Chapter 4. Angle of Light Rays and Surface Distribution: A Structured-Inquiry Activity

Think About This!

Is the Sun ever directly overhead at any time during the day throughout the year where you live? Explain. On what day of the year is the Sun lowest in the sky at midday? On what day of the year is the Sun highest in the sky at midday? Explain. Between what latitudes is the Sun directly overhead twice during each year? Research this question or discuss it with your teacher. Do you think this phenomenon has anything to do with our weather? Why?

Probing Further

On a bright, sunny day, drive a stick into the ground and observe the variation in the position and the length of the stick's shadow as the Sun moves across the sky. About what time did you observe the shadow to be the longest? About what time did you observe the shadow to be the shortest? Explain. Where you live, is there ever a time during the day (when the sun is shining) when there is no shadow cast by the stick? Is the shadow cast by the stick always on the same side of the stick? Why?

After completing the following activity, students should better understand the effect that the angle of the Sun's rays have on the Earth's surface.

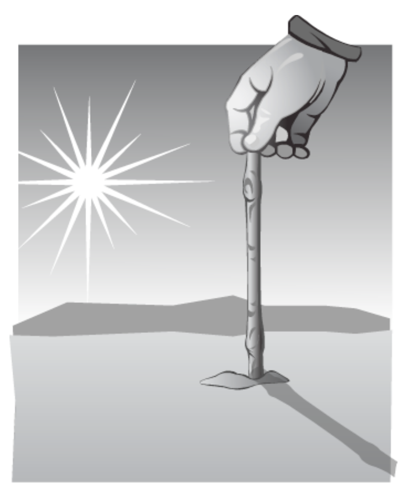
Objectives for the Learner (Essentials of Inquiry)

Conceptual Theme: To develop basic understanding of interrelationship between the angle of light rays and the area over which the light rays are distributed and the potential to affect changes in the temperature of materials.

Content: Developing basic information that relates to the angle of incidence (angle at which light rays strike the surface) of light rays, understanding the difference in the area of distribution of the light rays, and eventually projecting this information to surface temperature differences on the Earth.

Skills: The focus is on the handling of laboratory equipment, making careful observations, measuring surface-area changes based upon angle of incidence, recording data, making conclusions, and describing and communicating results.

Scientific Habits of Mind: The importance of careful observations, respect for data, verifying results, and forming conclusions consistent with the derived data.



Materials

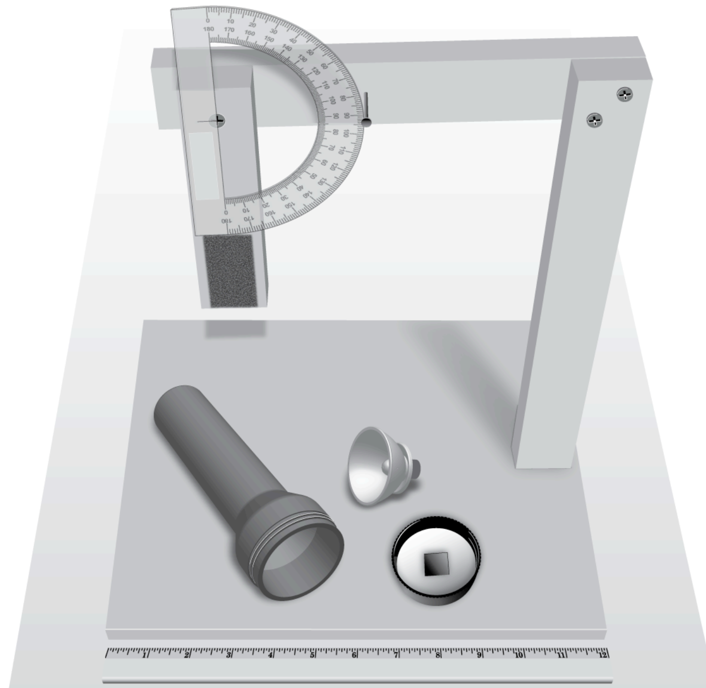
Flashlight

Circular piece of cardboard with a 1.25 cm (.5 in.) square opening cut into the center to cover lens (or cover lens with masking tape leaving a 1.25 centimeter (0.5 in.) square opening)

Flashlight holder that permits the flashlight to be rotated through different angles (See Appendix VI for instructions for constructing the flashlight holder.)

Protractor

Ruler



Preparation

If a school is well equipped with supplies and materials, a ring and ring-stand holder and clamps can be used to hold a flashlight at various angles. However, an angle-adjustable flashlight holder as shown in Figure 4-1 will hold the flashlight at more accurate angles.

Place the flashlight holder on a flat surface and attach the flashlight to the holder. **NOTE:** two thick rubber bands, spaced a short distance apart, may be wrapped around the flashlight and angle adjuster to attach the flashlight to the angle adjuster.

Position the flashlight at a 90° angle (as shown on the left in Figure 4-1) so that the light rays contact the surface from directly overhead. **NOTE:** this corresponds to a 90° **solar elevation angle** (angle of incidence), meaning that the sun is 90° from the horizon, i.e., directly overhead. The angle of incidence is read using the degree mark of the protractor at the nail. Turn on the flashlight and use the ruler to measure the surface area covered by the light rays at this angle. For best results, dim overhead lights in the room before turning on the flashlight. Record your results. Turn off the flashlight.

Next, rotate the flashlight to a 60° angle (60° solar elevation) (as shown on the right in Figure 4-1). Turn on the flashlight and measure the surface area covered by the light rays at this angle. Record your results. Turn off the flashlight.

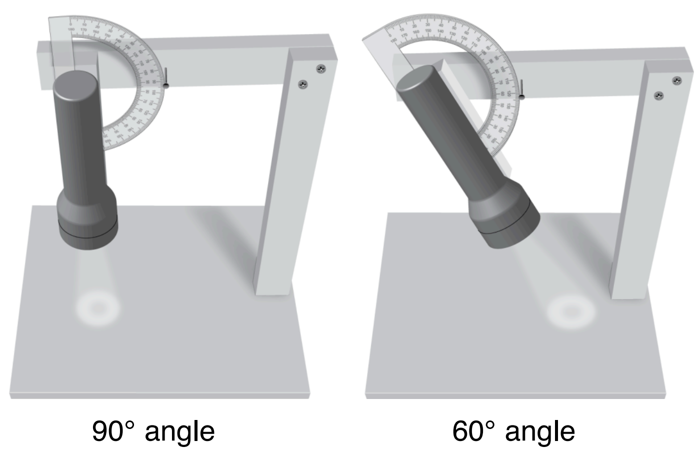


Figure 4-1. Experiment setup using the flashlight holder.

Next, rotate the flashlight to a 30° angle (30° solar elevation). Turn on the flashlight and measure the surface area covered by the light rays at this angle. Record your results. Turn off the flashlight.

Examining the Results

Did you find any differences in the area covered by the light rays as you varied the angle of the flashlight? Explain.

Use the experiment results. The expected results would be that the more perpendicular the rays (90°), the smaller the area covered by the flashlight beam, and the more slanted the rays (60° for example), the larger the area that would be covered. Compare the illustrations in Figure 4-1.

Did you discover other differences in the area covered by the light rays as the angle of incidence changed? Explain.

Again, base the response to this question on the results obtained by the investigator. However, it is expected that a greater angle (90°) would cover less area than a lesser angle (30°). Also, you might find that the light rays expand at right angles to the surface as the angle becomes less.

Assume that the unit of light coming through the 1.25 cm (0.5 in.) square opening represents a certain unit of energy. At which angle would the surface of the material be receiving the greatest amount of energy?

It is at the greater angle (higher solar elevation) that the surface area receives the most energy because the rays are spread out less.

At which angle would the surface be receiving the least amount of energy?

The smaller the elevation angle (30°, 20°, 10°) the less energy received per square centimeter, because the rays spread out over a greater area.

Over a long exposure to light rays at the various angles, predict which angle would likely have the highest temperature reading. Why?

At a higher angle the surface area should have the highest temperature because the rays are concentrated in a smaller area.

What natural factors cause the Sun's rays to strike the Earth's surface at different angles? How could you find out?

The tilt of the Earth's axis, the position of the Sun above the horizon and the observer's position north and south of the equator are some factors. If students do not know any of these factors, the teacher can suggest researching the topic both online and at the library, and/or talking with an expert.

Conclusion

Based on the data generated with the activity, what major conclusion did you make?

Again, the conclusion should be based upon the data that was generated by the activity, but it is expected that the greater the angle the less area that will be covered by the rays.

Going Further

At your latitude, is the Sun ever directly overhead? Explain.

The Sun would not be directly overhead at any time during the year for people living north of the Tropic of Cancer (23 1/2° N) or those living south of the Tropic of Capricorn (23 1/2° S).

At your latitude, on what day of the year do the Sun's rays strike the Earth most directly? Explain. What are the consequences of this situation?

North of the Tropic of Cancer and south of the Tropic of Capricorn, the first day of summer is the time of year that the Sun's rays strike most directly. This factor results in greater heating of these regions at opposite times of the year.

Challenge

How could you verify that slanted rays heat a surface differently than direct rays?

Background for the Teacher

If the Sun is directly overhead (the angle of incidence of the Sun's rays to the surface is 90°), the shadow is of minimum size, and the sunlight is concentrated into a small area, the maximum amount of heating takes place, and higher temperatures result. If the Sun is lower in the sky (e.g., 30° angle of incidence), the shadow length increases, sunlight is less concentrated; hence, less heating takes place, and a smaller increase in temperature occurs.

If students vary the angle several times and measure the surface area covered at each angle, they can show this relationship graphically. They can measure and sketch the differences and show the results.

At your latitude, is the Sun ever directly overhead? Explain. On what day of the year is the Sun lowest in the sky at midday?

In the Think About This! section there are several concepts to discuss. The 23° tilt of Earth's axis produces interesting results and can become complicated. Most students in the United States are found well north of the Tropic of Cancer and well south of the Arctic Circle (66°34' N), so most of the complicating factors associated with these zones can be ignored.

The answer to the question, "What day of the year is the Sun highest in the sky at midday?" can be found in Figure 4-2. Between the Tropic of Cancer and the Tropic of Capricorn, the Sun is directly overhead twice each year, around March 21 (vernal equinox) and September 21 (autumnal equinox). Across the continental United States, the Sun's highest position occurs around June 21, the first day of summer (summer solstice), after which the angle of the Sun begins to lessen. Summer occurs between June 21 and September 21 in the northern hemisphere. Between September 21 and December 21, the Sun's rays become more oblique north of the equator, bringing winter. The Sun is at its lowest point in the sky at noon on December 21 (winter solstice), and after that time it begins to rise in the sky. Winter occurs from December 21 to March 21. The tilt of the Earth's axis causes the rays of the Sun to strike more directly north of the equator between March 21 and June 21, thus bringing summer to the northern hemisphere. The seasons in the southern hemisphere are the opposite of the seasons in the northern hemisphere. The actual starting dates of the seasons will not always fall exactly on the 21st of the month.

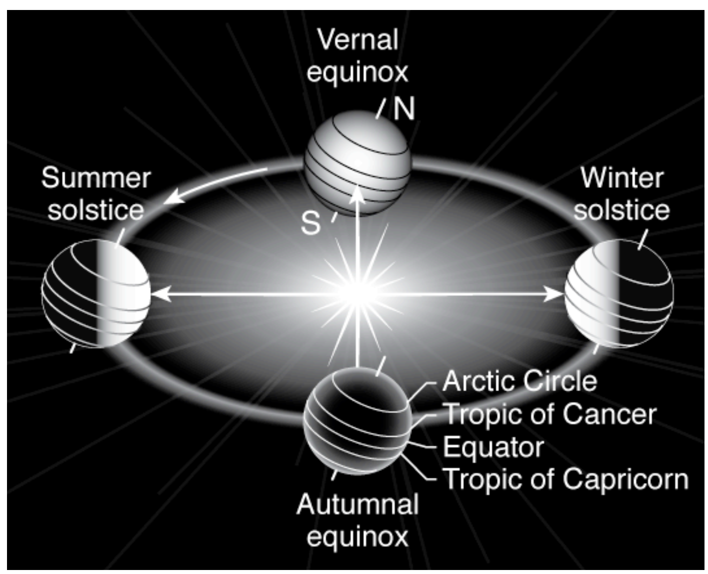


Figure 4-2. The tilt of Earth's axis affects the angle at which the Sun's rays strike the Earth.