# Heat Transport by Radiation

**Purpose/Objective:** To perform an experiment to show the difference between radiative heat transport vs. conductive heat transport.

**Background:** Thermal energy is the energy that is associated with the motion of the particles (molecules, atoms, protons, neutrons, etc. ) that make up any object. As more thermal energy is added, the particles move faster. When thermal energy is transported, it is called heat. There are three ways that heat can be transported: convection, conduction, and radiation.

*Conduction* is the process where the rapidly moving particles in an object transfer their rapid motion to nearby particles through collisions between the particles. This happens when you touch your hand to a hot plate. Or how eggs cook in a pan where the heat from the stove gets transferred through the pan to the eggs. Conduction also occurs when you try to lick a flagpole in the wintertime in Minnesota; the water molecules from your tongue transfer their heat to the metal in the pole and the water freezes onto the pole sticking your tongue to the pole with the frozen water.

*Radiation* is heat transport by light. All objects in the Universe emit light because of the motion of the particles that make up those objects. The colder the object, the longer the wavelength of light it emits. The warmer the object, the shorter the wavelength of light it emits. Our sun is at 5700 Kelvin, and emits most of its light at visible wavelengths. Humans, on the other hand, are much cooler (around 310 Kelvin), and we emit light at much longer wavelengths, in the infrared part of the spectrum. In our every day lives, we see this effect of heat transfer by radiation when we turn on an incandescent light bulb where a metal filament (usually tungsten) is heated to a high temperature to the point where it emits visible light; if you place your hand to the side of the bulb, you will feel the heat coming from it because the light is carrying that heat from the hot metal to your hand and making the particles in your hand move faster. (Do you feel this heat when placing your hand near a florescent bulb, or an LED bulb? Why do you think those bulbs are advertised as using less energy?)

*Convection* is the process where something that has thermal energy carries that energy to a new location. Two classic examples are (a) when air is heated near asphalt and it becomes less dense and rises or when air cools and sinks, or (b) boiling water where water that is heated at the bottom of a bowl rises and brings heated water to the surface. This experiment will not be dealing with convection.

In this experiment we will be primarily concerned by the transport of heat by radiation and how it differs from conduction. Also we will be concerned with how different colors have different efficiencies in absorbing and emitting heat by radiation. Dark colors absorb radiation and heat up much more efficiently than light colors. That is the reason that we tend to wear darker colors in Winter -- it helps us remain warm by taking the light that is around us and converting it to heat in the clothes we are wearing. In the Summer we wear lighter colors to reflect away light so that the light is not converted into heat in our clothes and we do not get too hot.

**Materials:** An empty metal soup can. Matte black paint. A digital infrared thermometer. Warm water.

**Preparation:** Start off with a regular empty metal soup can. Make sure that it is a kind where you can peel off its label, and that underneath the label, the can is silver in color.

Peel off the label, paint half of the outside of the can with the matte black color and wait for it to dry (Figure 1). It's not necessary to have the can be perfectly half black and half silver but a good portion of the can should be black.

Figure 1. A soup can with its label peeled off and painted half black.

Familiarize yourself with the infrared digital thermometer (IRDT) by reading the instructions contained with it. The IRDT should have various settings; among other things, you can use the Fahrenheit or Celsius temperature scale. Also, most IRDTs can either show the temperature continuously (usually by pressing their "on" button and holding it down), or they can show the temperature at a single moment (usually by pressing and then releasing the "on" button). Note that the IRDT does not measure temperature at a single infinitesimally small point in space -- it measures temperature in a small circular area. The farther the IRDT is from an object, the larger the area in which the temperature will be measured.

For example, point the IRDT 2-3 cm from the palm of your hand and measure the temperature. Now keep pointing it at your hand but move the IRDT 1 meter further from your palm. Notice that the temperature is no longer the same. Even though you are pointing in the same direction as your hand, because the IRDT is further away, it is measuring the temperature in a large circle around your hand.

Your hand still contributes heat but it is no longer the *dominant* heat source in that circle as compared to when the IRDT was closer to it.

**Procedure: How the Color Black Radiates Heat Better**

Fill the metal can with warm water nearly to the top. The temperature of the water should be about 38 degrees Celsius (100 degrees Farenheit). This can easily be gotten from a hot faucet where the water is warm but not hot enough to burn your hand.

Now record the following data by pointing your IRDT 5 cm from the can: Silver side temperature, black side temperature, water temperature (measured from the open top part of the can).

Are the IRDT temperatures the same?

Now close your eyes and use your hand to touch the can and feel the temperature on the outside. Can you tell the difference between the silver side and the black side by touch?

This is the difference between heat transferred by conduction vs heat transferred by radiation. In the case of conduction, when you touch the can, the temperature you feel is the result of the thermal motion of the water molecules being transferred by collisions to the metal atoms in the can, and then the metal atoms transferring those thermal motions to your hand. On the unpainted side, the heat is directly making the molecules in your hand move faster; on the painted side, the metal transfers the motion of its atoms to the paint and then to your hand. Once again all of this is by direct contact or conduction.

But the case with the radiative transfer of heat is different. The process starts the same by having the water molecules transfer their heat to the metal. On the black side, the metal transfers its heat by conduction to the black paint and then the black paint converts that motion of molecules to light very efficiently. On the silver side, the metal atoms are not as efficient in converting their thermal motion into radiation and so less light is emitted. The IRDT is detecting that light, and so the black side of the can, emitting more light, has a higher measured temperature than the silver side. In our warm water example , the light that is generated is in the infrared. Now, if we heated the can to much higher temperatures, the metal would start to glow red. This is still the exact same process of converting heat to light. When the metal can starts to glow in visible light, it means that it is simply at a higher temperature than it was before and is now also emitting shorter wavelength light, which is detectable by our eyes instead of only emitting the longer wavelength infrared light, which is not detectable by our eyes but is detectable by the IRDT.