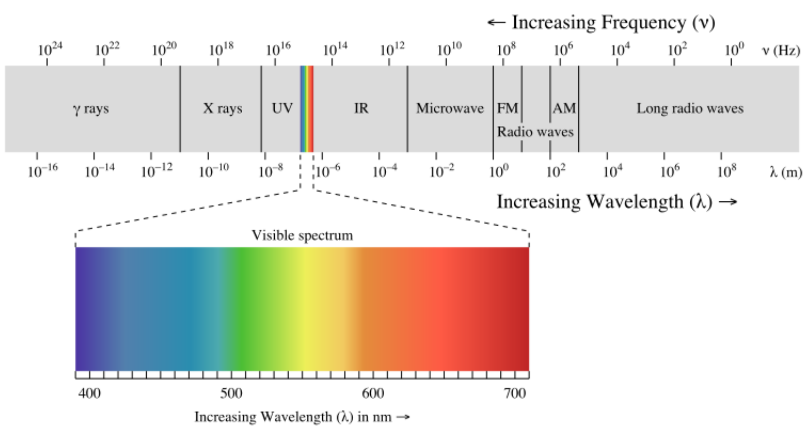
Heat Transfer

Radiation

Introduction

In this activity you will explore infrared radiation, which you can't see but can feel as heat.

Radiation is the common name for electromagnetic energy traveling through space. It goes very fast (ten times around the earth in one second) and can pass through a vacuum. It doesn't need material to travel in. It has many forms, including visible light, infrared (IR), ultraviolet (UV), X-rays, microwaves, and radio waves. These are all the same form of energy, just with different frequencies and amounts of energy. Different frequencies of radiation interact with matter differently, which makes them seem more different to us than they really are.



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Radiation is not heat. Radiation and heat are two different forms of energy. But one is often transformed into the other in everyday situations. Thermal energy is often transferred by radiation, mostly in the infrared (IR) and visible range. All materials that are warmer than absolute zero (-273 °C) give off radiation due to the fact that their atoms are vibrating. The amount of radiation is proportional to the fourth power of the temperature (T^4), measured from absolute zero. So, the hotter an object, the more radiation it emits.

Do objects at room temperature give off radiation?

Learning goals

Electromagnetic radiation includes visible light but has other invisible forms as well, including infrared radiation.

All objects give off some radiation though not necessarily in the visible spectrum. It increases with increasing temperature.

Different surfaces absorb radiation at different rates.

Radiation energy, when absorbed, is usually converted into heat.

Note: This is one section of the "Science of Heat Transfer" chapter of the Engineering Energy Efficiency Project. See: http://concord.org/engineering

Also most surfaces absorb radiation and transform it into heat. White surfaces reflect visible light, but absorb infrared. Black surfaces absorb both visible light and infrared.Shiny surfaces reflect both of them.

The fact that all objects give off radiation energy is a little surprising. We usually imagine that only “red hot” materials radiate, because we can’t see other wavelengths that aren’t visible light. This experiment will explore radiation from objects at ordinary temperatures. This radiation is mostly in the infrared range, which is right next to visible light but with longer wavelengths. Note the infrared range on the chart above.

Depending on the level of your students, you may wish to begin this chapter with a brief inquiry into what they understand about electromagnetic radiation. Much of this is not intuitive! For instance,

- Can radiation travel through empty space? Yes, for example, light from the sun.
- Is radiation a form of heat? No, they are two different forms of energy. But hot object radiate, and absorbed radiation turns into heat.
- Can radiation go through things? Yes, depending on wavelength and materials. For instance, X-rays (short wavelength) and radio waves (long wavelength) can go through solid opaque objects that stop light and IR. Ask for other examples.
- What are “heat rays”? **Radiation is not heat (that is, molecular motion)**, but it carries energy from one object to another, heating the cooler one and cooling the hotter one, so it seems like a “heat ray.”
- Can surfaces “attract” radiation? No.
- What happens when radiation strikes a surface? It can be reflected, scattered, absorbed, or transmitted.

A note about aluminum foil
Misconceptions about foil are common. Students will say it attracts or repels heat. They may think it keeps things cold but not hot. They may say it’s a good insulator.

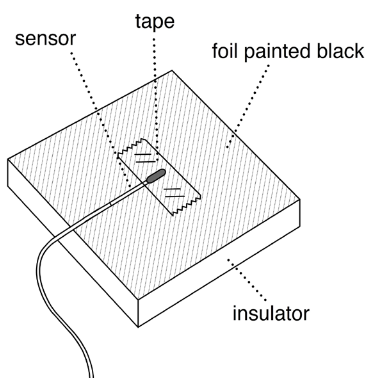
Foil is a **very** good conductor, so it doesn’t stop conduction. But because it’s shiny it does not **emit** IR radiation very much, so there is very little radiative energy loss. It also **reflects** IR, so there is very little radiative energy gain. Therefore, it adds overall insulating value **if it is facing an air space but not if it is touching something**. For example, the foil wrapping the light bulb gets very hot (it’s a good conductor) but doesn’t radiate much IR, so it only heats its surroundings by conduction to the air and subsequent convection of the air inside the model house. An ice cube wrapped in foil reflects IR from the (warmer) surroundings and melts more slowly than a bare ice cube.

Infrared radiation detection

In this experiment you will use a "radiation meter"– a temperature sensor taped to a thin layer of aluminum foil that is glued to a piece of insulation and painted black. Radiation that strikes this surface will be absorbed and will quickly heat up the foil and the sensor. If the sensor temperature is different from the air temperature around it, you have detected heating from radiation.

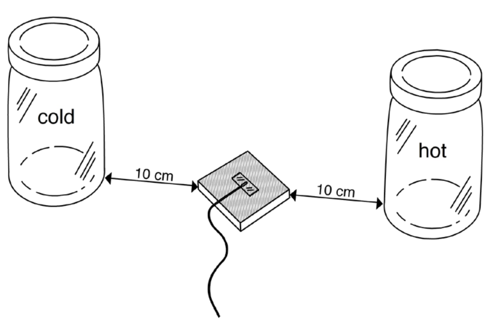
Procedure & data collection

1. Tape your temperature sensor to a "radiation meter." Your teacher will provide this. The clear tape should cover the sensor so that it is held tight against the black surface.



2. Fill a jar with hot water (close to boiling if possible – be careful! You may need cloth or paper towels to pick it up) and another jar with cold water (ice water). The jars should have tops so they won't spill.

3. Place the two jars on a table and the radiation meter between them, with the radiation meter facing upward.



Tools & materials

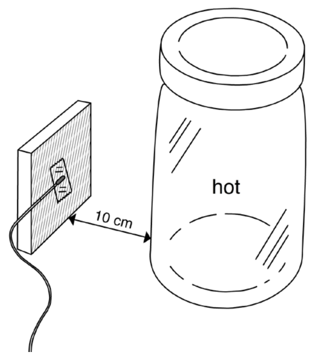
- One fast-response temperature sensor (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- Hot tap water
- "Radiation meter": foil-faced rigid insulation, about 5 cm square, painted black
- Logger Lite
- USB Flash drive
- Ruler (cm)
- Clear tape
- Hot water jar (plastic or glass)
- Cold water jar (plastic or glass)

This experiment allows students to detect infrared radiation by measuring its heating effect on a low-mass black surface. Three sources of radiation are compared: hot water; cold water; walls of the room (ambient). Expect changes of 1 – 2 °C.

As an extension, measure the transmission of IR by various materials, such as glass, acetate, or clear plastic. Thin black or white plastic is interesting because it stops visible light but transmits IR quite readily. With a hotter source, students could test differences with multiple layers.

5. Start measuring. Let the sensor settle down to room temperature. Be careful not to touch it! If you do, wait until it goes back down to room temperature. It should remain unchanged (to 0.1 °C) for at least ten seconds. Record the room temperature in the table below.

6. Face the sensor toward the hot water jar. It should be 10 cm away. Wait for the sensor to settle down and then record the temperature in the table below. Note: your hands radiate IR too. Keep them away from the front of the meter!



7. Face the sensor toward the cold water jar and repeat the measurement. Record the temperature in the table below.

8. Save your Logger Lite file.

9. Calculate the change from room temperature.

Infrared heating

Measurement	Temperature °C	Change from room temperature
Room temperature		
Toward hot water		
Toward cold water		

Results

Summarize your results, which compared the radiation meter facing the room (straight up), the hot jar, and the cold jar.

Could the radiation meter show a different temperature than the air immediately around it? Why?

Yes, if the incoming radiation was different from the room walls.

Analysis

The radiation meter you used was black so that it would absorb radiation. What if it were white or shiny?

It would not be affected by the surrounding radiation.

If the hot and cold jars influenced the temperature of the radiation meter, how did they do it? Explain in terms of conduction, convection, and radiation. Include specific evidence for your explanation.

The incoming radiation would be greater or less than the outgoing radiation, so the temperature would be different. When the meter faces in different directions, the air around it is the same temperature but the reading changes, so the change is not due to conduction or convection with the air.

Does the cold jar “radiate cold,” or does it “radiate less heat”? Why?

It radiates less. “Cold” is the absence of heat, not a form of negative energy.

Describe a real-world situation where you have felt radiation from something hot and something cold even though they were not visibly hot or cold.

Hot: oven burner, wood stove, radiator, a hot cup (if you don’t touch it)
[Note errors: item either glowing red-hot or heat being transferred by some other means, such as a hair dryer or a hot-air furnace or something you touch]
Cold: window, ice cube

Explain why it is uncomfortable to sit near windows on a cold night even if they are tightly sealed and don’t let cold air in.

The window surface, being at a lower temperature, radiates less IR toward your skin than your skin radiates toward it. Your skin receives less IR than it would from, say, a warm interior wall. So it senses the lack of warmth of the window purely by radiation, independent of cold air that might be circulating from it.

Connection to buildings

Application

Passive solar heating consists of letting in sunlight energy (mostly visible light) and stopping heat loss, some of which is IR radiation outward from the warm building. There's a trade-off between the two processes. Larger windows gain more sunlight, but they also lose much more heat than walls. There have been considerable technical advances over the years to make windows that are transparent (let light in), but also have a high insulating value (keep heat in).

For example:

- two layers of glass (three layers in northern climates), with an air space between
- argon gas in the air space, which is less conducting than regular air
- "low-emissivity" coatings on the glass surfaces, which reduces the emission of radiation from the glass itself. If you coated the jar of hot water in this way, the radiation meter would not show a temperature rise when it faced the jar.

Picture a room with large windows on one wall and a steam radiator on the opposite wall. Steam radiators are large cast-iron objects that get very hot — almost too hot to touch. On a cold night, or when the sun is not shining, sketch on the drawing below all of the ways that the heat from the steam radiator and the loss of heat from the windows become distributed throughout the room.

The diagram would show arrows of air rising from the radiator by convection and perhaps making a complete loop in the room. Radiant energy would travel directly across the room to other surfaces in straight lines.