

# What does color have to do with cooling?



## Overview

A lot, as it turns out.

You know that if you go out in the sun wearing a black shirt, you'll get warmer than if you were wearing a white shirt. That's because a black surface will absorb more radiant energy than a white surface.

But radiation is also a mechanism of cooling off. All warm objects radiate energy, but objects of different colors radiate different amounts. That's why color can affect cooling.

## Theory

All warm objects emit electromagnetic radiation. Hotter objects emit more radiation, and it's of shorter wavelengths than that emitted by objects that aren't as hot, but anything warm will "glow." You've no doubt seen colorful pictures of objects taken with thermal cameras; the hot spots appear bright, the cool spots dim. You've perhaps also seen videos taken on thermal cameras that show dim objects becoming bright (warming up) or bright objects becoming dim (cooling off). Objects that emit a lot will quickly cool; objects that don't emit as much will stay warm longer. Emission of thermal radiation is a very important determinant of the rate at which an object warms or cools.

Now, let's think about color in this context. You know that the color of an object will affect how much energy it absorbs; black will absorb more than white, so clothing designed for outdoor work in hot, sunny conditions is generally light in color. Color also affects emission of energy. Most objects near room temperature are very "black" in the thermal energy region of the electromagnetic spectrum — that is, they are good absorbers and good emitters of this type of energy. Human skin, regardless of color, is a very good absorber and emitter of thermal energy. No matter what color your skin is in visible light, you are black at thermal radiation wavelengths! The same is true of fabrics and of painted surfaces. All colors of clothes and all colors of paint are black at thermal energy wavelengths; they absorb and emit quite nicely.

The rate at which any object emits thermal radiation is described by this relationship:

$$Q/\Delta t = e\sigma AT^4$$

In this relationship,  $Q$  is the amount of thermal energy emitted, and  $\Delta t$  is the amount of time in which that thermal energy is emitted (thus, the term  $Q/\Delta t$  is a rate of emission of thermal energy). You can see that an object's temperature ( $T$ ) is the most important factor determining heat absorption or emission;  $T$  and  $Q$  are exponentially related. However, the object's emissivity ( $e$ ), a unitless quantity determined in part by color (but by other properties as well), is also important; it is linearly related to  $Q$ . It is with emissivity that we are presently concerned. (The other variables in the relationship,  $A$  and  $\sigma$ , are the object's surface area and the Stefan-Boltzmann constant,



Two cylinders on a hot plate. After they are warmed, they will be set aside to cool. Which will cool fastest—the white or the silver?

respectively.)

The emissivity of silvery metals, unlike that of most objects at room temperature, is quite low. Silvery metals reflect visible light, and thermal energy as well. They are poor absorbers of electromagnetic radiation and thus are poor emitters as well. This is why, in this experiment, the two cylinders your students warm up cool at different rates. The bare aluminum cylinder radiates less and cools slowly; the painted cylinder (it could be any color at all!) will radiate more, and thus it will cool off more quickly.

This is a very surprising result that drives home the importance of radiation — which here we use to mean emission of thermal radiation — in cooling.

## Doing the experiment

This experiment/demo involves some waiting time. You may want to set up this first part while your class is engaged in another activity or discussion, and then proceed when ready.

This is a great activity for predictions. You should certainly have students vote (perhaps a good use of the waiting time in the initial setup phase): Which cylinder do they think will cool off more quickly? Which will cool off less quickly? Most students will guess that the bare cylinder will cool off more quickly. The painted one seems insulated somehow.... In fact, it is! Painting will provide some insulation, limiting transfer of thermal energy by conduction. But the increase in radiation far outweighs this effect.

► Run this experiment as an activity or a demo as follows:

- 1) Turn on your mug warmer.
- 2) Place the bare and painted cylinders on the mug warmer, with the holes facing up. Make sure the cylinders aren't touching one another (so there's no conduction of heat between them).
- 3) Turn on the two digital thermometers and insert one probe into each cylinder.
- 4) Give the cylinders about 15 minutes to warm up. They probably won't warm to the same temperature, your first hint that something is up... Try to use the thermal radiation sensor to take the temperature of each cylinder as well. What you measure likely will not match the reading on the digital thermometers. Why? It's all about the emissivity! The thermal radiation sensor uses thermal radiation as a proxy for temperature, but to do this it must assume an emissivity. The emissivity is typically set at the factory, and can be manually reprogrammed by the user. If an object's emissivity varies substantially from this assumed value, as that of the bare aluminum cylinder does, the sensor cannot accurately calculate its temperature.

► When both aluminum cylinders have been warmed for 15 minutes or so, continue the experiment:

- 5) Tell your students that you will be removing the cylinders from the heat source. Have them each predict which cylinder will cool the fastest and why.
- 6) Record the temperature on the digital thermometers, then set the cylinders on the table or a hot pad.

### Necessary materials:

- 2 digital thermometers
- 2 aluminum cylinders with holes for the thermometer probes
- paint (any color)
- mug warmer
- optional, but quite nice: thermal radiation sensor ("infrared thermometer")

The aluminum cylinders are the key piece of this experiment. We used a 1" diameter rod from a metal supply company, cut to 1.5" lengths to make two cylinders of identical size. (You don't have to use cylinders — you may prefer cubes — but it's crucial that they are the same size.) We drilled a hole halfway down the length in both pieces so the thermometer probes would fit nicely. We left one cylinder bare metal and painted the other one white.

- 7) Take temperatures of the cylinders using the digital thermometers at 1-minute intervals and ask: How do the two temperatures vary? Try measuring the temperatures with the thermal radiation sensor as well.
- 8) You can stop taking data in a short time, once it becomes clear that the painted cylinder is cooling more quickly. Now it's time to talk about why...
  - ▶ Discuss the results. Some questions you could ask:
    - Why did the white cylinder cool more quickly?
    - Why are "space blankets" that are used for emergencies made of silvery plastic?
    - Why is the inside of a thermos silvery?

## Summing up

Radiation is an important but underappreciated mechanism for heat exchange. Painting a cylinder might make a very tiny insulating effect but, more importantly, it makes a huge difference in emissivity, leading to a much greater rate of radiative cooling. This experiment helps make the importance of radiation as a heat exchange mechanism tangible and understandable.

## For more information

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

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