LESSON 7

The Sun as an Energy Source

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Sun, water, and the air we breathe are ingredients for life on Earth.

INTRODUCTION

In Lesson 6, you investigated solar and lunar eclipses. You saw that the Sun's light can be temporarily blocked by a particular alignment of the Sun, Earth, and Moon. But what if the Sun's light were not available to us on a daily basis? How much do our lives depend on the Sun's energy? In this lesson, you will learn about the Sun as an energy source. To begin, you will conduct an investigation to determine how the distance from a light source to an "energy detector" affects the amount of energy received. You then will design an investigation to test how other variables, such as the angle of light, affect the amount of energy received from the light source. You then will compare your results to what you know about the Sun. This lesson prepares you for Lesson 8, in which you will track sunspots and analyze how changes in the Sun's energy output affect Earth.

OBJECTIVES FOR THIS LESSON

Investigate the effects of distance on the amount of energy received from a light source.

Design an investigation to observe the effects of different variables on the amount of energy received from a light source.

Use a radiometer to observe the effects of solar energy.

Read to learn more about the Sun.

Getting Started

1. Read "Using Eclipses To Study Solar Wind." What do you know about solar energy? Discuss your ideas with the class.

2. Review the Safety Tips with your teacher. Then carefully unwrap the radiometer.

3. The radiometer is an "energy detector." Test how it works, first under your classroom lights and then with your clamp lamp. Observe the lamp and radiometer when they are set up at different distances. Discuss your observations with your group by answering questions such as the following:

   How does the light affect the radiometer?

   What causes the radiometer to behave as it does?

   Why are the panels inside the radiometer black and white?

4. Discuss the following question as a class: *How does the distance from the clamp lamp to the radiometer affect the length of time the radiometer vane spins?* You will investigate this question further in Inquiry 7.1.

MATERIALS FOR LESSON 7

For you

- 2 copies of Planning Sheet
- 1 copy of Student Sheet 7.1: Collecting Radiant Energy Data
- 1 sheet of graph paper

For your group

- 1 transparency copy of Student Sheet 7.1: Collecting Radiant Energy Data
- 1 transparency
- 1 transparency copy of graph paper
- 1 set of fine-point transparency markers
- 1 clamp lamp with reflector
- 1 50-W lightbulb
- 1 100-W lightbulb
- 1 150-W lightbulb
- 2 bookends
- 1 radiometer
- 1 removable dot
- 1 student timer (or other timepiece)
- 1 protractor
- 1 pair of heat-resistant KEVLAR® gloves
- 1 metric measuring tape or ½-meter stick
- Access to electrical outlet

SAFETY TIPS

The radiometer will shatter on impact. Keep it away from the table's edge.

Avoid touching the metal reflector or lightbulb on the clamp lamp while it is on or cooling.

Inquiry 7.1
Investigating the Effects of Radiant Energy

PROCEDURE

1. Record the question you will try to answer in this investigation on your planning sheet. Consider what you are testing (the distance from the clamp lamp to the radiometer) and its effect (the length of time the radiometer vane spins).

2. What do you think will happen if you change the distance between the lamp and the radiometer? Record your prediction on your planning sheet.

3. On your planning sheet, list the materials you will use and the procedures you will follow.

4. How will you control your experiment? Record what you will change. Record what you will keep the same.

5. What will you look for? What you will measure? Record these on your planning sheet.

6. Use the removable dot to mark a spot in your workspace away from any edges. Keep the radiometer on that dot at all times. This may help prevent your radiometer from being knocked to the floor.

7. Read the directions on Student Sheet 7.1. Record the power (in watts) of the lightbulb your group will use. (Remember not to change the lightbulb once you start. Change only the distance.) Record the number of seconds you will keep the clamp lamp on during each trial. Examine Table 1 on the student sheet. On Table 1, list the three different distances you will test. You will conduct three trials for each distance and then average your results.

8. Set up your equipment as outlined on your planning sheet (see Figure 7.1.) (Use either a metric measuring tape or a ½-meterstick).

9. Conduct your investigation. Complete Table 1 on the student sheet as you work.

10. Graph your data on Student Sheet 7.1. Use your data to determine the scale of your *x*- and *y*-axes. Record your independent variable (distance) on the *x*-axis. Record your dependent variable (average time the radiometer vane spins after shutting off the clamp lamp) on the *y*-axis.

REFLECTING ON WHAT YOU'VE DONE

1. Share your results with the class. You may want to show your data table and graph to the class.

2. Answer the following questions in your science notebooks, and then discuss them with your class:

A. Do you see a general pattern in your data? What is the pattern?

B. What do the patterns in the data tell you?

C. Why might different groups get different results?

D. If the conditions on all planets were the same, except for their distance from the Sun, how would distance affect the amount of energy a planet receives from the Sun?

E. Why do you think distance from the Sun affects how much energy a planet receives?

3. Read "Distance and Light." Review your answers to Questions D and E. Is there anything you want to change or add to your answers on the basis of this new information?

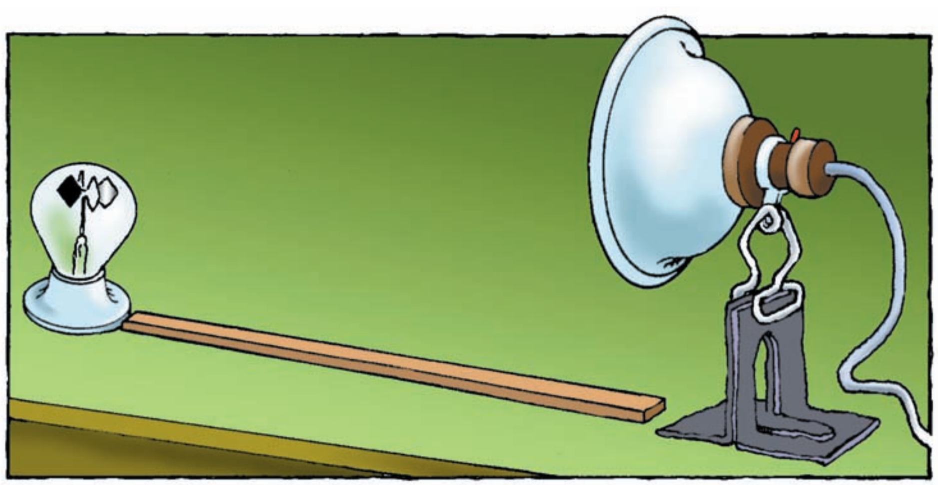


Figure 7.1 *One suggestion for setting up the investigation. Between trials, what variables would you change in this investigation? What variables would you keep the same?*

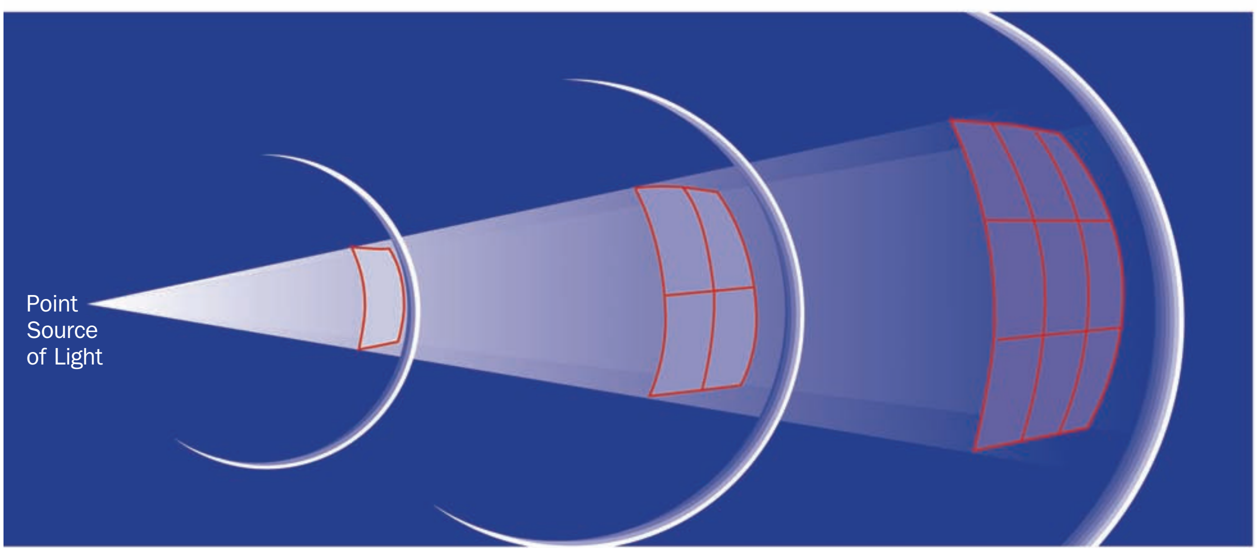
DISTANCE AND LIGHT

Light spreads out spherically from a source. As light gets farther from its source, it covers an ever-widening area. The size of the surface area of light is related to its distance. If you double the distance from the light source, the light spreads out more than four times the area (2 x 2 = 4). The surface area of light is "squared" ($2^2 = 4$). (See the illustration.) If you make the distance three times as great, the light spreads out more than nine times the area ($3 \times 3 = 3^2 = 9$). We can describe this relationship by saying: The larger the area over which light is spread, the smaller the amount of energy that passes through any unit area of that sphere. Less light means less energy. This is why the farther you are from the clamp lamp, the more the light spreads and the less energy the radiometer receives.

How does this apply to our solar system? When light from the Sun reaches Earth, it is spread over a sphere that is equal to the radius of one Earth-distance to the Sun.

When light from the Sun has gone twice as far as Earth, that light is spread out over an area four times larger than Earth's distance from the Sun. By the time the Sun's light reaches Saturn, which is 10 Earth-distances from the Sun, the Sun's light is spread out over an area 100 times larger than one Earth-distance. The fact that energy decreases with increasing distance from the source is sometimes called the inverse square law. "Inverse" means that the relationship is reversed. You might think that if you increase one factor, another factor related to it also would increase. (For example, increase the food you feed your dog and his weight also may increase.) But the relationship between light and energy is inverse—or reversed. Energy decreases as the distance from the light source increases.

The inverse square law explains why the inner planets closer to the Sun are hotter than the outer planets farther away from the Sun. Of course, other factors—such as the tilt of a planet on its axis, surface composition, and atmosphere—also affect the temperature of a planet. But overall, the farther a planet is from the Sun, the less solar energy it receives.



Sunlight spreads out spherically. The farther a planet is from the Sun, the larger the area over which the sunlight spreads and the smaller the amount of energy the planet receives.

Inquiry 7.2
Designing an Energy Investigation

PROCEDURE

1. What other questions would you like to explore using this equipment? Discuss possible ideas with your group. Then decide with your group which question you will test. Complete your group's planning sheet.

2. Review your group's plan with your teacher.

3. Discuss with your group how to record your results. Set up a data table in your notebook similar to the one you used during Inquiry 7.1.

4. Review the Safety Tips that relate to your investigation. Then complete your investigation.

5. Graph your results. You may be asked to graph your results on a transparency as well so that you can share your data with the class.

SAFETY TIPS

Turn off your clamp lamp and unplug it before changing lightbulbs.

Use heat-resistant KEVLAR gloves when changing hot lightbulbs.

REFLECTING ON WHAT YOU'VE DONE

1. Share your results with the class.

2. Answer the following in your notebook, and then discuss them as a class:

   A. Do you see a general pattern in your data? If so, what is it?

   B. How are your data like those of other groups?

   C. Why do you think different groups that tested the same thing may have gotten different results?

   D. Draw some conclusions from your investigation. For example, how does changing the wattage of the lightbulb affect the amount of energy received by the radiometer?

   E. Make a prediction: How do you think the Sun will affect the radiometer?

   F. What characteristics of the Sun will affect how the radiometer spins?

   G. What characteristics of Earth will affect how much solar energy the radiometer receives?

3. You might be able to take your radiometer outside, or work near a sunlit window, to see how it responds to the Sun's light. If so, how do your observations compare to your predictions? What explanation can you give for your observations?

4. How many radiometers do you think the Sun could "power" compared to a clamp lamp? Discuss your ideas with the class. If possible, test your ideas in the lab.

5. With your class, return to the Question E folder (from Lesson 1) with its accompanying photo card. Review the self-stick responses from Lesson 1 about the points of light in the night sky. As a class, work together to remove any postings that may now prove incorrect. Add any new ideas you may have to the folder.

Using Eclipses To Study Solar Wind

Physicist Shadia Habbal does not have an easy job. At the Smithsonian Astrophysical Observatory, she studies the solar wind. The best time to observe the solar wind is during total solar eclipses—which occur only once every year or two and last only for a few minutes.

"Not only are total solar eclipses rare and short-lived, but if one occurs during cloudy weather—well, it can be frustrating," says Dr. Habbal. An additional difficulty is that each total solar eclipse can be seen only along a narrow stretch of Earth—and that narrow stretch may occur on the other side of the planet.

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Dr. Shadia Habbal working at the Smithsonian Astrophysical Observatory

Solar eclipses occur when the Moon, aligned perfectly between Earth and the Sun, blocks the bright solar disk. For just a few minutes, the Sun's outer layer, or corona, becomes visible—and so does the path of solar wind. "It shows up as bright streaks in the Sun's corona," says Dr. Habbal.

What Is Solar Wind?

Solar wind is a flow of particles out of the Sun's corona. The particles may be few and far between, but they are speedy! Some particles that escape from the Sun's poles travel as fast as 800 kilometers per second. Particles that blow out from other regions of the Sun move at a slower rate—about 300 kilometers per second. But even at this slower speed, solar wind could travel around the Earth's equator in less than 2½ minutes! Some winds can even travel beyond Pluto!

Is solar wind really a wind? "Not one you will ever feel," explains Dr. Habbal. "The flow of particles is much less dense than in wind on Earth, so you wouldn't even feel it if you stood in its way." Not that you could. Earth's magnetic field shields the planet from solar wind as it moves throughout the solar system.

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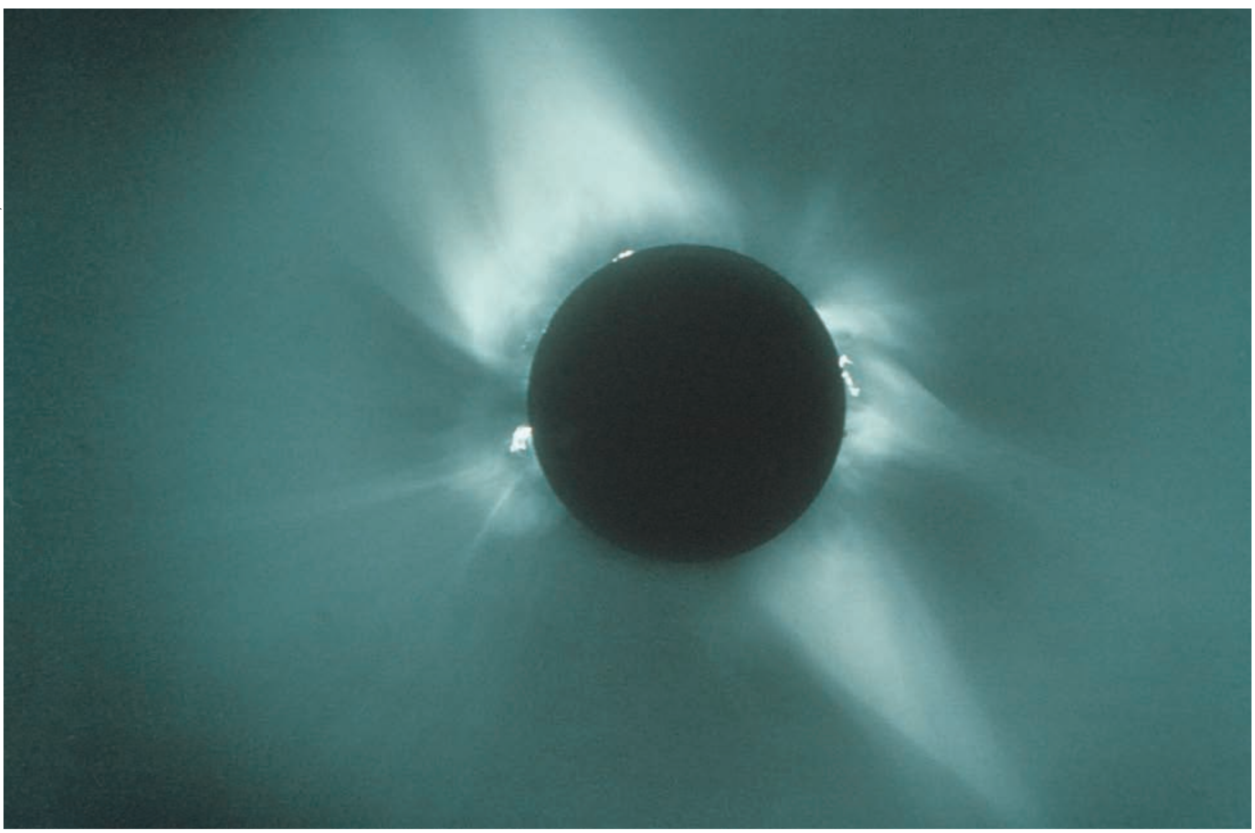
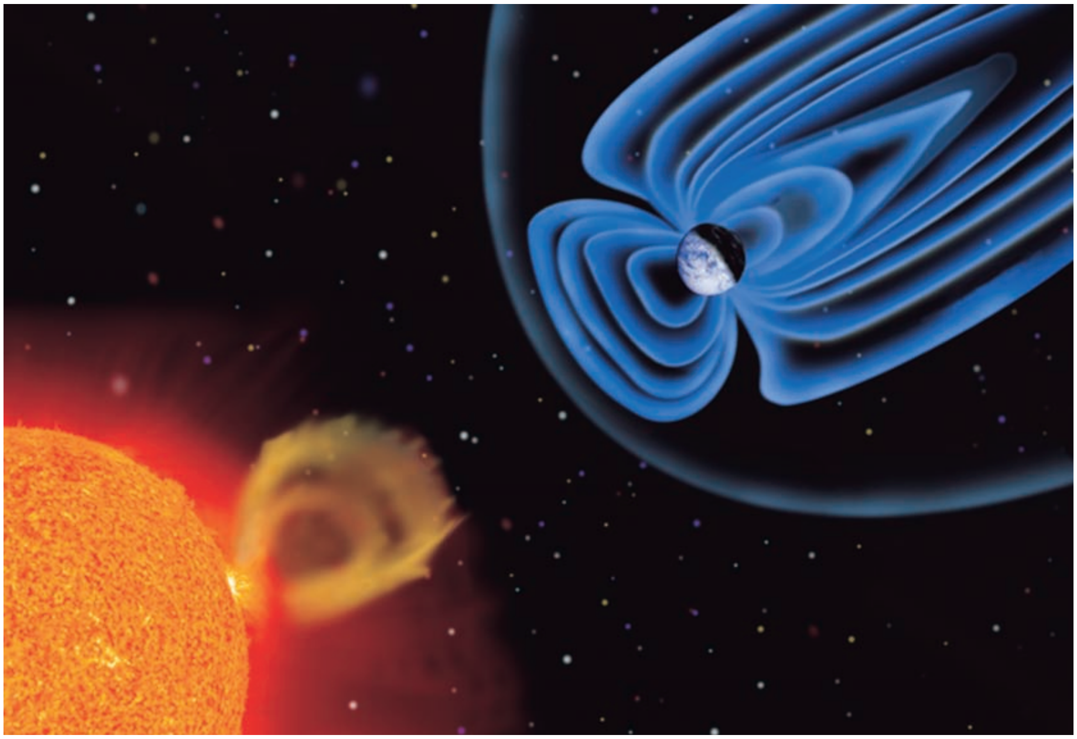


During "totality," when the bright solar disk is covered, the Sun's outer layer—the corona—becomes visible.



This NASA illustration shows Earth's magnetosphere and its interaction with the solar winds.

What Exactly Is Blowing?

As it turns out, the Sun sheds—that is, it gives off particles. The particles making up solar wind are mainly electrons and protons coming from the Sun itself. These particles are electrically charged, and according to Dr. Habbal, they are super-hot, measuring more than a million degrees! The hotter something is, the more energy it has. Solar wind particles have so much energy that the Sun's gravity cannot hold them back. "It's this heat that enables these particles to escape solar gravity and flow out to space," she explains.

Why Study Solar Winds During an Eclipse?

A total solar eclipse is a perfect opportunity for scientists like Dr. Habbal to study the Sun. The eclipse blocks the Sun's bright light, making it easier to see solar winds, flares, and other flamelike eruptions. In her 20-year career, Dr. Habbal has traveled to many continents to witness solar eclipses. "The beauty of the total eclipse is that it offers terrific resolution and details of the corona all the way to the solar surface," she says. A coronagraph is a tool that attaches to a telescope and blocks out most of the Sun and creates an artificial eclipse. But according to Dr. Habbal, it doesn't give the same sharp, complete picture as a total solar eclipse. And partial eclipses, says Dr. Habbal, "do not block the solar disk enough to be able to study the corona."

Find out when the next total solar eclipse will occur and where. You can bet that Dr. Habbal and other solar scientists will have a front-row seat. ☐

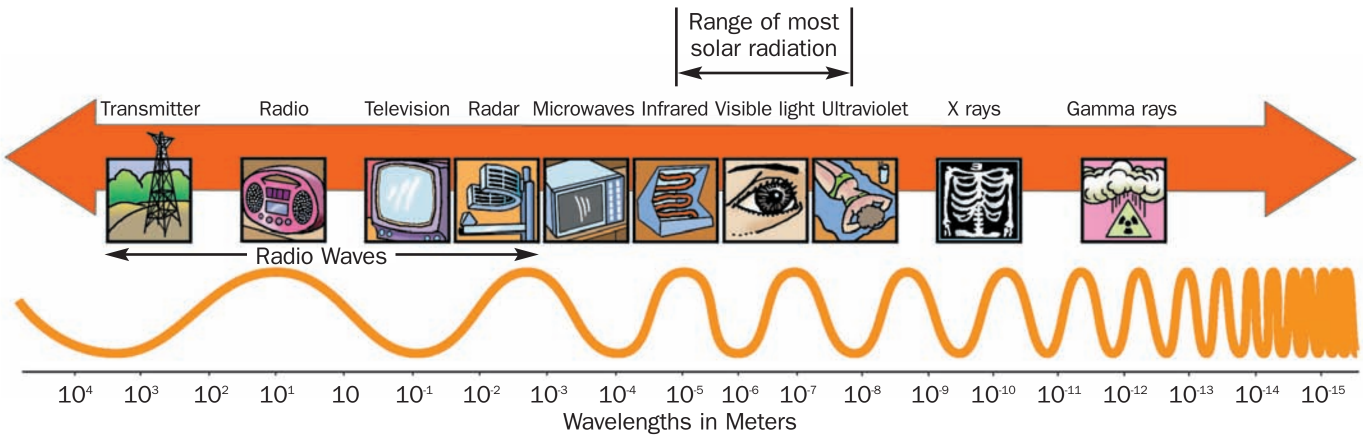
OUR SUN'S ENERGY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The Sun is a star—a huge nuclear reactor.

The Sun may be only one star among billions of other stars in the universe, but it's the one that makes our life on Earth possible. How? The Sun provides us with energy that gives us solar power, fossil fuels, waves, and surface wind. Without heat and light from the Sun, Earth would be just another dark, cold planet in space where life as we know it could not exist.

Where does the Sun get all its energy? It all starts with its size. The Sun's mass is enormous—approximately 300,000 times greater than Earth's. The more mass an object has, the greater the pressure at its center due to the force of gravity. And when gas is squeezed, or compressed, it becomes hot. Most of the Sun's mass is composed of hydrogen gas atoms. Physicists came up with the hypothesis that the Sun's tremendous mass squeezed the hydrogen atoms until they fused and released the heat and light energy that reaches Earth.



Solar energy travels through space in the form of electromagnetic waves. Along the electromagnetic spectrum, solar energy is mostly visible energy, infrared energy, and ultraviolet energy.

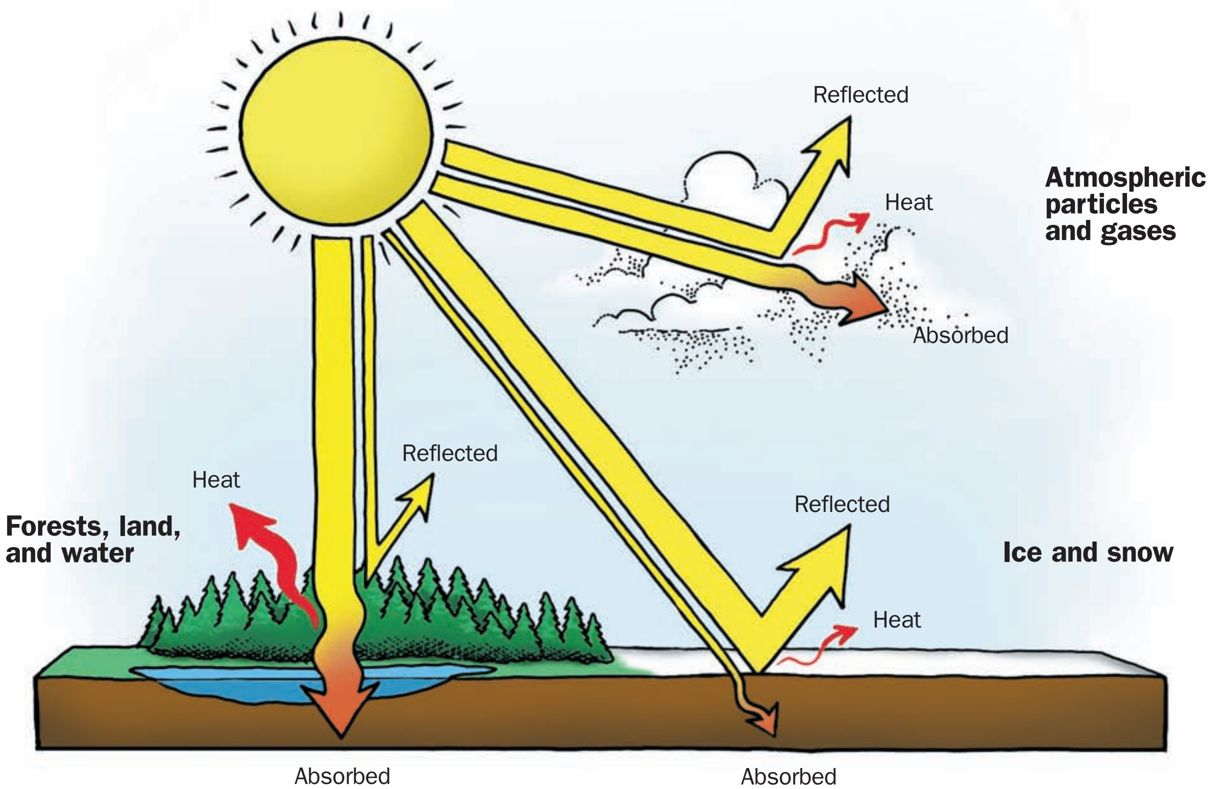
Think about the hottest oven you can imagine—and then turn up the temperature to about 14,000,000 °C (or 1.4×10^7). That's how hot it gets in the center of the Sun. At that temperature, the hydrogen nuclei—or centers of each hydrogen atom—are moving so fast that when they crash into each other, they stick together to form helium.

The result of the crash of hydrogen nuclei is a tremendous amount of energy, released mainly in the form of heat and light. This reaction is called nuclear fusion. Scientists calculate that there is enough hydrogen in the Sun to continue the fusion reaction and provide heat and light energy for at least another 5 billion years or so.

Solar Energy

Energy from the Sun is called solar energy. Solar energy is the source of most of the heat on Earth's land, in its oceans, and in its atmosphere. This energy makes its way through the vacuum of space to Earth by a process known as radiation. Radiation is often identified by the effect it produces when it interacts with an object. Some solar radiation is visible as light (43 percent), but not all solar radiation can be detected by the human eye. Infrared radiation (49 percent) cannot been seen at all, but we can detect it as heat. Another type of radiation is responsible for the sunburn that can occur after exposure to the Sun (scientists call that ultraviolet radiation, which makes up 7 percent). Gamma rays, X rays, microwaves, TV waves, and radio waves make up the remaining 1 percent.

Solar energy is important to life on Earth. But surprisingly, most of the Sun's energy does not reach Earth at all; it travels out through space in all directions. Earth's land and oceans absorb about half of the small amount of solar energy that reaches us. The rest is reflected back into space or absorbed by the thin blanket of air—the atmosphere—that surrounds Earth. The interaction of solar energy with air, soil, and water on Earth creates our weather. The uneven heating of Earth causes wind, rain, and other elements of weather, and makes our planet unique and habitable.



Earth's atmosphere and surfaces absorb and reflect the Sun's energy. Some of the absorbed energy is given off as heat.

Our Atmosphere and Life on Earth

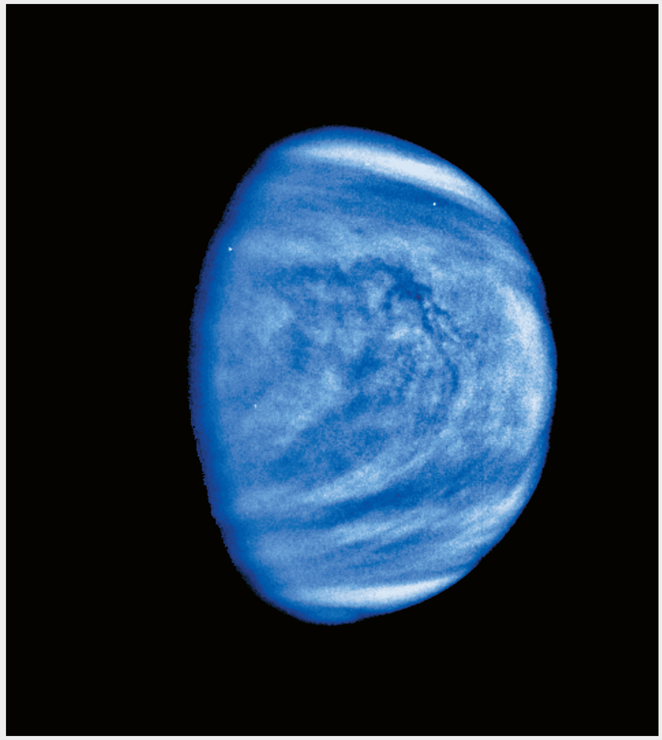
Earth's atmosphere protects our planet. How? The atmosphere keeps us from receiving too much solar energy. The tilt of Earth on its axis and Earth's rotation help vary the amount of solar energy that reaches any one place on our planet at any time. Too much of the Sun's energy—too much ultraviolet radiation, for example—would be harmful to life on Earth. Like a blanket, Earth's atmosphere also helps keep our planet warm at night. And most meteors and other rocks from space burn in the atmosphere before they reach Earth's surface.

Our planet receives just the right amount of solar energy to sustain life. If Earth were just a little farther away from the Sun, or just a little closer, life as we know it probably could not exist. ☐

Solar Energy on Other Planets

Planets get most of their energy from sunlight. If all conditions were the same, the closer a planet is to the Sun, the warmer that planet should be. But this is not always the case. The temperature of each planet depends not only on the amount of sunlight that strikes it but also on the way that planet's surface returns infrared radiation into space.

The way a particular planet absorbs the Sun's radiant energy depends on its atmosphere. For example, Earth's atmosphere reflects part of the radiation back into space and distributes heat from the sunlit regions to the cooler poles and to the side facing away from the Sun. Without its atmosphere, which is made up mostly of nitrogen and oxygen, the temperature of Earth would be nearer to –260 °C and the oceans would freeze.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Venus is covered by a hot, cloud-filled atmosphere made up mostly of carbon dioxide.

The climate of Venus is very different from Earth's even though Venus is similar to Earth in size, mass, density, and distance from the Sun. Its atmosphere is made up of 95 percent carbon dioxide and trace amounts of water vapor. This mixture lets in visible light from the Sun but does not release the infrared radiation generated by its hot rocky surface. This "greenhouse effect" makes Venus extremely hot, with surface temperatures that can reach 482 °C.

Mars also has an atmosphere that is made up of 95 percent carbon dioxide. But because Mars' temperature is always below freezing, its water vapor is frozen in the planet's polar ice caps and soil. Without water in the atmosphere, most of the Sun's energy that reaches Mars returns to space. In addition, the Martian atmosphere is so thin that it cannot block the deadly ultraviolet rays of the Sun, greatly reducing the greenhouse effect as compared to Earth or Venus.