12

EXERCISE

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 1).

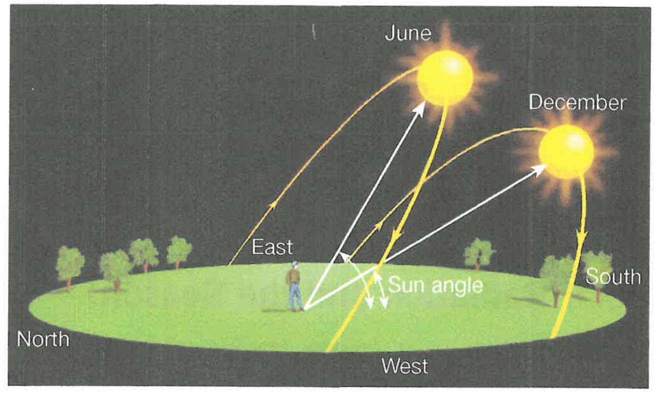

Figure 1 Daily paths of the Sun for June and December for an observer in the middle latitudes in the Northern Hemisphere. Notice that the angle of the Sun above the horizon is much greater in the summer than in the winter.

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.

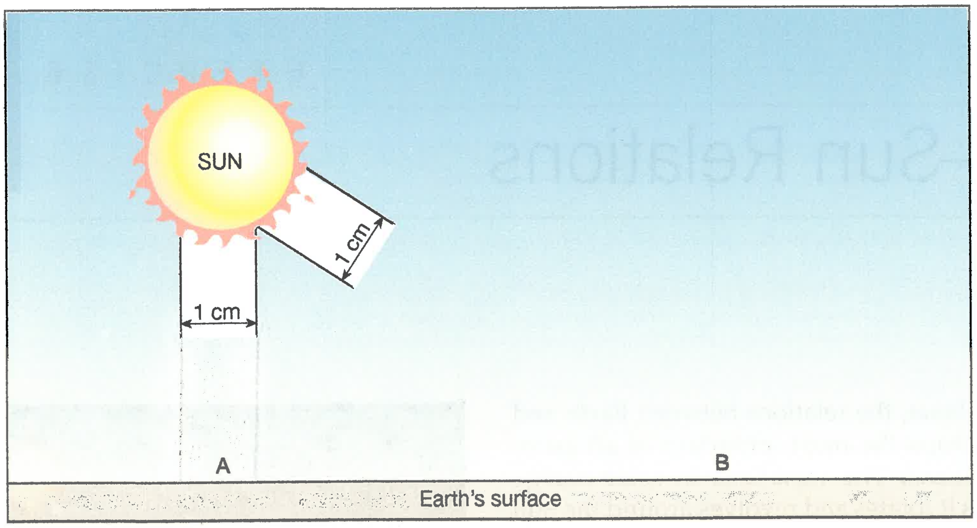

Figure 2 Vertical and oblique Sun beams.

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 1). To illustrate this fact, answer questions 1–11 using the appropriate figure.

1. On Figure Table 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 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 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 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 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.

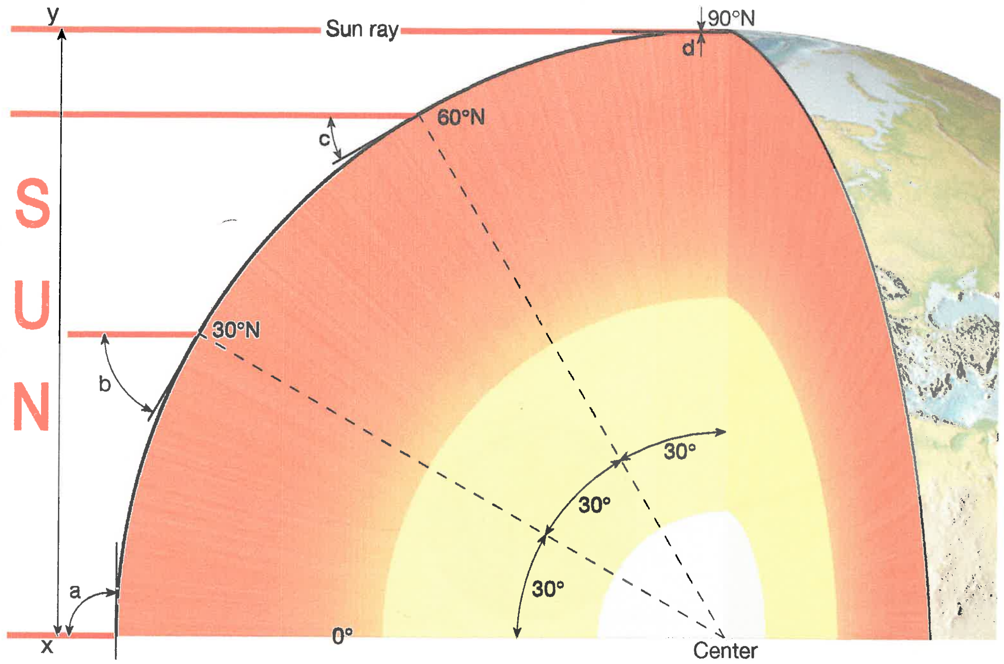

Figure 3 Distribution of solar radiation per 30° segment of latitude on Earth.

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.

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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: _______________________

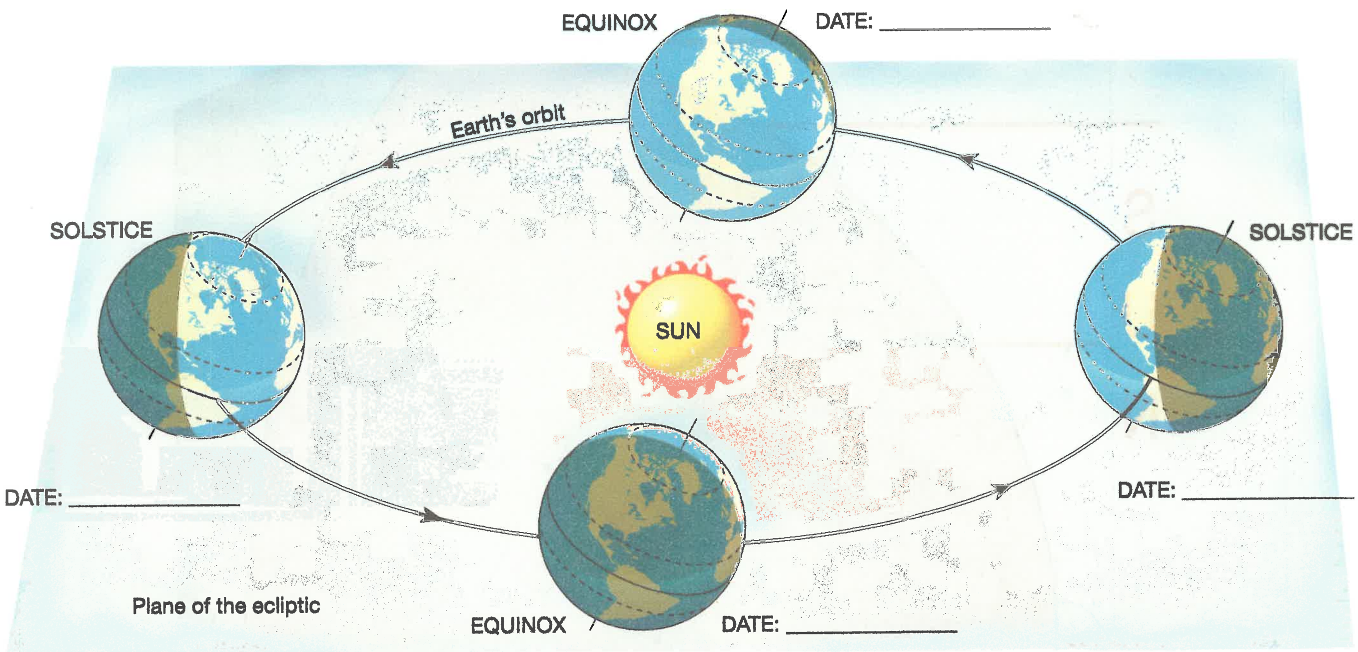

Figure 4 Earth–Sun relations.

13. Write the date represented by each position of Earth at the appropriate place in Figure 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 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 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 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 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 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 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 the lat-

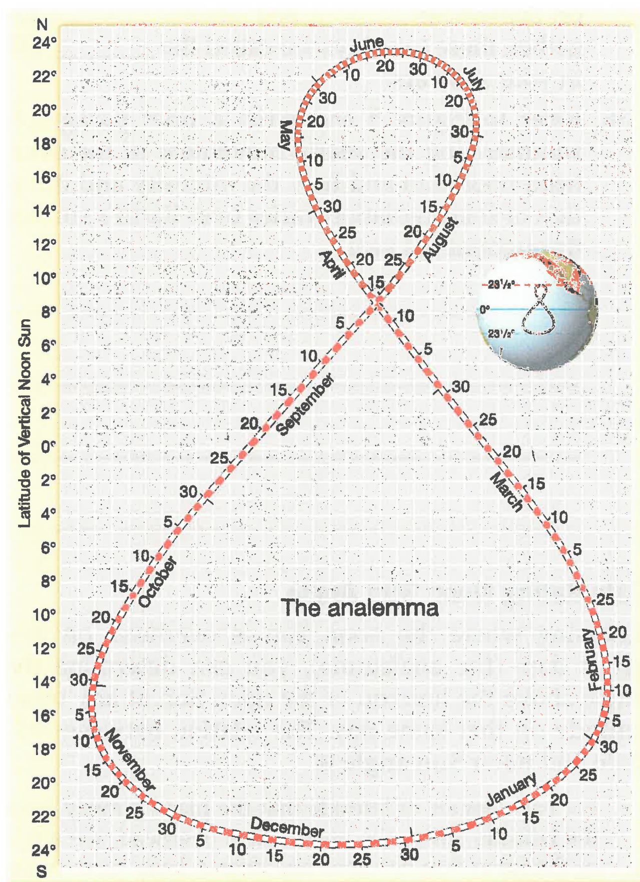

Figure 5 The analemma, a graph illustrating the latitude of the overhead (vertical) noon Sun throughout the year.

itude 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 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 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 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.

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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 6).

37. Complete Table 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 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 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 the exercise "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.

____

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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 6).

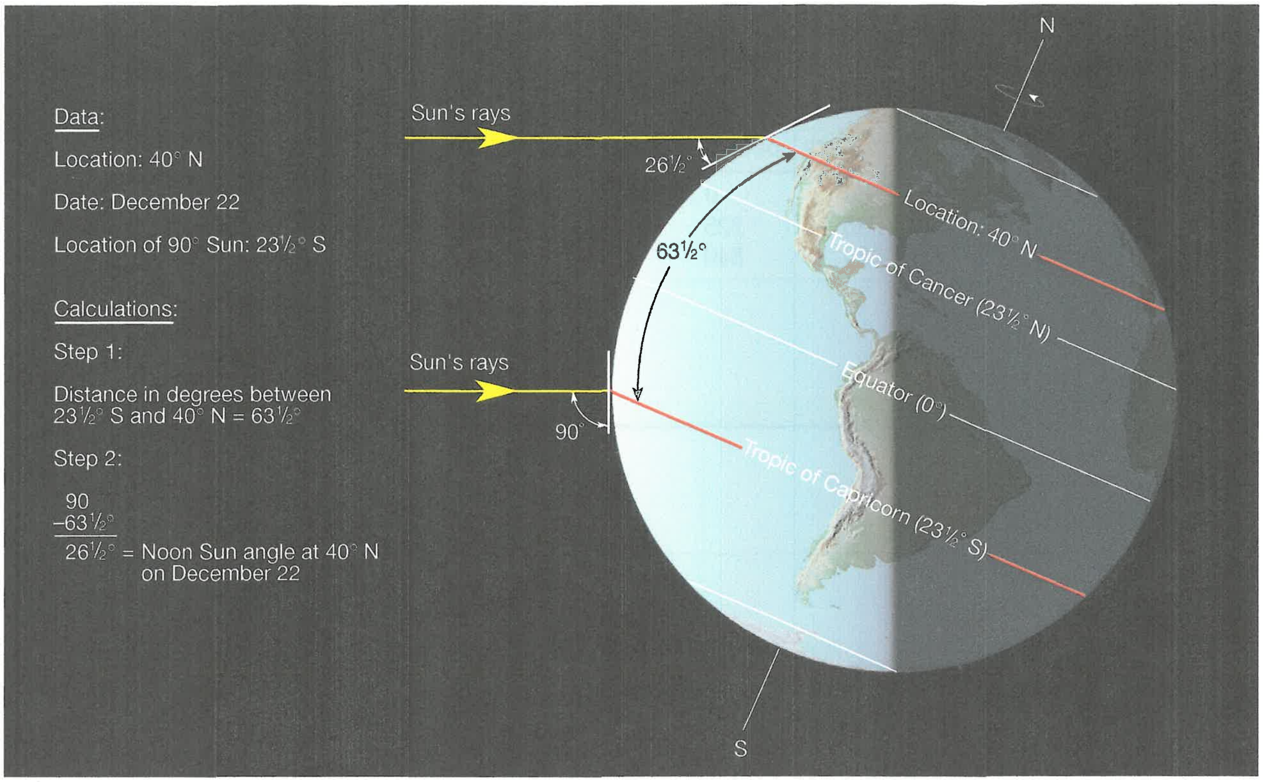

Figure 6 Calculating the noon Sun angle. Recall that on any given day, only one latitude receives vertical (90°) rays of the Sun. A place located 1° away (either north or south) receives an 89° angle at any location; a place 2° away, an 88° angle, and so forth. To calculate the noon Sun angle, simply 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 3 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 3 on the graph in Figure 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?

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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 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

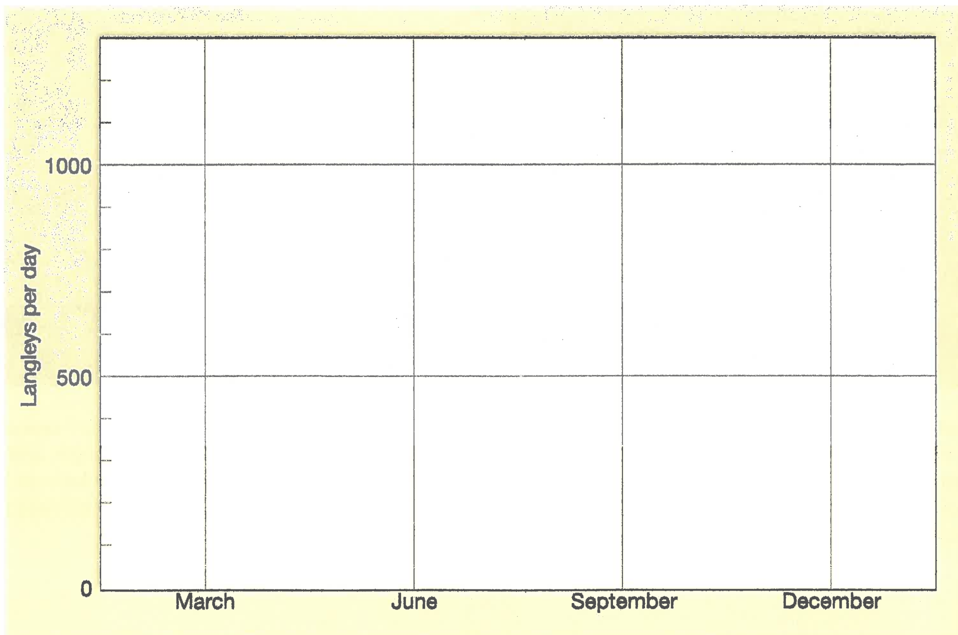

Figure 7 Graph of solar radiation received at the outer edge of the atmosphere.

Earth–Sun Relations

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished this exercise, 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 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?

   ____

   ____

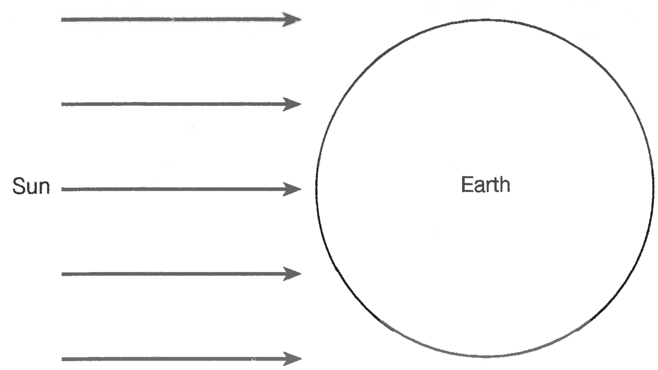

Figure 8 Earth's relation to the Sun on June 22.

5. Complete Figure 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?

   ____

   ____

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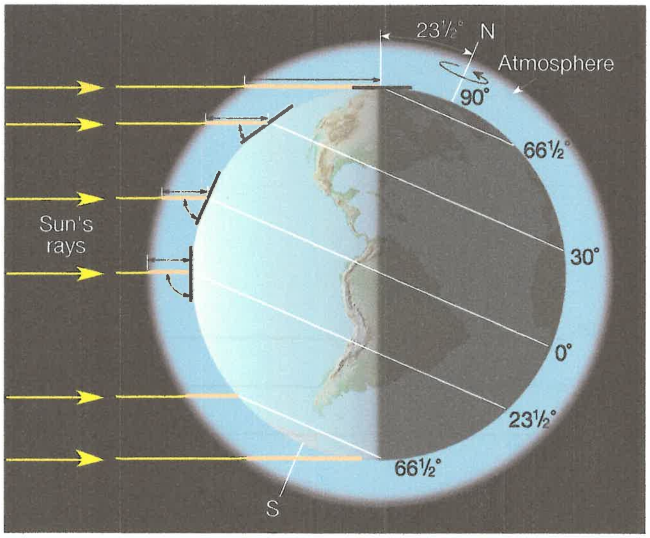

Figure 9 Earth–Sun relation diagram.

7. What is the date illustrated by the diagram in Figure 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.

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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.

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

Latitude: ______________________