

Teacher Guide: Radiation



Learning Objectives

Students will:

- Learn that hot objects naturally transfer heat to their environment via radiation (light).
- Observe that the color we see radiated by a hot object is determined by its temperature.
- Determine that objects emitting visible light also emit invisible infrared light.
- Observe that both visible and invisible light can heat objects.
- See that radiation given off by a hot object is usually a blend of several colors of light.



Vocabulary

filament, infrared, Kelvin scale, radiation

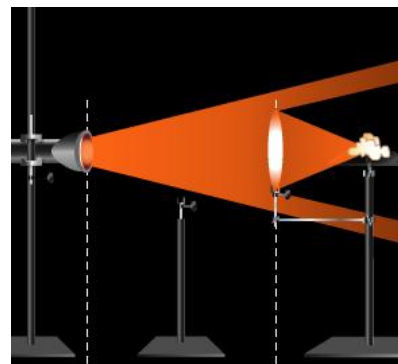


Lesson Overview

In the *Radiation Gizmo™*, students pop popcorn with a super-powerful flashlight. The temperature of the filament can be varied. Students can place cardboard or colored glass between the flashlight and the lens.

The Student Exploration sheet contains three activities:

- Activity A – Students see that the corn is popping due to radiation (not conduction or convection).
- Activity B – Students study visible vs. invisible light.
- Activity C – Students investigate the colors contained within visible light.



Suggested Lesson Sequence

1. **Pre-Gizmo activity: Cooking s'mores!** (🕒 20 – 40 minutes)
Make two batches of **s'mores** (sandwiches of graham crackers, marshmallows, and chocolate). Use a blow dryer to heat the first batch. Ask the students how heat from the blow dryer got to the s'mores. (Air carries the heat. This is heating by **convection**.)

Use a heat lamp to cook the second batch. (You can create a heat lamp by putting an inexpensive heat bulb in a flexible clip-on desk lamp.) Have students feel the air between the lamp and the s'mores. Not only is there no jet of air, but the air will not be particularly hot. Ask the students how heat from the lamp can get to the s'mores without heating the air in between. (This is heating by light, or **radiation**.)

Finally, ask students which of these examples shows how the Sun heats the Earth. Is it radiation or convection? Light or hot air? The answer is radiation. To see why, remember that the Sun is about 150 million kilometers (93 million miles) from Earth, but the Earth warms up as soon as the Sun rises. If hot air from the Sun was heating the Earth, that air would need to be traveling awfully fast! In fact, the heating occurs due to light—radiation.

2. **Prior to using the Gizmo** (🧠 10 – 15 minutes)
Before students are at the computers, pass out the Student Explorations and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations.

3. **Gizmo activities** (🧠 10 – 15 minutes per activity)
Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Encourage students to paste screenshots of their results into a document so they can compare their work. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (🧠 15 – 30 minutes)
As students are working or just after they are done, discuss the following questions:
- Why does it start getting warmer almost immediately after sunrise?
 - Do you think a yellow Sun or a red Sun is hotter? Why?
 - Why does “White light” from a hot bulb actually have more “red light” in it than the red light from a cooler filament?
 - Why does distance affect popping time?
 - How would changing the size of the lens affect the time needed to pop the kernel? [A larger lens focuses more light on the kernel, decreasing popping time.]

5. **Follow-up activity: Seeing infrared** (🧠 15 – 30 minutes)
Our eyes can actually see some infrared light. Most of the time, our eyes are overwhelmed by normal, visible light, to which our eyes are much more sensitive. However, by clever use of filters, we can see things completely differently!

Buy a few sheets of “Congo Blue” theatrical filter gel as well as a couple sheets of “Primary Red” or “Scarlet Red.” (See **Selected Web Resources** for sources.)

Cut the filter paper into squares 2 inches by 2 inches. Take the students outside on a sunny day and have them put five squares of Congo Blue in front of one of their eyes. This lets in blue light as well as some infrared. Some objects will look very different. *[Safety note: Do not let the students look directly at the Sun while doing this.]*

Next, have the students add 2 squares of red filter gel to their 5 blue squares. The red cuts out the blue but still lets in infrared, so now the students are seeing light they normally never perceive. Plants can look very different now. In fact, infrared light can be used to find damaged spots on plants that normally look fine.

Finally, take the students inside and plug in a space heater. Set the heater on a low setting so that it just barely glows. Have students look at it through the squares of filter gel and see the infrared light emitted by the space heater.

You can use welder goggles to create infrared goggles using filter gel. (See **Selected Web Resources**.)



Scientific Background

Almost all objects radiate light naturally as the very small particles that comprise them jostle around. This is known as **blackbody radiation**. The greater the jostling of particles, the greater the quantity and energy of radiation. This means that hotter objects not only radiate different kinds of light than colder objects, but they generally radiate more light *of all kinds* than colder objects. This is why temperature makes a huge difference in how much heat an object radiates.

For example, a 1000 K filament radiates mostly infrared light and a little red light. We perceive faint red light. A 3600 K filament radiates *more* infrared light, *more* red light, green light, and a bit of blue light as well. Our eyes perceive yellow light (red light + green light = yellow light), but this yellow light contains more red than the red light emitted from the 1000 K filament.

The blackbody radiation given off by an object is a wide spectrum of light that includes many colors blended together. For example, a prism shows us that sunlight contains different colors (types of light) that our eyes perceive as a single color. Most blackbody radiation is imperceptible to humans, either being ultraviolet light or infrared light. If an object does not glow, it is not hot enough to emit visible light.

This is not always the case for other sources of radiation. Microwave ovens create radiation of a particular kind, designed to be easily absorbed by water and other molecules inside food. **Fluorescent** lighting also creates light of a particular kind, which is why certain clothes can look very different inside a building with fluorescent light compared to outside under the Sun.

Because radiation travels as light, it allows transfer of heat without matter. This is why we receive heat from the Sun even though there is almost no matter in space to ferry the heat to us. The heat of the Sun is converted to light, travels through space, and is absorbed by Earth.



Technology Connection

Because blackbody radiation covers a wide range of frequencies, only a small amount of the light given off by light bulbs is visible to humans. Most of the rest is infrared. This is not a big problem in winter, when this energy helps to heat the building, but it causes significant energy waste in summer.

To achieve higher efficiency, engineers have designed light bulbs that do not emit infrared radiation. Just as a microwave heats food by sending radiation at a particularly useful frequency, fluorescent lighting creates light at just a few frequencies. Compact fluorescent bulbs use only a quarter of the energy that is used by equivalent incandescent bulbs.



Selected Web Resources

S'mores: <http://en.wikipedia.org/wiki/S'more>

Seeing infrared light: <http://amasci.com/amateur/irgoggl.html>

Supply source for theatrical filter gels: <http://www.rosco.com/us/filters/supergel.asp>

Making a night vision video camera: http://www.metacafe.com/watch/789830/diy_night_vision/

Chocolate bunny vs. heat transfer video: <http://www.youtube.com/watch?v=ZCrGnd3ljqA>

Color Absorption Gizmo:

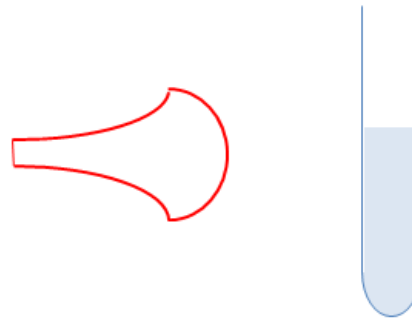
<http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=652>

Extra Demonstration

Pre-demonstration instructions:

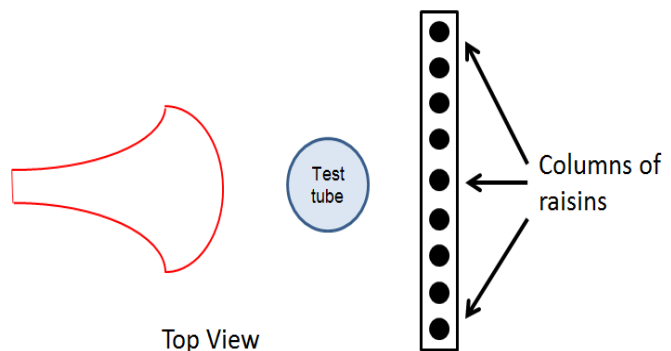
You can perform an interesting demonstration showing the absorption and refraction of thermal energy by using one or two heat lamps, water, and alcohol. It is recommended that you use both a hotter heat lamp (with visible light) and a cooler one operating mostly in the IR range with little or no visible light. However, you can run the demonstration with just one heat lamp.

1. Half fill a test tube with water and support it using a test tube clamp and clamp stand. Support the hotter heat lamp so that it shines horizontally, with the center of the heat lamp bulb (outlined in red to the side) slightly below the water line of the test tube.



Side View

2. Using tape, array a lattice of raisins on a white piece of poster board on the other side of the test tube. We recommend nine columns of raisins spaced 1 cm apart with 5–7 raisins per column. The middle column should line up with the heat lamp and the test tube. One or two raisins should be above the water line, the rest below the water line.



Top View

3. When you turn on the heat lamp, the water will focus the radiation. Adjust the poster board and/or test tube so that the middle column of raisins is at the point of focused light.

Demonstration instructions:

1. Turn off the lights, and turn on the heat lamp; ask the students to observe the light. They should notice the light focused on the screen. Above the water line, the light will weaken very gradually from center going outward. Below the water line, the light will be focused on the middle row of raisins. Compare what is occurring to how eyeglasses focus light, but point out that the light is transferring thermal energy. After sufficient time, either take the temperature of the raisins or turn off the light and let students compare by feel the raisins near the center with those right next to it. Contrast raisins above the water line to those below it.

2. Next, perform the same experiment with a cooler heat lamp, which operates mostly in the infrared range. The raisins will still get warm, though understandably they will not get quite as warm quite as quickly. Emphasize that both heat lamps actually radiated *most* of their energy in the infrared range, so most of the heat energy they sent out was invisible to our eyes. You may wish to discuss how incandescent lighting uses much more energy than fluorescent lighting, partially because so much of its energy is wasted putting out radiation with wavelengths too long for humans to see.
3. Next, replace the test tube with a wide beaker and compare the two heat lamps. Replace the raisins (which might be cooked from the previous two steps) with dark construction paper. When the hotter heat lamp is turned on, you should still find light making it through the water and focusing on the paper, but it will heat up less in the middle below the water line than above it.

If you are using a cool, purely IR weak lamp as your second lamp, it may cause almost no heating below the water line directly behind the beaker. Ask students why. They will probably come to the conclusions that the water absorbed or blocked much of the light.

4. Pour out the water and replace it by partially filling the beaker with pure ethanol. Run the experiment again and you should find that the heat lamps have a much easier time heating the paper when shined through alcohol as compared to water.

Post-demonstration discussion:

At this point, you can explain to your students that different molecules absorb different kinds of light. The wavelengths of light a substance can absorb match up with the types of motion the atoms in its molecules can undergo. Complex molecules like water, carbon dioxide, and ethanol can bend, vibrate, and rotate in many different ways. In water, some of those motions match up with wavelengths just near the edge of the red side of the spectrum. This means water absorbs red light and infrared light pretty well, giving thick bodies of water a bluish look.

Alcohol, on the other hand, has different bonds in its molecules, so it lets different types of light through, including most infrared light at the edge of the spectrum. This is why it allowed thermal energy to pass through the beaker more easily.

Finally, you can connect this to the “greenhouse effect.” Oxygen and nitrogen gas make up more than 95% of the atmosphere, but they absorb almost none of the infrared light radiated by Earth’s surface. The reason for this is that they are very simple molecules. They just have two atoms in each molecule, so there are only a few ways the atoms can vibrate or rotate.

The most significant greenhouse gases are water vapor, carbon dioxide, and methane. They all have three or more molecules, meaning there are several ways for the atoms inside each molecule to vibrate, rotate, or bend. This lets these three molecules absorb much of the energy radiated away by Earth’s surface.