
(Photo by Warren Faidley/DRK Photo)

PART 3

Meteorology

EXERCISE 12

Earth–Sun Relations

To life on this planet, the relations between Earth and the Sun are perhaps the most important of all astronomical phenomena. The variations in solar energy striking Earth as it rotates and revolves around the Sun cause the seasons and therefore are an appropriate starting point for studying weather and climate.

In this exercise you will investigate the reasons why the amount of solar radiation intercepted by Earth varies for different latitudes and changes throughout the year at a particular place (Figure 12.1). The next exercise, Exercise 13, examines how the atmosphere is warmed by this radiation.

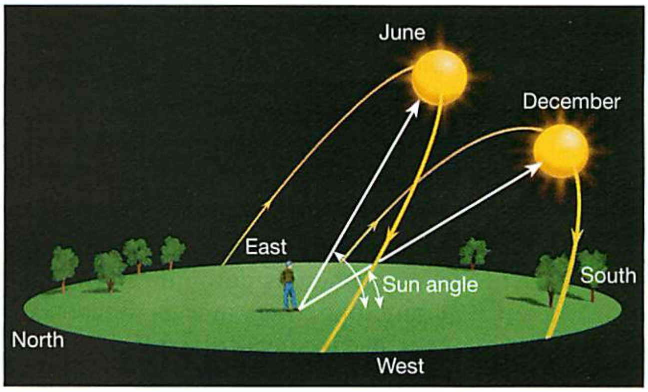

Figure 12.1 Daily paths of the Sun for June and December for an observer in the middle latitudes in the Northern Hemisphere. Notice that the angle of the Sun above the horizon is much greater in the summer than in the winter.

Objectives

After you have completed this exercise, you should be able to:

1. Describe the effect that Sun angle has on the amount of solar radiation a place receives.
2. Explain why the intensity and duration of solar radiation varies with latitude.
3. Explain why the intensity and duration of solar radiation varies at any one place throughout the year.
4. Describe the significance of these special parallels of latitude: Tropic of Cancer, Tropic of Capricorn, Arctic Circle, Antarctic Circle, and equator.
5. Diagram the relation between Earth and the Sun on the dates of the solstices and equinoxes.
6. Determine the latitude where the overhead Sun is located on any day of the year.
7. Calculate the noon Sun angle for any place on Earth on any day.
8. Calculate the latitude of a place using the noon Sun angle.

Materials

metric ruler
protractor
colored pencils
calculator

Materials Supplied by Your Instructor

globe
large rubber band or string

Terms

weather
weather element
weather control
solar intensity
solar duration
langley
calorie
solar constant
equator
Tropic of Cancer
Tropic of Capricorn
Arctic Circle
Antarctic Circle
solstice
equinox
analemma
noon Sun angle

Introduction

Weather is the state of the atmosphere at a particular place for a short period of time. The condition of the atmosphere at any location and time is described by measuring the four basic **elements** of weather: temperature, moisture, air pressure, and wind. Of all the **controls** that are responsible for causing variations in the weather elements, the amount of solar radiation received at any location is the most important.

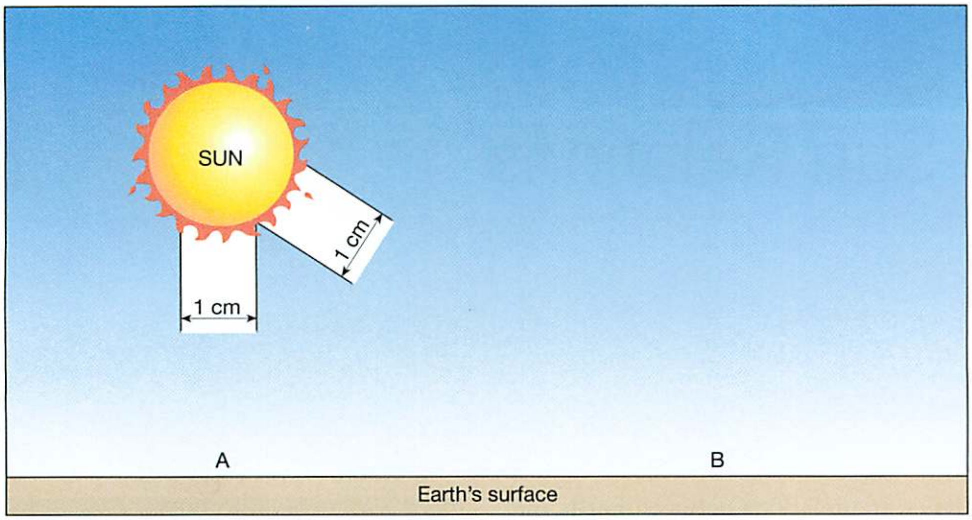

Figure 12.2 Vertical and oblique Sun beams.

Solar Radiation and the Seasons

The amount of solar energy (radiation) striking the outer edge of the atmosphere is not uniform over the face of Earth at any one time, nor is it constant throughout the year at any particular place. Rather, solar radiation at any location and time is determined by the Sun's **intensity** and **duration**. Intensity is the angle at which the rays of sunlight strike a surface, whereas duration refers to the length of daylight.

The standard unit of solar radiation is the **langley**, equal to one **calorie**[1] per square centimeter. The **solar constant**, or average intensity of solar radiation falling on a surface perpendicular to the solar beam at the outer edge of the atmosphere, is about 2 langleys per minute. As the radiation passes through the atmosphere, it undergoes absorption, reflection, and scattering. Therefore, at any one location, less radiation reaches Earth's surface than was originally intercepted at the upper atmosphere.

Solar Radiation and Latitude

The amount of radiation striking a square meter at the outer edge of the atmosphere, and eventually Earth's surface, varies with latitude because of a changing Sun angle (see Figure 12.1). To illustrate this fact, answer questions 1–11 using the appropriate figure.

1. On Figure 12.2, extend the 1-cm-wide beam of sunlight from the Sun vertically to point A on the surface. Extend the second 1-cm-wide beam, beginning at the Sun, to the surface at point B.

Notice in Figure 12.2 that the Sun is directly overhead (vertical) at point A and the beam of sunlight strikes the surface at a 90° angle above the horizon.

Using Figure 12.2, answer questions 2–5.

2. Using a protractor, measure the angle between the surface and the beam of sunlight coming from the Sun to point B.

   _______° = angle of the Sun above the surface (horizon) at point B.

3. What are the lengths of the line segments on the surface covered by the Sun beam at point A and point B?

   Point A: _______ mm point B: _______ mm

4. Of the two beams, beam (A, B) is more spread out at the surface and covers a larger area. Circle your answer.

5. More langleys per minute would be received by a square centimeter on the surface at point (A, B). Circle your answer.

Use Figure 12.3 to answer questions 6–11 concerning the total amount of solar radiation intercepted by each 30° segment of latitude on Earth.

6. With a metric ruler, measure the total width of incoming rays from point x to point y in Figure 12.3. The total width is _______ centimeters (_______ millimeters). Fill in your answers.

7. Assume the total width of the incoming rays from point x to point y equals 100% of the solar radiation that is intercepted by Earth. Each cen-

[1]The most familiar energy unit used to measure heat is the calorie, which is the quantity of heat energy needed to raise the temperature of one gram of water one degree Celsius. Do not confuse it with the so-called large Calorie (note the capital C), the kind counted by weight watchers. A Calorie is the amount of heat energy needed to raise the temperature of a kilogram (1,000 grams) of water 1 degree Celsius.

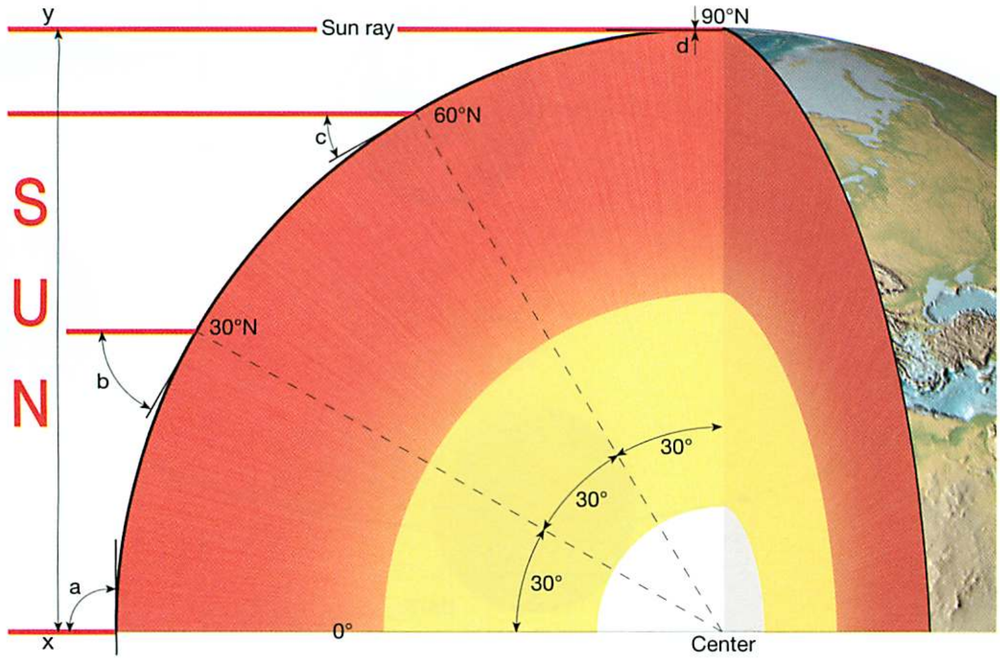

Figure 12.3 Distribution of solar radiation per 30° segment of latitude on Earth.

timeter would equal ________%, and each millimeter would equal ________%. Fill in your answers.

8. What percentage of the total incoming radiation is concentrated in each of the following zones?

   0°–30° = ________ mm = ________%

   30°–60° = ________ mm = ________%

   60°–90° = ________ mm = ________%

9. Use a protractor to measure the angle between the surface and Sun ray at each of the following locations. (Angle b is already done as an example.)

   Angle a: ________° angle c: ________°

   Angle b: ____60°____ angle d: ________°

10. What is the general relation between the amount of radiation received in each 30° segment and the angle of the Sun's rays?

   ____

   ____

11. Explain in your own words what fact about Earth creates the unequal distribution of solar energy, even though each zone represents an equal 30° segment of latitude.

   ____

   ____

   ____

Yearly Variation in Solar Energy

The amount of solar radiation received at a particular place would remain constant throughout the year if it were not for these facts:

- Earth rotates on its axis and revolves around the Sun.
- The axis of Earth is inclined 23.5° from the perpendicular to the plane of its orbit.
- Throughout the year, the axis of Earth points to the same place in the sky, which causes the overhead (vertical or 90°) noon Sun to cross over the **equator** twice as it migrates from the **Tropic of Cancer** (23.5°N latitude) to the **Tropic of Capricorn** (23.5°S latitude) and back to the Tropic of Cancer.

As a consequence, the position of the vertical or overhead noon Sun shifts between the hemispheres, causing variations in the intensity of solar radiation and changes in the length of daylight and darkness. *The seasons are the result of this changing intensity and duration of solar energy and subsequent heating of the atmosphere.*

To help understand how the intensity and duration of solar radiation varies throughout the year, answer questions 12–31 after you have examined the location of the Tropic of Cancer, Tropic of Capricorn, **Arctic Circle**, and **Antarctic Circle** on a globe or world map.

12. List some of the countries each of the following special parallels of latitude passes through.

   Tropic of Cancer: ________________________

   Tropic of Capricorn: ________________________

   Arctic Circle: ________________________

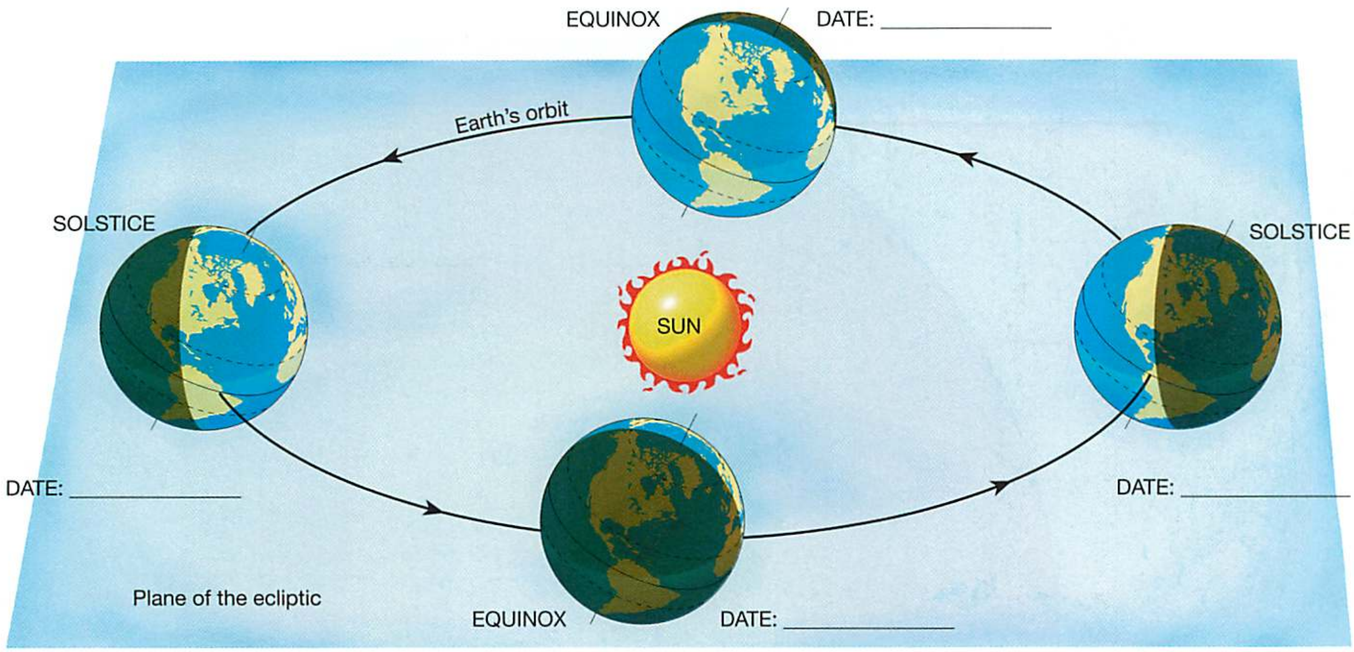

Figure 12.4 Earth–Sun relations.

13. Write the date represented by each position of Earth at the appropriate place in Figure 12.4. Then label the following on Earth at an equinox AND a solstice position.

    North Pole and South Pole
    Axis of Earth
    Equator, Tropic of Cancer, Tropic of Capricorn
    Arctic Circle and Antarctic Circle
    Circle of illumination (day–night line)

Questions 14–19 refer to the June **solstice** position of Earth in Figure 12.4.

14. What term is used to describe the June 21–22 date in each hemisphere?

    Northern Hemisphere: _______________ solstice

    Southern Hemisphere: _______________ solstice

15. On June 21–22 the Sun's rays are perpendicular to Earth's surface at noon at the (Tropic of Cancer, equator, Tropic of Capricorn). Circle your answer.

16. What latitude is receiving the most intense solar energy on June 21–22?

    Latitude: _______________________________

17. Toward what direction, north or south, would you look to see the Sun at noon on June 21–22 if you lived at the following latitudes?

    40°N latitude: ___________________________

    10°N latitude: ___________________________

18. Position a rubber band, string, or pieces of tape on a globe corresponding to the *circle of illumination* on June 21–22. Then determine the approximate length of daylight at the following latitudes by examining the proportionate number of degrees of longitude a place located at each latitude spends in daylight as Earth rotates. (*Note:* Earth rotates a total of 360° of longitude per day. Therefore, each 15° of longitude is equivalent to one hour.)

    70°N latitude: __________ hrs __________ min

    40°S latitude: __________ hrs __________ min

    40°N latitude: __________ hrs __________ min

    90°S latitude: __________ hrs __________ min

    0° latitude: __________ hrs __________ min

19. On June 21–22, latitudes north of the Arctic Circle are receiving (6, 12, 24) hours of daylight, while latitudes south of the Antarctic Circle are experiencing (6, 12, 24) hours of darkness. Circle your answers.

Questions 20–24 refer to the December solstice position of Earth in Figure 12.4.

20. What name is used to describe the December 21–22 date in each hemisphere?

    Northern Hemisphere: _______________ solstice

    Southern Hemisphere: _______________ solstice

21. On December 21–22 the Sun's rays are perpendicular to Earth's surface at noon on the (Tropic of

Table 12.1 Length of Daylight

LATITUDE (DEGREES)	SUMMER SOLSTICE	WINTER SOLSTICE	EQUINOXES
0	12 h	12 h	12 h
10	12 h 35 min	11 h 25 min	12
20	13 12	10 48	12
30	13 56	10 04	12
40	14 52	9 08	12
50	16 18	7 42	12
60	18 27	5 33	12
66.5	24 h	0 00	12
70	24 h (for 2 mo)	0 00	12
80	24 h (for 4 mo)	0 00	12
90	24 h (for 6 mo)	0 00	12

Cancer, equator, Tropic of Capricorn). Circle your answer.

22. On December 21–22 the (Northern, Southern) Hemisphere is receiving the most intense solar energy. Circle your answer.

23. If you lived at the equator, on December 21–22 you would look (north, south) to see the Sun at noon.

24. Refer to Table 12.1, "Length of daylight." What is the length of daylight at each of the following latitudes on December 21–22?

90°N latitude: ________ hrs ________ min

40°S latitude: ________ hrs ________ min

40°N latitude: ________ hrs ________ min

90°S latitude: ________ hrs ________ min

0° latitude: ________ hrs ________ min

Questions 25–31 refer to the March and September **equinox** positions of Earth in Figure 12.4.

25. For those living in the Northern Hemisphere, what terms are used to describe the following dates?

March 21: ________________ equinox

September 22: ________________ equinox

26. For those living in the Southern Hemisphere, what terms are used to describe the following dates?

March 21: ________________ equinox

September 22: ________________ equinox

27. On March 21 and September 22 the Sun's rays are perpendicular to Earth's surface at noon at the (Tropic of Cancer, equator, Tropic of Capricorn). Circle your answer.

28. What latitude is receiving the most intense solar energy on March 21 and September 22?

Latitude: ________________

29. If you lived at 20°S latitude, you would look (north, south) to see the Sun at noon on March 21 and September 22. Circle your answer.

30. What is the relation between the North and South Poles and the circle of illumination on March 21 and September 22?

____

31. Write a brief statement describing the length of daylight everywhere on Earth on March 21 and September 22.

____

As you have seen, the latitude where the noon Sun is directly overhead (vertical, or 90° above the horizon) is easily determined for the solstices and equinoxes.

Figure 12.5 is a graph, called an **analemma**, that can be used to determine the latitude where the overhead noon Sun is located for any date. To determine

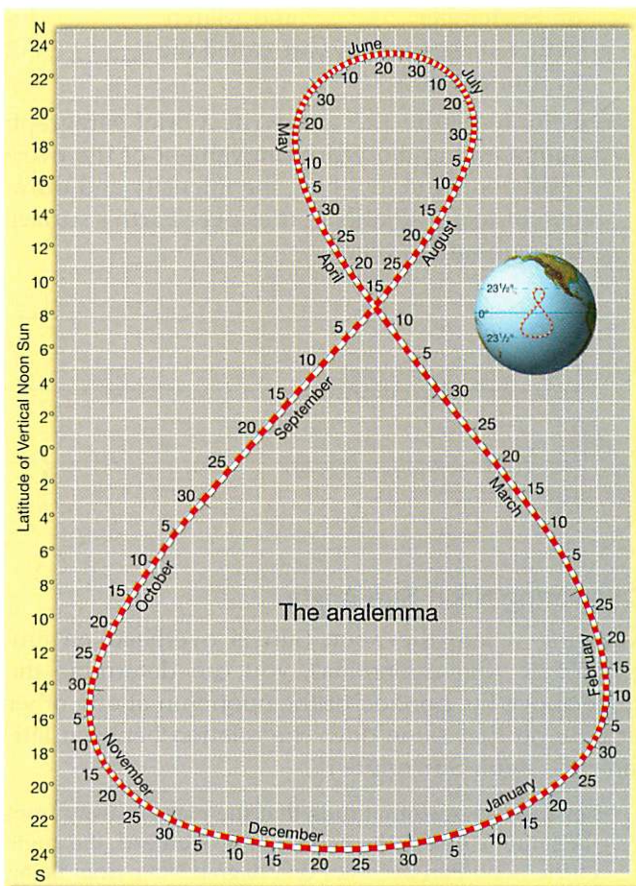

Figure 12.5 The analemma, a graph illustrating the latitude of the overhead (vertical) noon Sun throughout the year.

the latitude of the overhead noon Sun from the analemma, find the desired date on the graph and read the coinciding latitude along the left axis. Don't forget to indicate North or South when writing latitude.

32. Using a colored pencil, draw lines on Figure 12.5 that correspond to the equator, Tropic of Cancer, and Tropic of Capricorn. Label each of these special parallels of latitude on the figure.

33. Using the analemma, Figure 12.5, determine where the Sun is overhead at noon on the following dates.

December 10: ____________

March 21: ____________

May 5: ____________

June 22: ____________

August 10: ____________

October 15: ____________

34. The position of the overhead noon Sun is always located on or between which two parallels of latitude?

_______°N (named the Tropic of _______) and

_______°S (named the Tropic of _______)

35. The overhead noon Sun is located at the equator on September _______ and March _______. Together, these two days are called the _______. Fill in your answers.

36. Refer to Figure 12.5 and write a brief paragraph summarizing the yearly movement of the overhead noon Sun and how the intensity and duration of solar radiation varies over Earth's surface throughout the year.

____

____

____

____

Calculating Noon Sun Angle

Knowing where the noon Sun is overhead on any given date (the analemma), you can determine the angle above the horizon of the noon Sun at any other latitude on that same day. The relation between latitude and **noon Sun angle** is

> For each degree of latitude that the place is away from the latitude where the noon Sun is overhead, the angle of the noon Sun becomes one degree *lower* from being vertical (or 90°) above the horizon (Figure 12.6).

37. Complete Table 12.2 by calculating the noon Sun angle for each of the indicated latitudes on the dates given. Some of the calculations have already been done.

Table 12.2 Noon Sun Angle Calculations

LATITUDE OF OVERHEAD NOON SUN	MAR 21 (____)	APR 11 (____)	JUN 21 (____)	DEC 22 (____)
		Noon Sun Angle		
90°N	_____	_____	_____	_____
40°N	50°	_____	_____	26½°
0°	_____	_____	66½°	_____
20°S	_____	62°	_____	_____

38. From Table 12.2, the highest average noon Sun angle occurs at (40°N, 0°, 20°S). Circle your answer.

39. Calculate the noon Sun angle for your latitude on today's date.

Date: ____________________

Latitude of overhead noon Sun: ____________

Your latitude: ____________________

Your noon Sun angle: ____________________

(*Note:* You may want to compare your calculated noon Sun angle with a measured noon Sun angle obtained by using the technique described in Exercise 17, *Astronomical Observations.*)

40. Calculate the maximum and minimum noon Sun angles for your latitude.

MAXIMUM NOON SUN ANGLE	MINIMUM NOON SUN ANGLE
Date: ________	Date: ________
Angle: ________°	Angle: ________°

41. Calculate the average noon Sun angle (maximum plus minimum, divided by 2) and the range of the noon Sun angle (maximum minus minimum) for your location.

Average noon Sun angle = __________°

Range of the noon Sun angle = __________°

42. Describe some situations in which knowing the noon Sun angle might be useful.

____

____

Using Noon Sun Angle

One very practical use of noon Sun angle is in navigation. Like a navigator, you can determine your latitude if the date and angle of the noon Sun at your location are known. As you answer questions 43 and 44, keep in mind the relation between latitude and noon Sun angle (Figure 12.6).

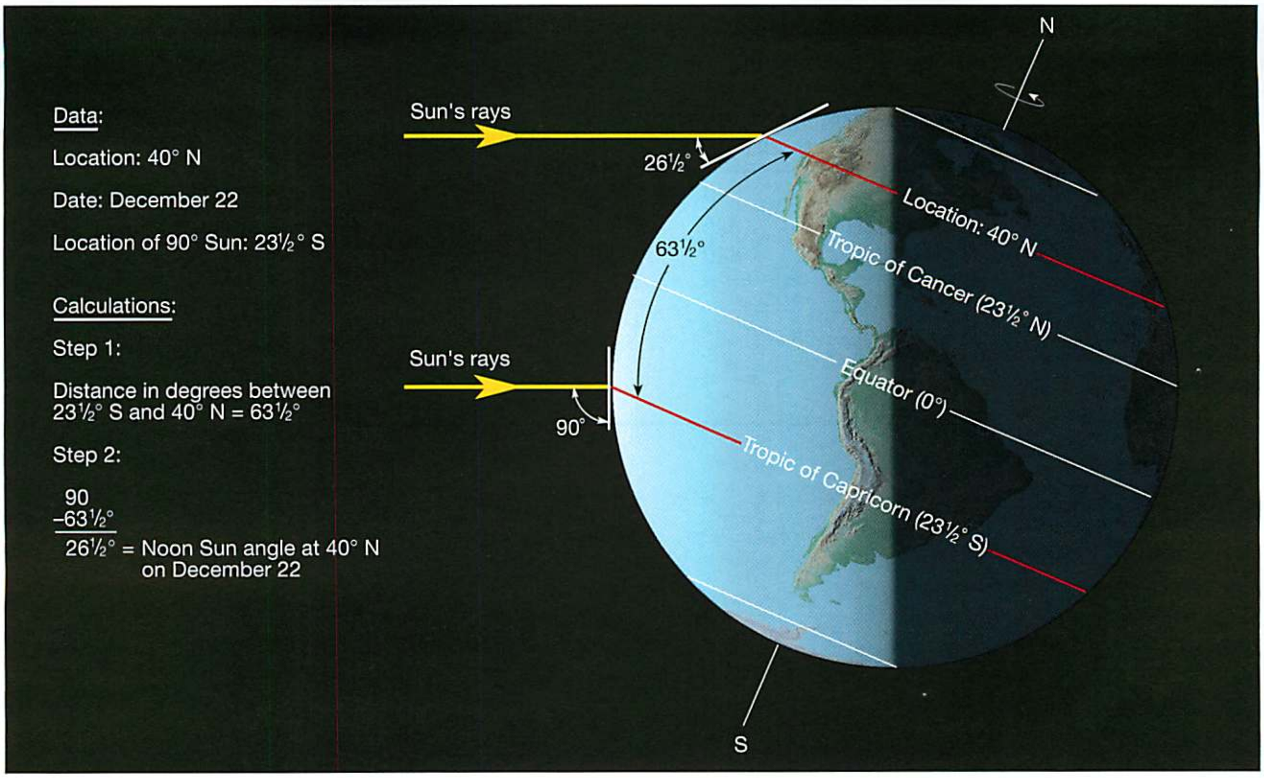

Figure 12.6 Calculating the noon Sun angle. Recall that on any given day, only one latitude receives vertical (90°) rays of the Sun. A place located 1° away (either north or south) receives an 89° angle at any location; a place 2° away, an 88° angle, and so forth. To calculate the noon Sun angle, simply find the number of degrees of latitude separating that location from the latitude that is receiving the vertical rays of the Sun. Then subtract that value from 90°. The example in this figure illustrates how to calculate the noon Sun angle for a city located at 40° north latitude on December 22 (winter solstice).

43. What is your latitude if, on March 21, you observe the noon Sun to the north at 18° above the horizon?

    Latitude: ______________________

44. What is your latitude if, on October 16, you observe the noon Sun to the south at 39° above the horizon?

    Latitude: ______________________

Solar Radiation at the Outer Edge of the Atmosphere

Table 12.3 (page 186) shows the average daily radiation received at the outer edge of the atmosphere at select latitudes for different months.

To help visualize the pattern, plot the data from Table 12.3 on the graph in Figure 12.7. Using a different color for each latitude, draw lines through the monthly values to obtain yearly curves. Then answer questions 45–48.

45. Why do two periods of maximum solar radiation occur at the equator?

    ____

46. In June, why does the outer edge of the atmosphere at the equator receive less solar radiation than both the North Pole and 40°N latitude?

    ____

    ____

47. Why does the outer edge of the atmosphere at the North Pole receive no solar radiation in December?

    ____

48. What would be the approximate monthly values for solar radiation at the outer edge of the atmosphere at 40°S latitude? Explain how you arrived at the values.

    March: __________

    June: __________

    September: __________

    December: __________

    Explanation: ______________________

    ____

Table 12.3 Solar Radiation at the Outer Edge of the Atmosphere (langleys/day) at Various Latitudes during Select Months

LATITUDE	MARCH	JUNE	SEPTEMBER	DECEMBER
90°N	50	1050	50	0
40°N	700	950	720	325
0°	890	780	880	840

Earth–Sun Relations on the Internet

Apply the concepts from this exercise to an examination of solar and terrestrial radiation by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

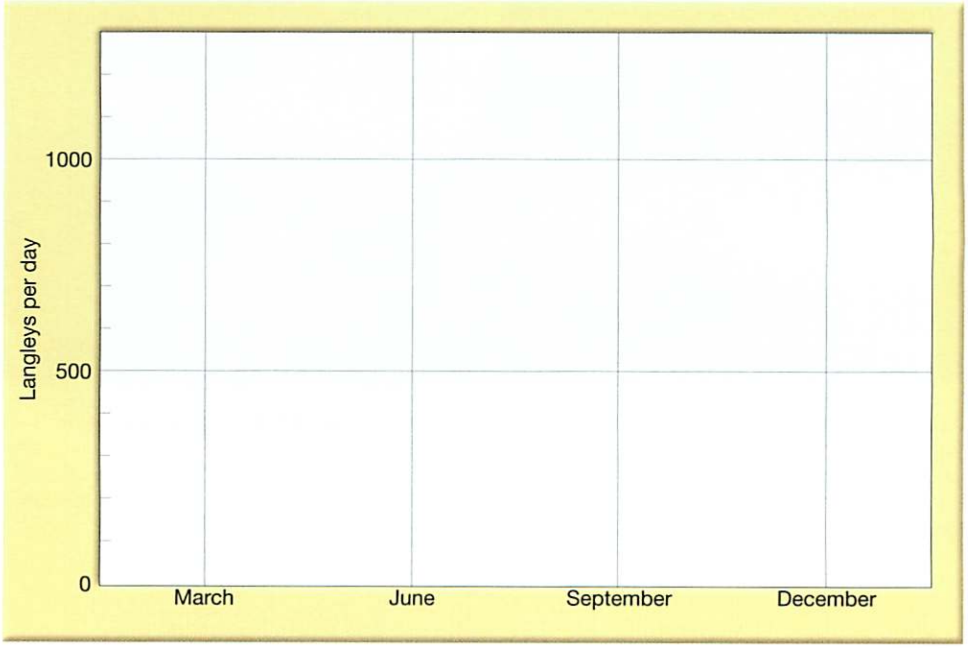

Figure 12.7 Graph of solar radiation received at the outer edge of the atmosphere.

Earth–Sun Relations

Date Due: ____________________

Name: ____________________

Date: ____________________

Class: ____________________

After you have finished Exercise 12, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. From Figure 12.3, what was the calculated percentage of solar radiation that is intercepted by each of the following 30° segments of latitude?

   0°–30° __________ %

   30°–60° __________ %

   60°–90° __________ %

2. How many hours of daylight occur at the following locations on the specified dates?

	MARCH 22	DECEMBER 22
40°N	______ hrs	______ hrs
0°	______ hrs	______ hrs
90°S	______ hrs	______ hrs

3. What is the noon Sun angle at these latitudes on April 11?

   40°N __________ °　　0° __________ °

4. What is the relation between the angle of the noon Sun and the quantity of solar radiation received per square centimeter at the outer edge of the atmosphere?

   ____

   ____

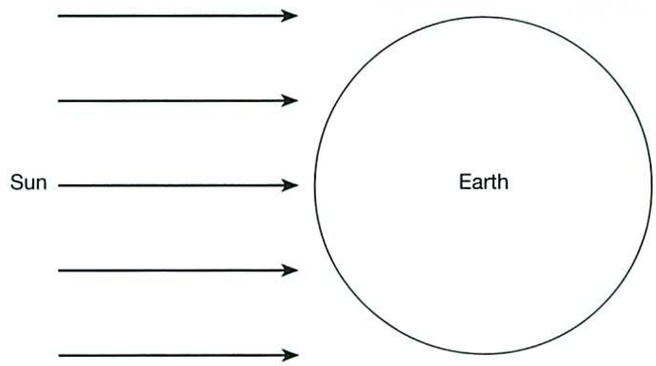

Figure 12.8 Earth's relation to the Sun on June 22.

5. Complete Figure 12.8 showing Earth's relation to the Sun on June 22. On the Earth, accurately draw and label the following:

   Axis
   Equator
   Tropic of Cancer
   Tropic of Capricorn
   Antarctic Circle
   Arctic Circle
   Circle of illumination
   Location of the overhead noon Sun

6. What causes the intensity and duration of solar radiation received at any place to vary throughout the year?

   ____

   ____

   ____

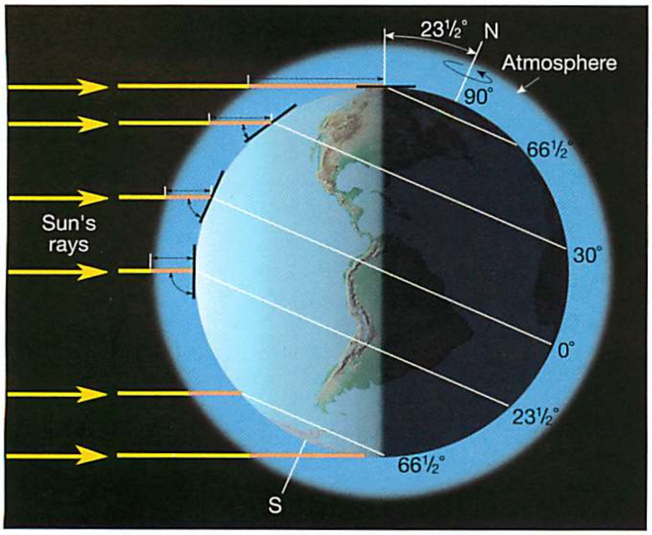

Figure 12.9 Earth–Sun relation diagram.

7. What is the date illustrated by the diagram in Figure 12.9? Calculate the noon Sun angle at 30° N latitude on this date and write a paragraph describing the distribution of solar radiation over Earth on this date.

____

____

____

____

8. What are the maximum and minimum noon Sun angles at your latitude?

Maximum noon Sun angle = ________° on ________ (date)

Minimum noon Sun angle = ________° on ________ (date)

9. What are the maximum and minimum durations of daylight at your latitude?

Maximum duration of daylight = ______ hrs

Minimum duration of daylight = ______ hrs

10. Write a brief statement describing how the intensity and duration of solar radiation change at your location throughout the year.

____

____

____

____

____

11. The day is March 22. You view the noon Sun to the south at 35° above the horizon. What is your latitude?

Latitude: ________________