# Cooking with the Sun

Facilitator's Guide

TechXcite Discover Engineering

# Module Overview

This TechXcite: Discover Engineering module introduces youth to the power of solar energy through the design of a solar oven. Youth will investigate the three types of heat transfer—radiation, conduction, and convection—and learn how they work. Youth will also learn how to use shadows to locate the sun in the sky. In the final activity, they will use this knowledge to design and build a solar oven.

This curriculum is intended for use with youth in middle grades in informal settings, such as after-school programs and summer camps. However, it has also been successfully implemented in formal school contexts, homeschool content, and with youth in elementary and high school.

**Activity 1:** Youth explore the effect of color on the amount of radiation absorbed or reflected.

**Activity 2:** Youth determine the sun's direction and elevation angle and learn how it affects both climate and solar oven design.

**Activity 3:** Youth learn how to reduce heat transfer with insulation and build a device to test different insulating materials.

**Activity 4:** Youth build a solar oven that maximizes heat gain via radiation and minimizes heat loss via conduction and convection.

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# TechXcite: Discover Engineering

TechXcite is an informal engineering program partnering 4-H Youth Development/Family and Consumer Sciences at North Carolina State University, National 4-H Council and the Engineering K-PhD Program at Duke University's Pratt School of Engineering. It was initially funded by a five-year grant from the National Science Foundation.

In 2000, Drs. Ybarra and Klenk created an informal after-school engineering program at Rogers-Herr Middle School in Durham called Techtronics, which spread to additional schools across North Carolina and other states. The TechXcite: Discover Engineering curriculum builds on the Techtronics foundation by implementing hands-on, exploratory, engineering learning modules in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school and home-school programs have chosen to use the TechXcite curriculum. TechXcite is an engaging, substantive, experiential and inquiry-based curriculum centered on engineering, while using technology, applied science and mathematics learned in school. TechXcite's mission is to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

TechXcite is the product of a collaboration of twelve 4-H leaders at land grant universities, two leaders at National 4-H Council and a team at Duke University.

### Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

### Training Videos

Each module comes with a set of training videos found on its curriculum page (techxcite.org/curriculum). These videos serve as a companion to the Facilitator's Guide. An introductory video provides an overview of the material and concepts. The corresponding video for each activity then covers basic setup, procedure, and helpful tips for facilitating that activity. It's recommended that instructors watch all of the videos before starting the module.

# Using this Guide

The Facilitator's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will be given basic information about the activity. This includes:

- Time Required
- Group Size – Suggested number of students per group.
- Materials List
- Youth Handouts – These will need to be copied.
- Getting Ready – What you need to do before the activity and approximately how much time it will take you.
- Education Standards
- Learner Outcomes
- Vocabulary

## Introduction and Activity Closure

The Introduction and Activity Closure are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics.

## Facilitating the Activity

This section contains step-by-step instructions for facilitating the activity. Students have their own procedure in the Youth Handouts.

## Exploration Questions

Provides possible answers to the Exploration Questions found at the end of each activity in the Youth Handouts. After the students have a chance to answer the questions individually, instructors should hold a class discussion. The main purpose of this section is to encourage critical thinking and to promote the exchange of ideas.

## Apply

When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new knowledge and skills; however, the application of new knowledge or skills to independent, real-world situations is a critical factor in the learning process. To complete the cycle of experiential learning, this section provides youth with an opportunity to apply the concepts to authentic situations.

# Activity 1: Heat from the Sun

**Time Required:** 20 minutes **Group Size:** Entire class

## Materials List

### Each class needs:

- Infrared thermometer
- Standard thermometer
- Black spray paint
- 2 Silver pans

### Youth Handouts:

- "Heat from the Sun"

## Getting Ready (20 minutes)

- The day before the activity, paint one of the pans black.
- Place the pans outside in the sun a few hours before class. You can do this activity if it's partly cloudy, but it works best on a sunny day. These should be placed on grass or another good insulator. Concrete will quickly conduct heat away from the pans and may not work as well.
- Activities 1 and 2 are good companion activities and may be done on the same day.

## Education Standards

NGSS: 1-PS4-2, 4-PS3-2, 4-PS4-2

## Learner Outcomes

- Explain that a black surface absorbs more radiation than a white surface.

## Vocabulary

| Word | Definition |
|---|---|
| Electromagnetic spectrum | The complete range of wavelengths of electromagnetic radiation including radio, microwaves, infrared, visible, ultraviolet, x-rays and gamma rays. |
| Frequency | The number of times that an event occurs within a given period. |
| Radiation | The transfer of energy via electromagnetic waves (does not require a medium). |
| Solar oven | A device that uses heat energy from the sun to cook food. |
| Wavelength | The distance from the peak of one wave to the peak on the next wave. |

# Activity 1: Heat from the Sun

## Introduction

Finding ways to use energy more efficiently is an important part of engineering in the 21st century. Energy from the sun can be used to cook food in **solar ovens**, heat homes with passive solar architecture, and generate electricity with solar panels. Over the next few weeks, you will be designing and building a solar oven with the goal of absorbing and retaining as much heat as possible.

You may not know it, but you've probably experienced how a solar oven works. What happens when a car sits in the sun on a hot summer day with the windows rolled up? [*The interior heats up.*] Can the car's interior get hotter than the outside air temperature? [*Yes.*] Light rays from the sun go through the windows and strike the surfaces inside the car. Energy from the sun's rays is called solar **radiation**. Depending on the color of the interior, some radiation will be absorbed and some will be reflected. The absorbed radiant energy is converted to heat in the surfaces inside the car. Your solar oven will gather heat in the same way.

Today we will conduct a simple experiment to discover how the sun heats objects and what factors affect the amount of heat they absorb or reflect.

## Facilitating the Activity

1. Take students outside and show them the two pans. Ask: "Which pan do you think will be hotter?" Let students offer a few explanations why one will absorb more solar radiation than the other.
2. Explain that the hottest pan is the one that has absorbed more solar radiation. Tell them it would be difficult to measure the temperature of a surface using a standard thermometer. Even if it were touched directly to the pan, part of the thermometer would still be exposed to the air. The reading would be somewhere in between the air temperature and the temperature of the surface, so it would be inaccurate. You can demonstrate this with one of the standard thermometers in the kit.

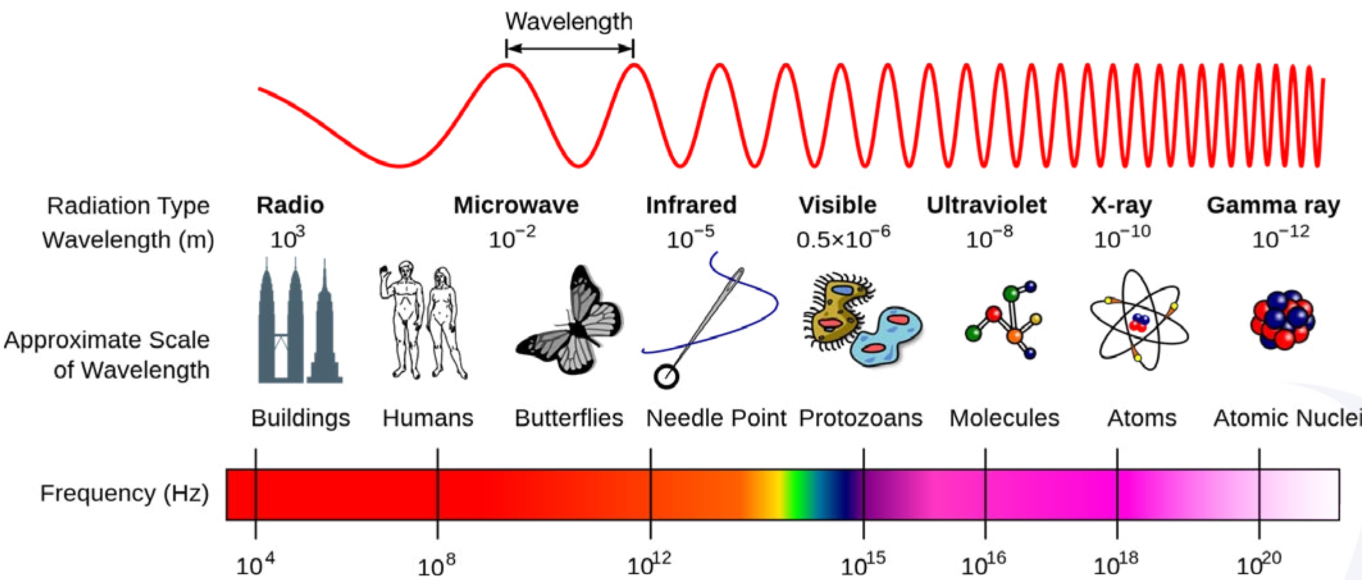
   For the most accurate reading, we need a special infrared thermometer, which reads the surface temperature by measuring the heat emitted in the form of infrared radiation.
3. Demonstrate how to use the infrared thermometer. To measure the surface temperature of one of the pans, point the thermometer toward the pan, holding it a few inches away, and press the button on the thermometer. The controls on the thermometers may vary.
4. Allow students to measure the temperature at several locations on each pan and average the results. The black pan should have a significantly higher temperature than the silver pan.
5. Optional: Allow students to experiment with the infrared thermometer by measuring the temperature of other objects such as the grass, their clothing, or their skin.

# Activity 1: Heat from the Sun

## Activity Closure

To understand why the black pan is hotter, we first need to understand some basics about light and color.

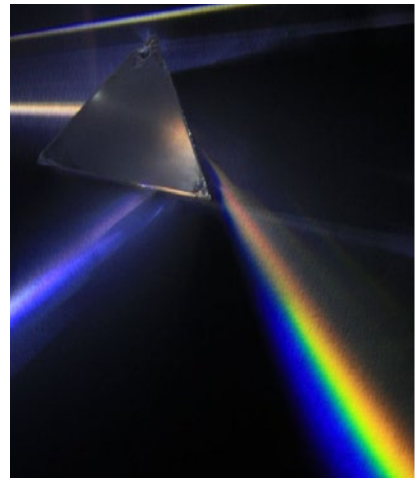
Light travels in the form of an electromagnetic wave. The distance between the peaks of each wave is called a **wavelength**, and each color of light has a different wavelength. For example, red light has a wavelength of about 650 nanometers, or billionths of a meter, and violet light has a wavelength of about 400 nanometers.




However, radiation that the human eye can see, or visible light, makes up only a tiny part of the entire **electromagnetic spectrum**. Although you may not realize it, you are already very familiar with many of the other types of "invisible" light. A radio wave carrying a music signal to a car radio has a wavelength over a mile long. A cellphone or microwave oven uses light with a wavelength of a little less than half a foot long. You also know about radiation with shorter wavelengths than visible light. Sunscreen protects against sunburn from ultraviolet light, which has a wavelength of about 300 nanometers. In hospitals, doctors shine light with wavelengths of less than a nanometer, called X-rays, through skin and muscle in order to see bones.

When a light strikes the surface of an object, it can be reflected, absorbed, or refracted. Reflection occurs when a wave hits the surface of an object and bounces back. The color of an object is determined by the wavelengths of visible light reflected to our eyes (as we will discuss later). Absorption occurs when the energy contained in the light wave is taken in, or absorbed, by the atoms of the material. This causes them to vibrate faster and increase in temperature. Refraction occurs when the light passes through the surface of the material and bends to travel in a new direction. When you look at a stick under water it looks broken or bent because the light rays get refracted as they pass through the surface of the water. Even though most objects look solid to our eyes, many wavelengths of light can pass right through them as if they were transparent. Ultra-short wavelength gamma rays emitted from stars in outer space are actually passing through your body right now!

# Activity 1: Heat from the Sun

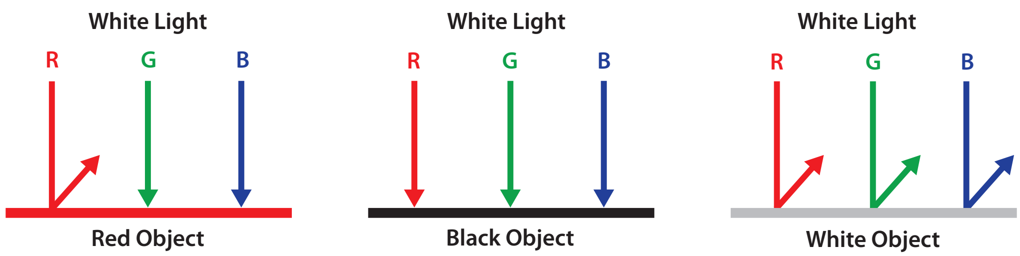


If you've ever seen what happens to sunlight when it hits a prism, you know that white light is made up of all the colors of the rainbow added together. Conversely, when none of the wavelengths of visible light are present, your eye perceives the color as black. Black is simply the absence of visible light.

When white light strikes an object and a specific wavelength (or color) is absorbed, that particular wavelength will never make it to your eyes. Only the wavelengths of visible light that are reflected back into your eyes contribute to the color of the object. For example, an object that reflects only the red wavelengths of light will appear red in color. All the other wavelengths of visible light that hit the surface of the red object were either absorbed by its atoms or transmitted through the object as refracted light.

Now that you understand a bit more about light and color can you guess why the black pan is hotter? [*Allow a few students to provide an answer.*]

The black pan is hotter because it absorbed energy from all of the wavelengths of visible light that hit its surface. The shiny pan is cooler because it reflected all the wavelengths of visible light, and therefore, didn't absorb any energy from them. Note that the shiny pan still absorbed some energy from invisible wavelengths of light, which is why it's hotter than the air around it.




## Exploration Questions

1. When you go outside on a hot day, would you feel cooler wearing a white shirt or a black shirt (assuming both were made of the same fabric)?

   [*You would tend to feel cooler in a white shirt. In general, black objects absorb more radiation than white objects.*]

2. If an object appears blue in the presence of white light, which colors is it reflecting and which colors is it absorbing?

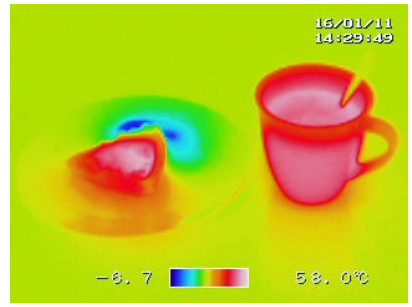
   [*A blue object appears blue because it is reflecting blue light and absorbing all other colors.*]

3. What color does a red object appear if the lights are turned off and the room is completely dark? What about a green object?

   [*An object in a room with no light source has no color (and appears black) because there is no light to reflect.*]

# Activity 1: Heat from the Sun

## Apply



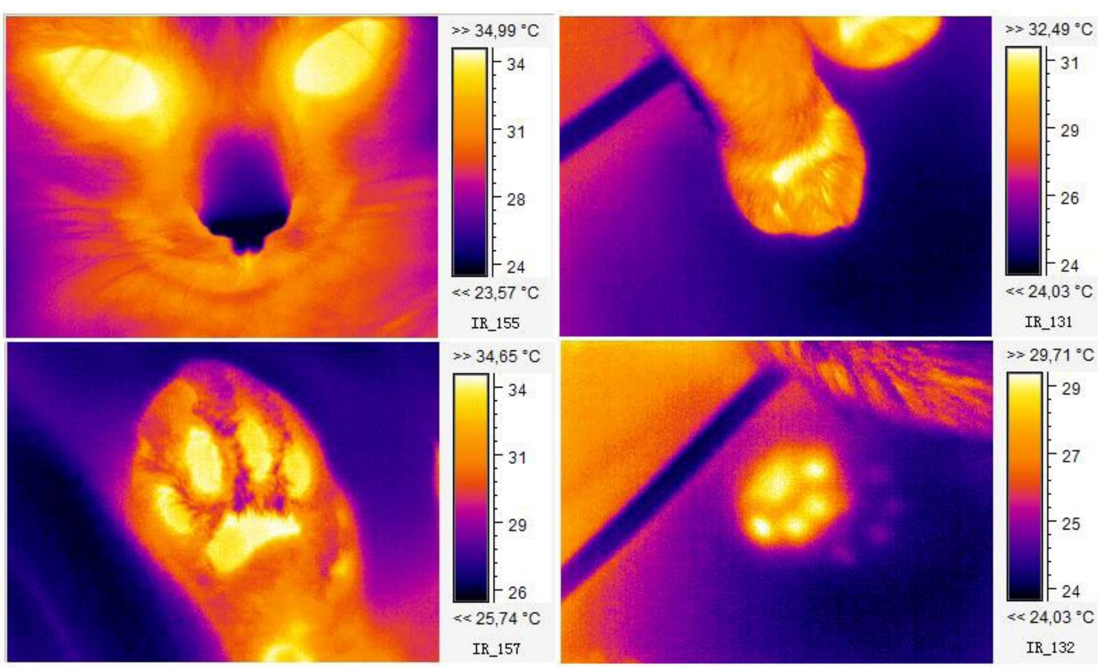

Infrared light is produced by the vibration of atoms in an object. The higher the temperature, the more the atoms vibrate and the more infrared light they produce. Atoms only stop vibrating at absolute zero (-459.67°F or -273.15°C). Therefore, any object with a temperature above absolute zero radiates infrared light. Although invisible to the human eye, infrared cameras allow us to detect infrared light, convert it into an electrical signal, and process the information to produce a thermal image.

What do you think would be some uses for an infrared (or heat-detecting) camera?

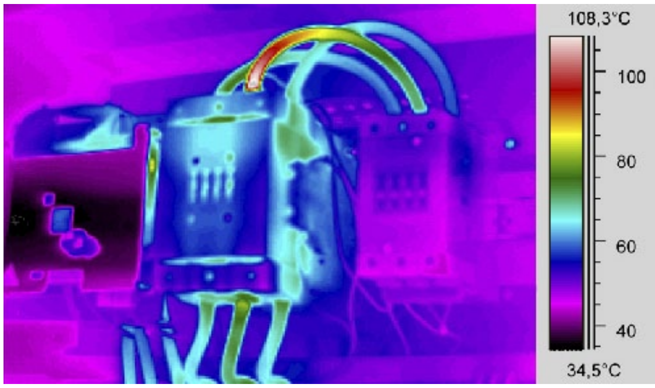
[*Possible uses:*

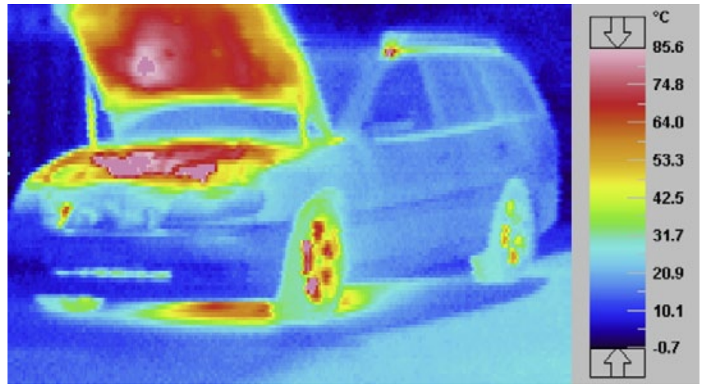
- *Firefighters looking through smoke to find people and localize the base of a fire*
- *Search-and-rescue crews finding people lost at sea*
- *Police helicopters locating fleeing suspects in the dark*
- *Engineers locating areas of heat loss in buildings, allowing for better insulating practices and increased energy conservation*
- *Maintenance technicians locating overheated joints and sections of power lines, which are signs of impending failure*
- *Scientists studying warm-blooded animals at night*
- *Military locating enemy combatants in the dark*

*To explore more everyday applications for infrared imaging visit: http://coolcosmos.ipac.caltech.edu/cosmic_classroom/light_lessons/our_world_different_light/*]



# Activity 1: Heat from the Sun

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# Activity 2: Where is the Sun?

**Time Required:** 30 minutes **Group Size:** 3


## Materials List

### Each group needs:

- Level
- Wooden skewer
- Compass
- Ruler
- Scientific calculator

### Each class needs:

- Flashlight
- Piece of paper (Not included in kit)

### Youth Handouts:

- "Where is the Sun?"

## Getting Ready (10 minutes)

- Find a place where students can place their skewers vertically into the ground. An ideal location is next to a level or fairly level sidewalk on which the shadow of the stick can fall. Use the level to locate a portion of sidewalk that is almost flat.
- Perform this experiment on a sunny day for the most defined shadow. If it is overcast on the day of the experiment and no shadows are visible, a flashlight may be used in place of the sun.

## Education Standards

CCSS: 4.MD.C.6, HSG.SRT.C.8
NGSS: 5-ESS1-2, MS-ESS1-1

## Learner Outcomes

- Use a shadow to describe the position of the sun in the sky and how it moves.
- Explain the importance of the solar azimuth and solar elevation angles.
- Explain that a solar oven should be moved throughout the day so that it always faces the sun.

# Activity 2: Where is the Sun?

### Vocabulary

| Word | Definition |
|---|---|
| Axial tilt | The angle between an object's rotational axis and its orbital axis. |
| Azimuth angle | The compass direction measured in degrees, with zero degrees corresponding to North and increasing in a clockwise fashion. |
| Intensity | The power transferred per unit area. |
| Elevation angle | The angle of the sun as measured from the horizon. |
| Gnomon | An object, such as the style of a sundial, that projects a shadow used as an indicator (pronounced “NO-mahn”). |
| Latitude | The angular distance north or south from the equator of a point on the earth's surface. |
| Longitude | The angular distance east or west from the prime meridian of a point on the earth's surface. |

### Introduction

Today you will be learning how to measure the direction and height of the sun. Based on this information, you can design your solar ovens to maximize the energy they receive.

The purpose of a solar oven is to use energy from the sun to heat food. Would you position a solar oven in the same direction in the morning as you would in the afternoon? [*No, because the sun rises toward the east and sets toward the west.*] A solar oven that moves with the sun can capture more energy than a stationary solar oven. When we test our solar ovens, we will need to determine the direction of the sun at the current time of day to know which way to point the ovens.

How would you describe the location of the sun right now?

[*Students might have a number of responses. They might point at it. They might say it is in a certain direction. They might compare its current location in the sky to various reference points.*]

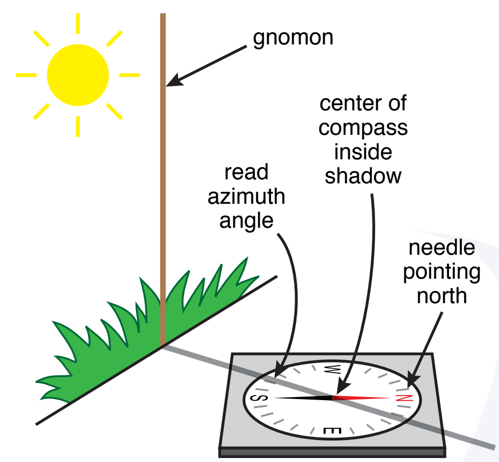
Engineers and scientists use two measurements to locate the sun in the sky. The first is **azimuth angle**, or compass direction, and the second is **elevation angle**, which describes how high the sun is in reference to the horizon.

# Activity 2: Where is the Sun?

## Facilitating the Activity

1. Place students in groups of 3 or 4 and distribute the materials. Don't pass out the handouts yet.
2. Ask students how they might determine the direction and height of the sun with these materials. Give them a few minutes to think about it and discuss amongst themselves. Ask them to explain their ideas.

   [*Because the sun is so big, it's difficult to measure the sun's direction by pointing the compass directly at it. Fortunately, the solar azimuth angle can determined using the shadow of the skewer and the compass. The direction of the sun will be exactly opposite the direction of the shadow. The solar elevation angle is determined by shadow's length. The longer the shadow, the lower the sun is in the sky. The shorter the shadow, the higher the sun is in the sky.*]
3. Distribute the handouts.
4. Have students use the level to find a flat place on the ground.
5. Stick the **gnomon** (wooden skewer) into the ground and make sure the gnomon is perpendicular (at a 90 degree angle) to the ground. The experiment works best with the gnomon stuck into the dirt next to a level slab of concrete, like a sidewalk, such that the shadow is cast onto the concrete. It is important for the gnomon to be straight up and down and for the shadow to be clearly visible.
6. Teach students how to use the compass (see *Tools Used in the Module*).
7. Instruct students to rotate the compass dial or body until the needle is lined up with the "N" at 0 degrees.

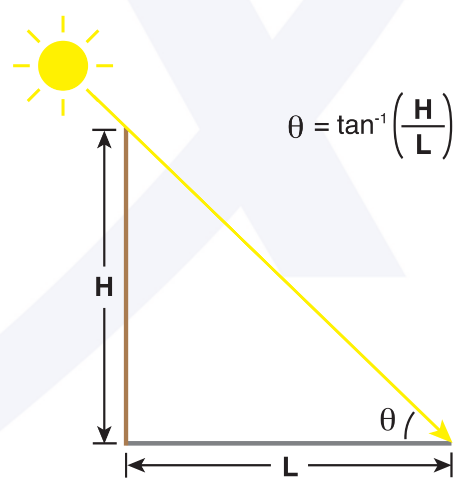



8. Place the compass on the ground inside the shadow of the gnomon and adjust it until the center of compass is in the middle of the shadow.
9. Read the angle inside shadow closest to the gnomon (see diagram). This is the solar azimuth angle.
10. Optional: To calculate the solar elevation angle, students should use a ruler to measure the height of the gnomon sticking up out of the ground and the length of the shadow. Then, plug the two measurements into the following formula:

$$\text{elevation angle} = \tan^{-1}\left(\frac{\text{height of gnomon}}{\text{length of shadow}}\right)$$

    Note: Make sure the calculator is in degrees, not radians.

    [*We don't want turn this into a math class to explain the meaning of the tangent and arctangent, but let students know that they will eventually be able to derive this formula themselves when they learn Trigonometry.*]



# Activity 2: Where is the Sun?

11. If time allows, take measurements for the azimuth and elevation angle every hour (or half hour) throughout the day. If it's not possible to take hourly readings, just try to take at least one more set of readings at a different time of day.
12. Use the data compiled by the U.S. Naval Observatory (http://aa.usno.navy.mil/data/docs/AltAz.php) to look up the azimuth and elevation (altitude) angle for the day and location the activity was completed. Compare the generated data to your own observations and calculations.

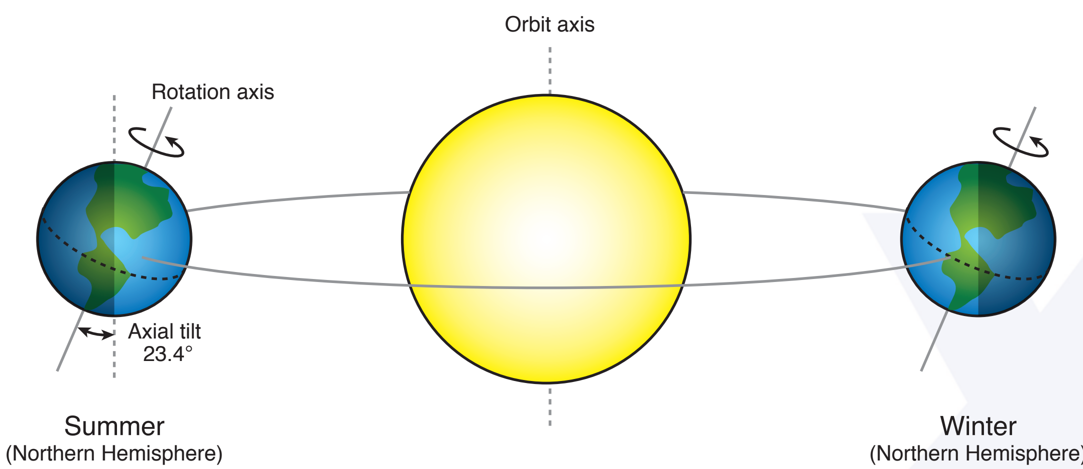
    Note: If the activity is performed in the summer and daylight savings time is in effect, add 1 hour to each of the times on the table generated by the website.

### Activity Closure

Does anyone know why we have seasons? [*Allows students to answer.*]

Contrary to popular belief, the seasons don't have anything to do with the distance between the earth and the sun. We know this explanation must be false because the seasons in the northern and southern hemispheres are opposite. On any given day in July, North America is experiencing summer while South America is experiencing winter. How is this possible?

Seasons are actually the result of earth's **axial tilt**, or the angle between the earth's rotational axis and its orbital axis around the sun. [*Redraw the illustrations below on the board.*] This angle is about 23.4 degrees and does not change throughout the year. What *does* change is the orientation of the earth's poles relative to the sun. In the northern hemisphere, summer occurs when the North Pole is pointed *towards* the sun and winter occurs when the North Pole is pointed *away* from the sun.




But why does the axial tilt matter to our weather? It's not that the surface of the northern hemisphere is *closer* to the sun during the summer—the change in distance from one side of the planet to another is minuscule compared to the millions of miles between the sun and earth—what really matters is the angle of the sun's rays with respect to the earth's surface. To understand this, we'll demonstrate with a piece of paper and a flashlight.

[*Hold the flashlight directly perpendicular to the paper such that all of the light hits the paper and forms a perfect circle. Then, slowly tilt the flashlight (or the paper) until the circle of light turns into an ellipse.*]

# Activity 2: Where is the Sun?

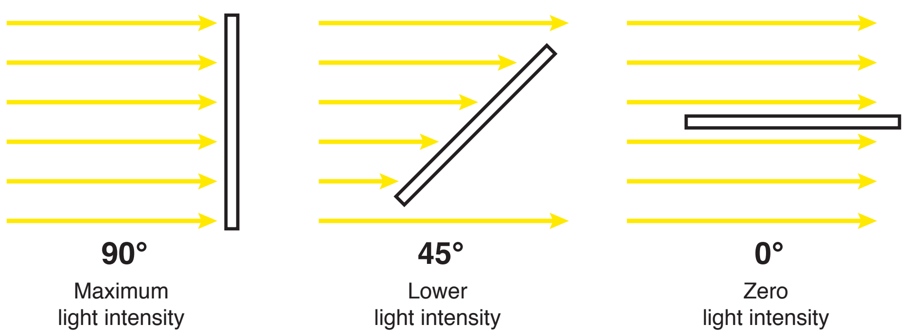
If we hold the flashlight directly over the paper, all the light from the flashlight will hit the paper and appear as an illuminated circle. But as we slowly tilt the flashlight, the circle turns into an ellipse. All of the light is still in that ellipse, but it's now spread out over a larger area. The **intensity** of light, or amount of light per square inch, has dropped. The same is true on the earth. When the sun is lower in the sky, the light gets more spread out over the surface of the earth and less heat per square inch can be absorbed.

It is also important to note that, because of the axial tilt and the rotation of the earth, the sun's elevation angle and direction is constantly changing. The position of the sun in the sky at any given moment depends greatly on your exact location (**latitude** and **longitude**), the time of year, and the time of day. All of these things must be taken into consideration when you design your solar oven.

## Exploration Questions

1. If you want to get the most power out of a solar panel, what angle should it be at relative to the sun's rays?

   [*The solar panel should be at a 90-degree angle (perpendicular) to the sun.*]




2. What time of day will the sun reach it's maximum elevation angle? Does this maximum angle stay the same or change throughout the year?

   [*The maximum elevation angle always occurs at noon, but the maximum angle it can reach depends on the location and time of year. Vary rarely will the sun ever be directly overhead (90-degreee elevation angle) at noon, and in some locations it will never be directly overhead*.]

3. Will the shadow of an object at a given location and time of day be longer in the winter or the summer? Why?

   [*Shadows are longer in the winter because the sun is lower in the sky. Generally, in the northern hemisphere, the shortest shadow occurs June 21st (known as the summer solstice) and the longest shadow occurs December 21st (known as the winter solstice). The opposite is true in the southern hemisphere.*]

# Activity 2: Where is the Sun?

## Apply

If your solar oven were fixed and could only be adjusted a couple times a year, how would you position it? Why?

[*Allow students to explain their reasoning. There are no "right" answers. One possible solution is to position the oven so that it is pointing directly at the sun at noon, when the sun is highest in the sky, during the summer and winter solstice. If this solution is used it would only need to be adjusted twice a year around the middle of March and September, directly in between the summer and winter solstice.*

*Another possible solution is to tilt the oven slightly lower than in the previous solution because the sun only reaches it's peak once a day and if it's slightly lower it will match the sun's elevation angle (although not the azimuth angle) two times each day instead of one.*

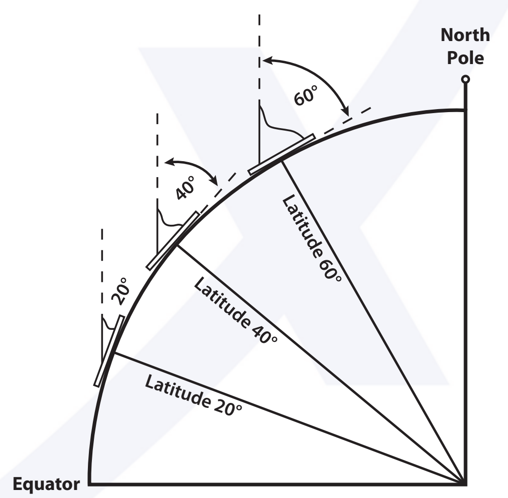
*For reference, the general rule of thumb for solar panels is to position them at the same angle as your latitude, plus 15 degrees in the winter and minus 15 degrees in the summer (see Optional Extension).*]

## Optional Extension

Practically every culture in recorded history has used the sun to keep track of time. One of the oldest and simplest devices invented for this purpose is the sundial. While it comes in many forms, the most common is the horizontal sundial, which consists of two parts: the dial face and the gnomon. The dial face is a flat surface on which lines are drawn indicating the hours of the day, and the gnomon is a triangular shape that sticks out and casts a shadow on the dial face. As the sun moves across the sky, the shadow cast by the gnomon's top edge aligns with different hourlines on the dial face.


The gnomon has a very specific orientation and an angle that varies by location (specifically latitude). Can you guess how the sundial should be oriented and what determines the gnomon's angle?

[*The gnomon on a sundial must be aligned with the earth's rotational axis to tell the correct time. Hence, the gnomon must always point towards true north and the gnomon's top edge should be parallel to the earth's axis (coincidentally meaning the angle between the gnomon's top edge and the ground should be equal to the latitude at any given location). This angle makes up for the earth's tilt and ensures the hour marks remain the same all year long.*]



# Activity 2: Where is the Sun?

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# Activity 3: Create a TechXcite Thermos

**Time Required:** 60 minutes **Group Size:** 3

## Materials List

### Each group needs:

- Standard thermometer
- 2 Soda cans (12 oz, empty)

### Each class needs:

- Scissors
- Duct tape
- Hot water (Not included in kit)
- Small funnel (Optional)
- Stopwatch (Optional; Not included in kit)
- Newspaper
- Cardboard
- Assorted insulating materials (Not included in kit, see *Getting Ready*)

### Youth Handouts:

- "Create a TechXcite Thermos"

## Getting Ready (10 minutes)

- Make sure you can get hot water from a faucet or somewhere nearby.
- Assorted items for insulation could include scraps of fabric (various sizes), socks from the lost and found, packing peanuts, pieces of foam, construction paper (both light and dark colors), bubble wrap, quilt batting, old overhead transparencies, rubber tubing, drinking straws, aluminum foil, large zipper-close plastic bags and any other materials you can think of that could be used as insulating or conducting material or to absorb or reflect radiation.
- If you allow students to bring in their own materials, you may want to impose some limitations. For example, it is a good idea to forbid human-made containers or devices such as insulated lunch boxes, thermoses, flashlights or classroom radiators. The idea is for students to start from scratch rather than use existing technology.

## Education Standards

CCSS: 5.G.A.2
NGSS: 4-PS3-2, MS-PS3-3, MS-ETS1-3

## Learner Outcomes

- Define heat transfer.
- Explain that insulation prevents heat loss through conduction.

# Activity 3: Create a TechXcite Thermos

## Vocabulary

| Word | Definition |
|---|---|
| Conduction | The movement of heat through objects in direct contact. |
| Heat transfer | The flow of energy from a higher temperature region to a lower temperature region. |
| Insulation | Any material that reduces the flow of heat. |

## Introduction

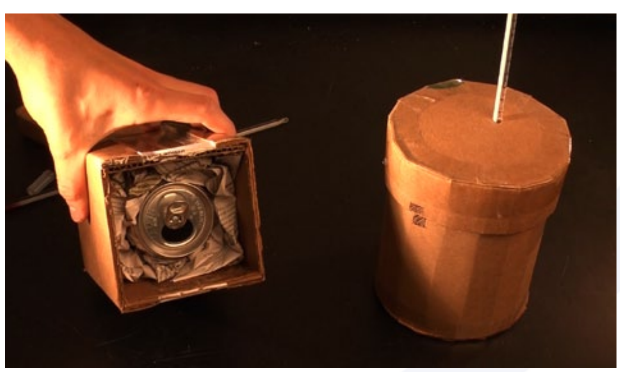
All matter is made up of atoms and the atoms are constantly in motion. The motion of these atoms creates heat, or thermal energy, which we measure as temperature. Hot objects contain more energy than cold objects, but even the coldest objects have at least a little heat energy. When the atoms inside an object inevitably collide, some energy is transferred from one atom to another. This is called **heat transfer**.

Heat transfer is the flow of energy from a higher temperature region to a lower temperature region. Heat transfer occurs any time there is a difference in temperature. Heat energy will always flow from the hot object, which has faster vibrating atoms, to the cold object, which has slower vibrating atoms, until their temperatures, or the speed of their vibrations, equalize.

One of the main methods of heat transfer is **conduction**. Conduction occurs when two objects at different temperatures are in direct contact. Think of a cast iron skillet on a stovetop. When the stove is turned on, heat is transferred from the burner to the skillet. After the stove has been on for a few minutes, the handle will also be hot because the heat has been conducted from the bottom of the skillet (in contact with the stovetop), up the sides, and into the handle. If you touch the handle, heat will also be transferred via conduction from the handle to your fingers.

While it's almost impossible to completely stop heat transfer, it can be slowed down with **insulation**. If you wanted to touch the skillet handle without being burned, you would need an insulated oven mitt or handle cover. Insulation is used in ovens, refrigerators, windows, and walls—anywhere we want to reduce the transfer of heat.

Your engineering challenge today is to design an insulated container that will keep as much heat as possible in an aluminum can.



# Activity 3: Create a TechXcite Thermos

## Facilitating the Activity

Part A: Designing the Thermos

1. Set up a table full of assorted insulation materials (see *Getting Ready*), scissors, and tape.
2. Let students examine the materials and then allow them 20 minutes—working in groups of 3 or 4—to plan and construct a TechXcite thermos. Have them use an empty can during planning and construction, but make sure it's removable so it can be replaced with a can filled with warm water during testing.
3. Encourage students to try a different material than another group. Also suggest that the students limit themselves to just one or two main materials. This activity should be a learning experience, not a competition. The goal is to figure out what works best as an insulator and if every group uses the same material or uses too many materials at once the results won't be as informative.
4. While students are designing and constructing, prepare the soda cans by filling them completely with 35-45°C water. Hot water from the faucet will generally work. You will need two cans per group, plus two extra. By the time students are ready to use the cans, the water will have cooled a few degrees and will be at a good temperature for the activity.

Part B: Testing

5. Place at least one or two extra water-filled cans in a central location. These will serve as the control, or reference. You may want to monitor the temperature in these cans yourself or you can assign the task to a student.
6. When everyone is ready, hand out the water-filled cans and thermometers. Each group should receive one thermometer for each can, if possible. If groups must share a thermometer, be sure they wait 2 minutes after switching between cans before reading the thermometer.
7. Instruct students to switch out their empty cans for the water-filled cans and place the thermometer inside. After about 2 minutes, tell the groups to take their first measurement (t = 0) and start the clock.
8. The groups must take a measurement every 5 minutes. Tell students they need an organized way to keep track of their time and temperature data.
9. After 30 minutes, have students gather the data from the control can and plot both sets of data on a graph.

# Activity 3: Create a TechXcite Thermos

## Tips

- After 5 or 10 minutes, some students may find that the device they have invented to keep their can warm is not performing well. They may want to change their design immediately, and this is OK. Real engineering solutions are seldom perfected on the first attempt, and mid-course corrections are commonplace.
- Check to make sure students are reading their thermometers accurately, especially if their device seems to be performing exceptionally well.
- As students test their arrangements, ask questions to help them begin analyzing their data, such as:
  - How much has the water temperature changed so far?
  - How does the temperature in your can compare to the temperature in the control cans? Does that mean that your strategy is working (to keep your can warm)?

## Activity Closure

Before starting the experiment, we learned that if we touched the handle of a hot skillet the heat would be conducted from the skillet to our hand. But what happens when you touch something cold, like ice?

[*Give students a chance to answer.*]

Did you know that "cold" does not actually exist (at least not in the same way as heat)? When you touch a piece of ice, what you feel is not the presence of "cold" but the absence of heat. It feels cold because, as soon as you touch the ice, heat energy from your hand is transferred to the ice as the two temperatures try to equalize. The greater the temperature difference between your hand and the object you touch, the colder it will feel as more and more heat is taken away from your body during the process of heat transfer.

This is an important distinction to understand when building your solar ovens. Insulation is not used to keep cold *out*, but to prevent heat from escaping.

## Exploration Questions

1. What are some materials that would work well as an insulator?

   [*Possible answers: fiberglass, wood, concrete, air, newspaper, and foamed plastics such as polystyrene*.]

2. How did you try to reduce heat transfer in your thermos via conduction and radiation? Was it effective?

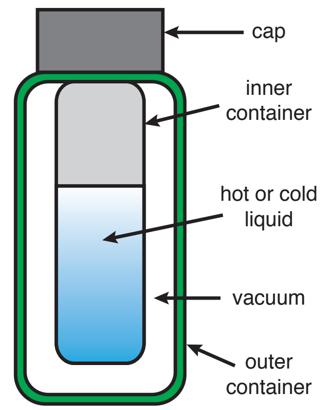
   [*Allow a couple groups to present their graphs and findings with the class. Have them show their device and explain how they tried to reduce heat transfer.*

   *Students may have difficulty articulating the roles of conduction and radiation in their devices, so be prepared to help them understand these roles. For example, insulation materials such as newspaper reduce heat transfer via conduction. Aluminum foil in the device would reflect heat back in and would reduce heat transfer via radiation. Aluminum foil is not a good insulator so it would not prevent heat transfer via conduction.*]

# Activity 3: Create a TechXcite Thermos

## Apply

Commercial thermoses are *very* good at keeping hot things hot and cold things cold. The secret is removing all of the air from between the inner walls, creating a vacuum, or completely empty space. Why do you think a vacuum is the best insulator?




[*Heat is caused by the motion of atoms and molecules, and heat is transferred when they collide. Generally, the closer the molecules, the easier it is for energy to pass from one molecule to the next. Gasses, such as air, are very good insulators because their molecules are so far apart. However, the best insulator is a vacuum, or completely empty space, because a vacuum contains no molecules to transfer the heat energy from one surface to the other.*]

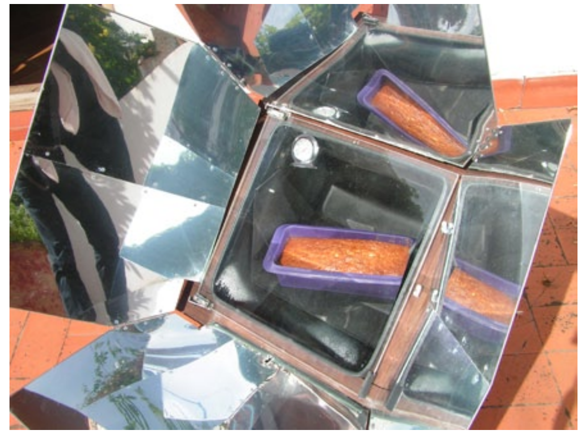
## References

"Insulation." How Stuff Works. <http://science.howstuffworks.com/dictionary/chemistry-terms/insulation-info.htm>.

"Heat Movement and Insulators." Department of Energy Office of Science. <http://www.newton.dep.anl.gov/askasci/phy00/phy00781.htm>.

# Activity 4: Building a Solar Oven

**Time Required:** 90 Minutes **Group Size:** 3



## Materials List

### Each group needs:

- 2 Cardboard boxes
- Cardboard scraps
- Aluminum foil
- Oven bag
- Thermometer

### Each class needs:

- Newspaper
- Assorted insulating materials (Not included in kit, see *Getting Ready*)
- Black spray paint
- Black construction paper
- Black duct tape

### Youth Handouts:

- "Building a Solar Oven"

## Getting Ready (10 minutes)

- Ask students to bring a box and some newspaper for this activity. It is also a good idea to have some extra boxes and newspaper available in case any students forget.
- You also might want to ask students to bring in additional materials. It will prompt them to think more about the project outside of class and contemplate what their ovens could look like. Instruct them not to buy or bring anything expensive. For example, students should not buy insulation from a home improvement store. You could specify that any supplemental materials must cost no more than $10, or you could say they must be available for free.

## Education Standards

CCSS: 5.G.A.2
NGSS: 4-PS3-2, MS-PS3-3, MS-ETS1-3, HS-PS3-3

## Learner Outcomes

- Identify and explain the two different types of convection.
- Build a solar oven using the principles of heat transfer.

# Activity 4: Building a Solar Oven

### Vocabulary

| Word | Definition |
|---|---|
| Convection | The movement of heat by circulation through liquids and gases. |
| Wind chill | The perceived decrease in air temperature felt by the body due to the flow of air. |

### Introduction

There are three types of heat transfer, but so far, we've only covered the first two: radiation and conduction. The final method is **convection**.

Convection is the transfer of heat by the motion of a fluid, such as air or water. Think about a pot of water on a stove. When the stove is turned on, the water at the bottom of the pot starts to heat up. As the heated water expands it becomes less dense and rises to the top. The cooler, denser water at the surface then sinks to take its place. As that water heats and rises, the process is repeated creating a pattern of circulation, which spreads the heat throughout the liquid. This is an example of natural convection.

The other type of convection is forced convection. This occurs whenever a fluid is forced over a surface by an external source, such as a fan. A good example of this is **wind chill**. You may have noticed when you're outside in a strong breeze, you feel a lot colder than if you were in a location at the same temperature with no breeze. This is because the heat from your body warms up a thin layer of air around your skin. When the air is still, that warm layer of air stays around your body, but when there's a breeze, the wind carries that layer away leaving cooler air in its place. The larger the temperature difference between you and the air around you, the more heat is transferred away from you to the air, and the colder you feel.

Let's recall the car example as we review the three types of heat transfer:

1. Radiation – Which would make a car hotter: if it had a black interior or a white interior? [*The car would be hotter if it had a black interior because heat transfer via solar radiation would be increased.*]
2. Conduction – Which would make a car hotter: if it's walls were made of a thin sheet of cardboard or made with 6-inch-thick foam insulation? [*A car made of foam insulating material would be hotter because heat loss through the walls via conduction would be reduced.*]
3. Convection – Which would make a car hotter: sitting in the sun on the side of a windy mountain or sitting in the sun with no wind? [*The car with no wind would be hotter because heat loss via forced convection would be reduced*.]

Now it's time to play the role of engineer as you design and build your solar oven. You must use what you have learned and the materials provided to create an oven that can attain the highest temperature possible using only energy from the sun.

# Activity 4: Building a Solar Oven

### Facilitating the Activity

1. Before students begin, go over the engineering design challenge and constraints.
2. Tell students to follow the steps in the handout. Encourage them to experiment with different materials, if available. The two nested boxes will provide the external and internal walls of the oven, while the oven bag will be the transparent window.
3. Once the ovens are completed, have students set them up outside for testing on a sunny day.
4. Instruct each group to measure the air temperature inside the oven and plot the temperature as time progresses. They are to take measurements every 10 minutes for 30-40 minutes, after which the increase in temperature should begin to slow down.
5. While students are observing the solar ovens in action, ask some of these questions to help them evaluate their accomplishments:
    a. Which solar ovens are working really well?
    b. Why do you think a particular solar oven is working well?
    c. How might you improve a solar oven that is not working well?
6. Students should compile their data so that they can observe everyone's heating curves and examine what variables may have caused differences. Ask questions that will prompt students to draw conclusions about their construction decisions.
7. After the ovens have been tested for their heating potential, have students test them using food (you may wait until a later date). The maximum temperature of the ovens might not be hot enough to cook some kinds of food. Cookie dough is a good choice because it is thin and is safe to eat if undercooked. You can bake cookies on small pieces of aluminum foil. Do not place any food directly on spray-painted aluminum foil. Use a clean sheet of foil as a barrier between any painted surfaces.

# Activity 4: Building a Solar Oven

## Activity Closure

Solar ovens are actually relatively new technology considering the fact that their main power source, the sun, has been around since the beginning of time. Although the sun has been used to dry fruits and other items for thousands of years, the first recorded solar oven didn't exist until the mid-1700s. Even then solar cooking did not become popularized until the 1980s because of the high initial cost of the equipment and lack of efficiency. Today, many relatively low-cost cookers have become available to the general public, and with the push toward alternative energy, solar cooking is slowly becoming more culturally acceptable.

Solar cooking is obviously the most practical in areas that receive plenty of sun. It's also the most beneficial to regions in desperate need of alternative energy sources. Solar cooking even has benefits beyond saving energy. People that still use fires to cook their food must have a constant supply of wood fuel to burn. This can greatly effect the surrounding environment (if such fuel is even readily available), and the toxic smoke from cooking fires has been recognized as a major health problem that kills as many as 1.5 million women and children each year, according to the World Health Organization. While not a perfect solution since the sun doesn't shine all day long, solar ovens have been a great help in many developing countries and hopefully will continue to spread around the world as they become more popular and affordable.

## Exploration Questions

1. Describe which parts of your oven are designed to increase the heat input from the sun.

   [*Possible answers: painting the walls black, calculating the angle of the sun and moving the solar oven during the cooking process, etc*.]

2. Which parts of your oven are designed to reduce heat loss?

   [*Possible answers: sealing up all the cracks and edges with duct tape, wadding up newspaper for insulation on bottom and the sides, etc*.]

3. What would you do differently if you were to repeat the experiment?

   [*Answers could include anything from redesigning the oven completely to modifying the testing procedure. Allow a few students to share their ideas.*]

## Apply

If you were a real engineer and could create a solar oven of any size with any materials, what would it look like and what materials would you use? Sketch your idea. Label and describe its features.

[*Give students plenty of time to sketch. Let a few individuals present their ideas to the class.*]

## References

"Heat Transfer." HyperPhysics. <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatra.html>.

"What is Forced Convection?" WiseGeek. <http://www.wisegeek.com/what-is-forced-convection.htm>.

"Solar Cooking and Health." Practical Action. <http://practicalaction.org>.

# Tools Used in the Module

## Compass

A compass is a navigational instrument that shows directions relative to the magnetic poles of the Earth. There are four cardinal points: North, South, East, and West. The needle of the compass (generally marked in red) always points *North*.

To read a compass, hold it steady in your hand or place it on a flat surface so that the baseplate is level. If tilted, the needle may contact the casing, preventing it from moving freely and giving a faulty reading. Rotate the body of the compass until the "N" and red end of the needle are lined up. Now the north and south ends of the compass are lined up with their corresponding poles.


The numbers from 0 to 360 around the outer edge of the dial are called azimuths. The azimuth angle, or compass bearing, is measured clockwise with North starting at 0 degrees. Thus, 90 degrees is East, 180 degrees is South, and 270 degrees is West.

# Glossary

**Axial tilt**
The angle between an object's rotational axis and its orbital axis.

**Azimuth angle**
The compass direction measured in degrees, with zero degrees corresponding to North and increasing in a clockwise fashion.

**Conduction**
The movement of heat through objects in direct contact.

**Convection**
The movement of heat by circulation through liquids and gases.

**Electromagnetic spectrum**
The complete range of wavelengths of electromagnetic radiation including radio, microwaves, infrared, visible, ultraviolet, x-rays and gamma rays.

**Elevation angle**
The angle of the sun as measured from the horizon.

**Frequency**
The number of times that an event occurs within a given period.

**Gnomon**
An object, such as the style of a sundial, that projects a shadow used as an indicator (pronounced "NO-mahn").

**Heat transfer**
The flow of energy from a higher temperature region to a lower temperature region.

**Insulation**
Any material that reduces the flow of heat.

**Intensity**
The power transferred per unit area.

**Latitude**
The angular distance north or south from the equator of a point on the earth's surface.

**Longitude**
The angular distance east or west from the prime meridian of a point on the earth's surface.

**Radiation**
The transfer of energy via electromagnetic waves (does not require a medium).

**Solar oven**
A device that uses heat energy from the sun to cook food.

**Wavelength**
The distance from the peak of one wave to the peak on the next wave.

**Wind chill**
The perceived decrease in air temperature felt by the body due to the flow of air.

# Education Standards

### Activity 1: Heat from the Sun

NGSS: 1-PS4-2 - Make observations to construct an evidence-based account that objects in darkness can be seen only when illuminated.

NGSS: 4-PS3-2 - Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

NGSS: 4-PS4-2 - Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

### Activity 2: Where is the Sun?

CCSS: HSG.SRT.C.8 - Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.

CCSS: 4.MD.C.6 - Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

NGSS: 5-ESS1-2 - Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

NGSS: MS-ESS1-1 - Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.

### Activity 3: Create a TechXcite Thermos

CCSS: 5.G.A.2 - Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

NGSS: 4-PS3-2 - Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

NGSS: MS-PS3-3 - Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

NGSS: MS-ETS1-3 - Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

### Activity 4: Building a Solar Oven

CCSS: 5.G.A.2 - Represent real world and mathematical problems by graphing points in the first quadrant of the coordinate plane, and interpret coordinate values of points in the context of the situation.

NGSS: 4-PS3-2 - Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

NGSS: MS-PS3-3 - Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

NGSS: MS-ETS1-3 - Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

NGSS: HS-PS3-3 - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

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# Acknowledgements


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