the thermometer at your forehead, this works pretty well; the emissivity of your forehead is $e = 0.98$ — pretty close to the assumed value. But if you are measuring a baked potato wrapped in aluminum foil, you'll get an erroneous reading; the foil's emissivity, $e = 0.03$, is lower by a factor of 30 than what the thermometer assumes!

For this reason, we tend to call "infrared thermometers" *thermal radiation sensors*. These devices detect emitted thermal radiation, and use this to deduce a temperature. (The more widely-used name comes from the fact that thermal radiation is also referred to as far-infrared radiation.) A high temperature reading means that a good deal of radiation is collected; a low temperature reading means that very little radiation is collected.

This way of interpreting the results of a measurement is very important for making environmental readings. If you point the thermometer at the sky and measure -20°C , this doesn't mean that the temperature of the sky is -20°C ; it just means that the total thermal radiation emitted by the sky above you is rather modest.

To help students can make sense of this interpretation, it's good to do a "warm up" activity with the thermometers: Have students take the temperatures of various objects in the classroom. They will likely find that, even though all the objects are (probably) at more or less the same temperature, the reading on the thermometer will vary with the nature of the objects' surfaces.

Doing the experiment

This experiment works well if students are divided into small groups.

- 1) Figure out how many groups you'll have, then acquire an equal number of empty metal cans. You'll want to remove any labels these may have before beginning the experiment. You'll be putting hot water inside the cans later; your students will need to know the water level as they make temperature measurements, so it may be helpful to mark a fill line on the exterior in advance.
- 2) Give each group a can, and access to paint, tape, and other surface coatings they might be curious to

Necessary materials:

- thermal radiation sensor ("infrared thermometer")
 - two important properties to look for:
 - 1) **Wide temperature range.** If you are going to use the thermometer for making environmental measurements, the lower limit is most important; -50°C is a very good lower limit. The radiation emitted from the sky can be quite minimal, so you may get a "low" reading if you point the thermometer at the sky.
 - 2) **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 12 cm, the spot from which radiation is collected is 1 cm in diameter. This corresponds to an angle of about 5° .
- empty metal cans, with labels removed
- paint, tape, or other supplies to adorn the cans' exteriors
- electric kettle, or other source of hot water

try. Have each group adorn their can with several different coatings, making sure to leave a bare patch or two as well.

- 3) As they're working (or before beginning), ask each group to predict how the different coatings will affect the temperature they measure with the thermal radiation sensor.

Now, fill each can with hot water (and offer the attendant warnings; you might test ahead of time the minimum water temperature that gives good results with your selection of surface coatings). The can is made of aluminum, which is a good thermal conductor; every point on the can below the fill line is, to a very close approximation, at the same temperature.

But that's not what your students will measure...

- 4) Have the students measure the temperature of different parts of the surface — treated with various coatings — and record the temperatures they observe. Compare these with the temperature of the water (the thermal radiation sensor will report this reasonably accurately, or you could measure it with a standard bulb or digital thermometer).
- 5) Let students know that, to a very close approximation, all parts of the outside of the can (below the fill line) are, truly, at the same temperature.
- 6) Ask your students to explain the odd results. Why do they measure different temperatures at different points on the can? What might explain any discrepancies with their predictions?

When students measure the temperature of a shiny surface, they'll pick up thermal radiation from other sources (such as the walls of the classroom) that reflects from the can. Paint typically transmits thermal radiation rather well, so students will most likely record higher temperatures over painted than non-painted portions of the can (interesting to explore here: does paint color matter?). How do temperature readings vary across different types of tape? What other surface coatings have interesting properties?

Ultimately, your students can determine what surfaces are good radiators and what surfaces are poor radiators. And they'll understand the thermal radiation sensors well enough to properly use these devices and interpret temperature readings in future experiments.

Summing up

This is an interesting exercise, a fun open-ended investigation, and an important activity to do before your class uses "infrared thermometers" to measure temperatures.

For more information

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

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