Name: ______________________ Laboratory Section: ______________________

Date: ______________________ Score/Grade: ______________________

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LAB EXERCISE

6

Insolation and Seasons

Earth's systems are powered by a constant flow of **insolation**—incoming solar radiation. Earth intercepts only one two-billionth of the entire solar output, yet this is the singular significant source of energy for living systems. This exercise examines the nature of this energy and contrasts the solar output with energy re-radiated by Earth's surface back to space. The Sun's rays arrive at the top of the atmosphere in parallel beams, but the curvature of Earth presents surfaces at differing angles to this incoming radiation: Lower latitudes receive more direct (vertical) illumination, whereas higher latitudes receive more indirect (oblique) rays. This pattern of uneven heating produces an energy imbalance in the atmosphere and on Earth's surface below—namely, equatorial and tropical energy surpluses and polar energy deficits.

Earth's systems are further influenced by shifting seasonal rhythms produced by changing daylength and Sun altitude (height of the noon Sun above the horizon at a given location). These seasonal changes become more noticeable toward the poles. Seasons occur as a result of Earth–Sun relationships produced by rotation, revolution, tilt of the axis, axial parallelism, and Earth's sphericity. Lab Exercise 6 has two sections.

Key Terms and Concepts

altitude
analemma
declination
insolation
revolution
rotation
zenith

KEY LEARNING concepts

After completion of this lab, you should be able to:

1. *Identify* the pattern of daily energy receipts at the top of the atmosphere at different latitudes throughout the year and *graph* the observations.
2. *Determine* the angle of incidence of insolation and the resultant intensity of the solar beam for various latitudes.
3. Utilize the analemma to *determine* the subsolar point, latitude, and noon Sun angle (altitude) for several locations using the analemma.

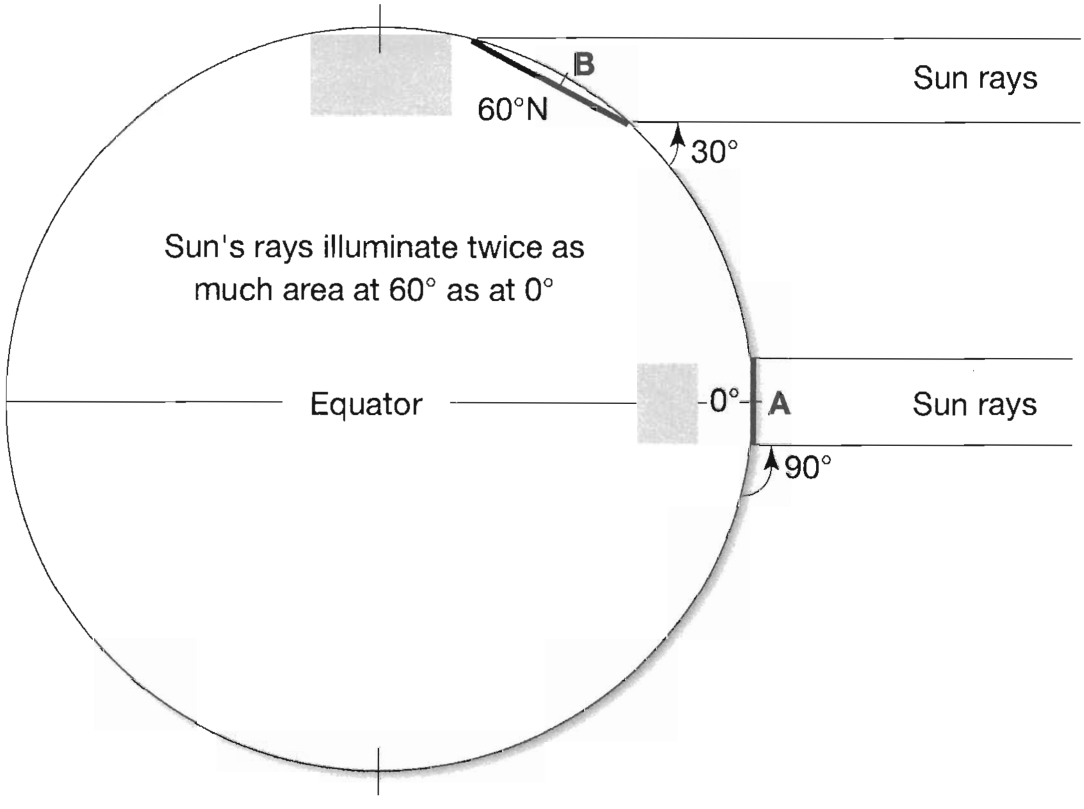
Materials/Sources Needed

pencil
calculator
color pencils
ruler

SECTION 1

Distribution of Insolation at the Top of the Atmosphere

As discussed in Lab Exercise 5, the spherical Earth presents a curved surface to the Sun's parallel rays, producing an uneven distribution of energy across the latitudes. Only the subsolar point receives insolation from directly overhead: All other locations receive the Sun's rays at increasingly lower angles of incidence as their distance increases from the subsolar point. A lower angle of insolation is less intense at the surface, that is, the energy arriving is more diffuse. The Sun's rays striking a surface at a 30° angle are diffused over twice the surface area as that receiving a perpendicular beam. Figure 6.1 shows that these oblique rays, striking Earth's surface at a 30° angle at point B, cover twice as much surface area (and are thus more diffuse and only one-half as intense) as the direct rays, which strike at a 90° angle at the subsolar point A.

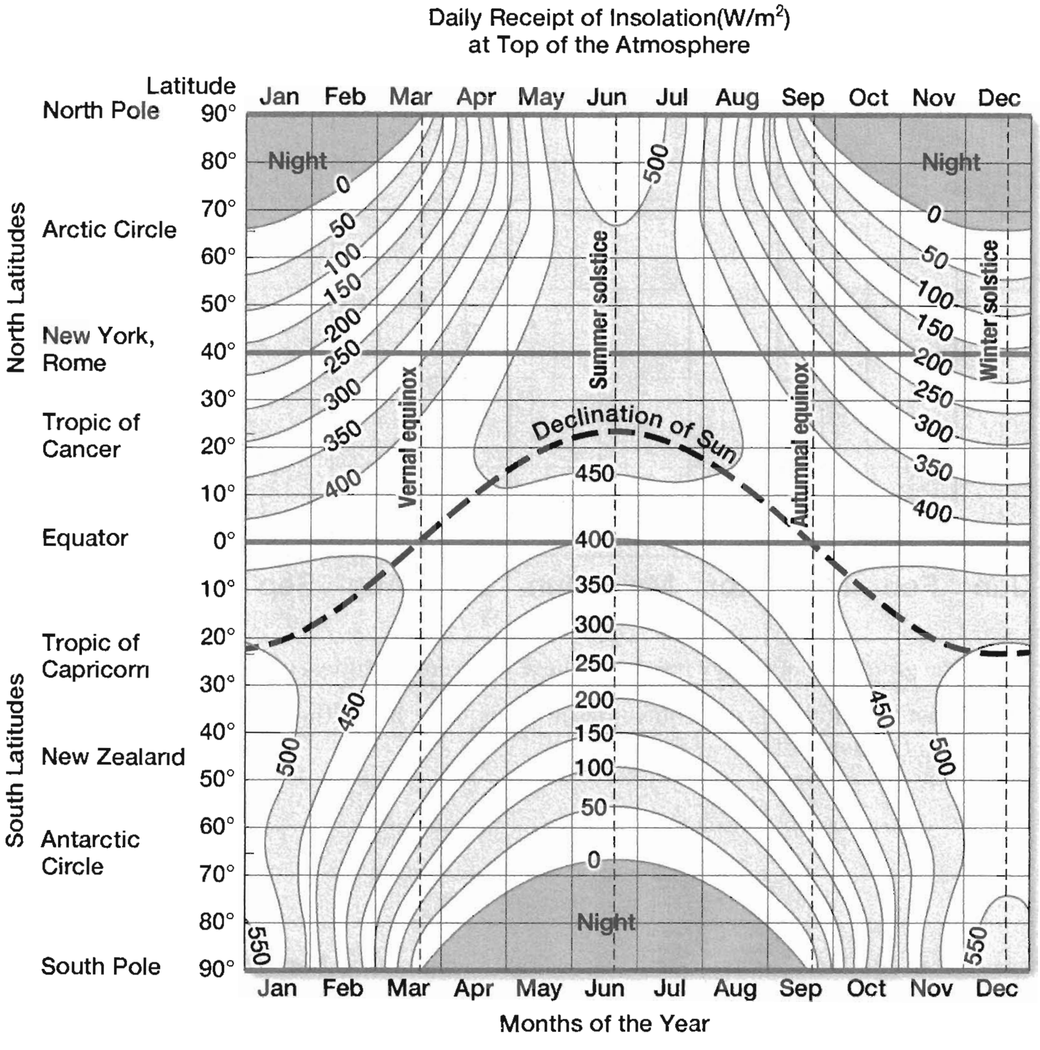


▲ Figure 6.1 Insolation angles and concentration of the Sun's energy

In addition, the greater length of travel through the atmosphere at higher latitudes reduces solar intensity due to increased reflection, absorption, and scattering within the atmosphere. This energy receipt also varies daily, seasonally, and annually as Sun angle and daylength vary—less toward the equator, more toward the poles.

A useful altitude at which to characterize insolation is the top of the atmosphere (480 km, 300 mi). The graph in Figure 6.2 plots the daily variation in insolation for selected latitudes. Latitudes are marked along the left side in 10° intervals. The months of the year are marked and labeled across the top and bottom. The dashed curved line shows the declination of the Sun (the latitude of the subsolar point) throughout the year.

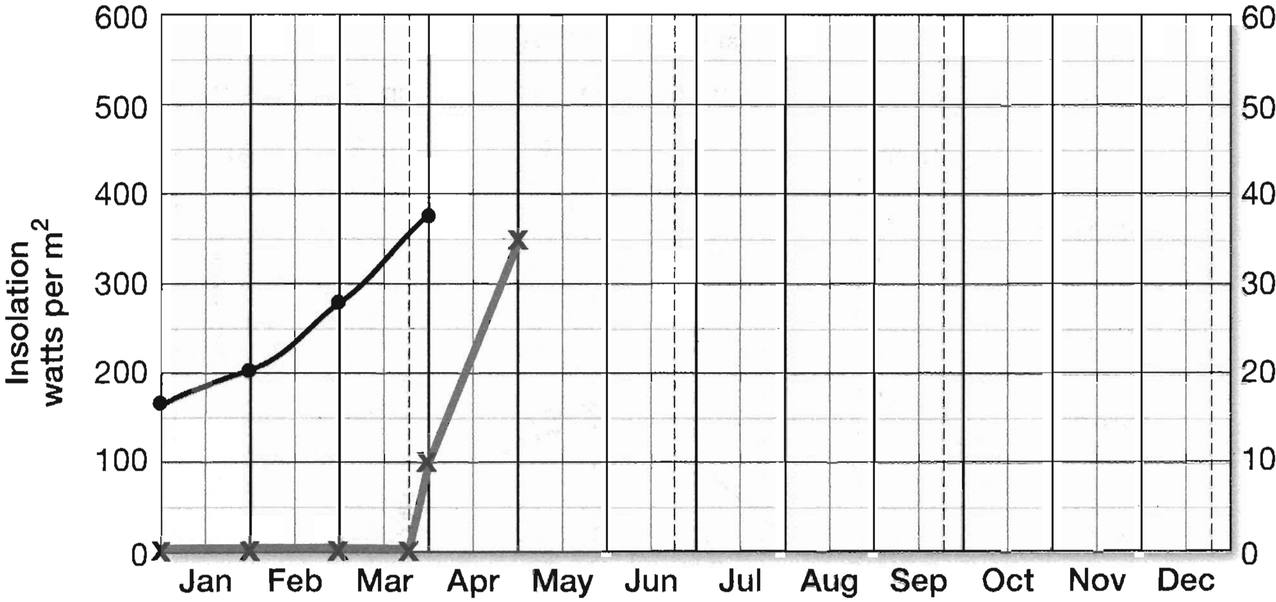
To read the graph, select a latitude line and follow it from left to right through the months of the year. The daily insolation totals are read from the curved lines, given in watts per square meter per day (W/m^2 per day). For example, at the top of the atmosphere above 30°N latitude the insolation values (in W/m^2 per day) are as follows (readings are approximate—extrapolate when necessary): 240 on January 1, 250 on January 15, and 275 on February 1.



▲ Figure 6.2 **Total daily insolation received at the top of the atmosphere charted in watts per square meter by latitude and month (1 watt/m^2 = 2.064 cal/cm^2/day). Adapted from the Smithsonian Institution Press from *Smithsonian Miscellaneous Collections: Smithsonian Meteorological Tables*, vol. 114, 6th Edition. Robert List, ed. Smithsonian Institution, Washington, DC, 1984, p. 419, Table 134.**

1. Using the data in Figure 6.2 and the graph provided below, plot data for specific latitudes for the first of each month. The graph you create will enable you to note the changes throughout the year in the amount of insolation received at a given latitude. Compare the differences in annual insolation patterns at various latitudes. Plot all seven latitudes on one graph, using color pencils to distinguish each. (Be sure to include a legend.)

   - North Pole (started on the graph with *x*s)
   - New York (started on the graph; city at 40°N with dots)
   - Tropic of Cancer
   - Equator
   - South Pole



After completing the graph of the energy receipt at these different latitudes, complete the following:

2. Compare and contrast the plotted insolation values at the equator and either of the poles. What factors explain these different patterns of energy receipt?

3. What factor results in the June (summer) solstice energy receipt at the North Pole exceeding that received on the same day at the equator?

4. What is happening at the poles on the March (vernal) equinox?

5. What kind of generalization can you make about the relationship between latitude and annual variation in insolation?

6. **Challenge question:** Why do you think the South Pole receives over 550 W/m^2 at the December solstice, whereas the North Pole receives over 500 W/m^2 during the June solstice?

SECTION 2

Seasonal Variation in the Sun's Declination and Altitude

Seasonal variations are a response to changes in the Sun's **altitude**, the angle between the horizon and the noon Sun. The Sun's **declination**, the latitude of the subsolar point, migrates annually through 47° of latitude—between the *Tropic of Cancer* at 23.5°N and the *Tropic of Capricorn* at 23.5°S. The **analemma** is a convenient device to track the passage of the Sun's path and declination throughout the year (Figure 6.3). The horizontal lines are latitudes from 25°N to 25°S. The "figure 8" is a calendar, with each day of the year represented by a black or white segment.

Find August 20 on the analemma; note that it lies on the 12°N line—the subsolar point on that date. While you should remember the subsolar points for the solstices and equinoxes, an analemma will help you determine the declination for the other days of the year.

The analemma also is useful for ascertaining the positive and negative equations of time and periods of "fast-Sun times" (greatest in October and November) and "slow-Sun times" (greatest in February and March). A 24-hour (86,400-second) average day determines *mean solar time.* However, an *apparent solar day* is based on observed successive passages of the Sun over a given meridian. Any difference between observed solar time and mean solar time is called the *equation of time.* On successive days, if the Sun arrives overhead at a meridian *after* 12:00 noon local standard time (taking longer than the 24 hours of a mean solar day)—like an airliner arriving later than scheduled—the equation of time is *negative*, and the Sun is described as "slow." If, on the other hand, the Sun arrives overhead *before* 12:00 noon local time on successive days (taking less time than 24 hours)—like an airliner arriving ahead of schedule—the equation of time is *positive*, and the Sun then is described as "fast." The combination of the tilt and the eccentricity of Earth's orbit around the sun produces this difference between mean solar time and apparent solar time. Because Earth's orbit is elliptical rather than circular, Earth actually travels more quickly when we are at perihelion and more slowly when we are at aphelion. The solar day increases in length by up to 7.9 seconds for several months and then decreases in length for several months. This difference accumulates from day to day and results in the equation of time ranging from up to 16 minutes slow and 14 minutes fast at different times during the year. The equation of time is across the top of the analemma.

Find January 17 on the analemma (marked with a dot). It lies on the line labeled 9 minutes, on the "Sun slow" side. This means that the Sun will reach its "noon" **zenith** (highest point in the sky on that day) at 12:09 P.M., 9 minutes "late."

1. Use the analemma to find:
   - **a)** The subsolar point on November 10 (marked) ________ [*17° south latitude*] ________
   - **b)** The subsolar point on May 11 ________________________
   - **c)** The subsolar point today ________________________
   - **d)** The date(s) when the declination is 9°S ________________________
   - **e)** The date(s) when the declination is 21°N ________________________
2. At what clock time does the Sun actually reach zenith on:

   October 13? 11:47 A.M. [*The Sun is 13 minutes fast, so it will reach its zenith at 11:47* A.M.]

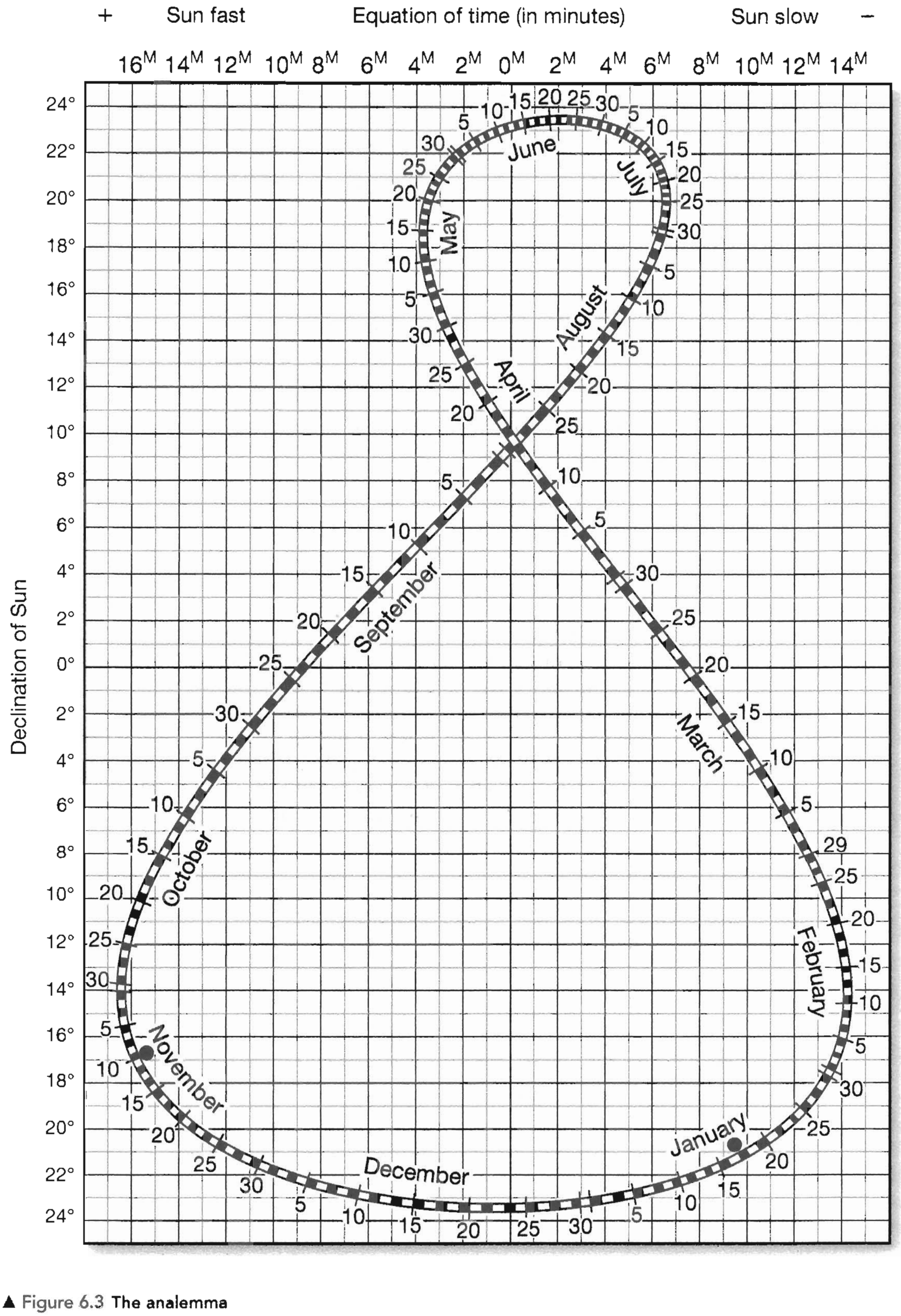
   March 8? ________________________

   May 20? ________________________

   Today? ________________________

As we have noted, the noon Sun angle changes at any given latitude throughout the year. Using the analemma to determine the subsolar point (Sun's declination), you can calculate the altitude of the noon Sun (Sun $\angle$) for any location by using the following formula:

$$\angle = 90° - (\text{arc distance between your latitude and subsolar point})$$



▲ Figure 6.3 The analemma

Examples:

You are at 30°N on December 21. You know that on the December solstice, the subsolar point of the noon Sun is 23.5°S. Using the above formula:

$\angle$ = 90° − (arc distance between your latitude and subsolar point)
$\angle$ = 90° − (30°N $\leftrightarrow$ 23.5°S)(*the symbol $\leftrightarrow$ is to indicate $\leftrightarrow$ "arc distance between"*)
$\angle$ = 90° − 53.5°
$\angle$ = 36.5° above the southern horizon from your location

You determined that on December 21, if you are standing at 30° north latitude, you observe the Sun's noon altitude at 36.5° above the southern horizon (since you are north of the subsolar point on this day).

If you are at 40°N on April 20, you determine from the analemma that the subsolar point is 10°N; therefore:

$\angle$ = 90° − (arc distance between your latitude and subsolar point)
$\angle$ = 90° − (40°N $\leftrightarrow$ 10°N)
$\angle$ = 90° − 30°
$\angle$ = 60° above the southern horizon*

*Note: You would observe the same Sun altitude on August 25, when the subsolar point is once again at 10°N. If you end up with a negative value for the Sun altitude, then the Sun is below the horizon and will not be visible on that day—as someone might experience north of the Arctic Circle in the Northern Hemisphere winter.

3. You are vacationing at Disney World near Orlando, Florida (28.5°N), on June 3. At what altitude will you observe the noon Sun? Include correct horizon. (Show work.) The problem has been started for you.

$\angle$ = 90° − (arc distance between your latitude and subsolar point)
$\angle$ = 90° − (28.5°N $\leftrightarrow$ subsolar point)

4. On that same day, friends of yours are sightseeing at Iguaçu Falls in Brazil (25.7°S). At what altitude will they observe the noon Sun?

5. Calculate the altitude of the noon Sun if you are vacationing in Kuala Lumpur, Malaysia (3.2°N), on July 25.

6. Suppose you were going to install photovoltaic solar panels to generate electricity from the Sun at your house, and you wanted the Sun to shine on them at a 90° angle on the equinoxes. At what angle would they need to be placed, based on the latitude of your home? Should they face north or south?

Whether you view the noon Sun above your northern or your southern horizon depends upon your latitude. The subsolar point is limited to the latitudinal belt between the Tropics of Cancer and Capricorn. An observer who is poleward of the tropics will see the noon Sun only above the "equatorward" horizon (above the southern horizon if north of the Tropic of Cancer and above the northern horizon if south of the Tropic of Capricorn). An observer on or between the tropics will measure the noon Sun above the northern horizon part of the year, above the southern horizon part of the year, and directly overhead on 1 or 2 days.

Use the analemma in Figure 6.3 to answer the following questions:

7. a) If you are at 5°N latitude, on what dates will the noon Sun be directly overhead?

____

b) Approximately how many days will you view the noon Sun above your northern horizon? ________

... above your southern horizon? ____________________

c) If you are at 18°S latitude, on what dates will the noon Sun be directly overhead?

____

d) Approximately how many days will you view the noon Sun above your northern horizon? ________

... above your southern horizon? ____________________

Using the same relationship between latitude and Sun altitude, you can also determine your latitudinal location by measuring the solar noon altitude, which can be done with a sextant or more simply with a protractor and a stick. For example:

Using a sextant, you measure the noon Sun angle at 59° above the southern horizon on March 11. From the analemma, you know that the subsolar point is 4°S; therefore:

$$\angle = 90^\circ - \text{(arc distance between your latitude and subsolar point)}$$
$$59^\circ = 90^\circ - \text{(your latitude} \leftrightarrow 4^\circ\text{S)}$$
$$59^\circ = 90^\circ - 31^\circ$$

If the arc distance between your latitude and the subsolar point = 31°, and the subsolar point is 4°S, then your latitude must be 27°N (31° − 4°). (You must be north latitude because the Sun is viewed above your southern horizon.)

This method of determining latitude, used along with chronometers and local time to determine longitude (Lab Exercise 1), allowed sailors or other navigators to obtain their absolute global location in the days before GPS (Global Positioning System) units were devised.

8. Calculate the latitude of a mariner who has measured the noon Sun altitude as 60° above the southern horizon on August 13.

9. What would the mariner's latitude be if the Sun had been measured above the northern horizon?

10. Using the graphs provided, plot the seasonal change in the Sun's noon altitude for:

a) North Pole (90°N)

____

b) La Ronge, Saskatchewan (55°N)—completed for you

____

c) Atlanta, Georgia (34°N)

____

d) Dunedin, New Zealand (46°S).

____

Complete these calculations only for each of the four seasonal anniversary dates at the solstices and equinoxes (March 20, June 20, September 22, and December 21). If needed, refer to your geography text to determine the Sun's declination on these dates for each of the four locations. Then use the procedure above to determine the Sun's altitude in the sky at noon that you would observe if you were standing at each location.