Discovering the Night Sky 1

Chapter Outline

1-1 Astronomical distances are, well, astronomical
1-2 Constellations make locating stars easy
1-3 The celestial sphere aids in navigating the sky
1-4 Earth's rotation creates the day-night cycle, and its revolution defines a year
1-5 The seasons result from the tilt of the Earth's rotation axis combined with its revolution around the Sun
1-6 Clock times based on the Sun's location created scheduling nightmares
1-7 Calendars based on equal-length years also created scheduling problems
1-8 Precession is a slow, circular motion of the Earth's axis of rotation
1-9 The phases of the Moon originally inspired the concept of the month
1-10 Eclipses don't occur during every new or full phase
1-11 Three types of lunar eclipses occur
1-12 Three types of solar eclipses also occur
1-13 Frontiers yet to be discovered

In This Chapter Students Will Discover

- How astronomers organize the night sky to help them locate objects in it
- That the Earth's spin on its axis causes day and night
- How the tilt of the Earth's axis of rotation and the Earth's motion around the Sun combine to create the seasons
- That the Moon's orbit around the Earth creates the phases of the Moon and lunar and solar eclipses
- How the year is defined and how the calendar was developed

Suggested Learning Objectives

At the end of this chapter, the student should be able to

1. Explain the importance of distance measurements in astronomy.
2. Describe the nature and use of constellations.
3. Define the elements of the equatorial coordinate system on the celestial sphere.
4. Define two solstices and two equinoxes.
5. Explain the orientation of the ecliptic on the celestial sphere and how it produces seasons on the Earth.
6. Describe the daily and yearly motions of the Earth.
7. Describe what precession is, what effect it has on our observations of stars, and why it occurs.
8. Draw a diagram to explain how lunar phases are controlled by the relative positions of the Sun and the Moon.
9. Explain when and why solar and lunar eclipses occur and why these eclipses do not occur every month.

Teaching Hints and Strategies

This chapter covers many of the topics that students associate with astronomy. It provides opportunities for a number of both short- and long-range observing projects. Some of these projects may be completed during one night or one day; others may extend over a few weeks or span the entire course. Such projects contribute to an understanding of modern observations as well as historical ones. Modern astrophysics depends heavily upon geometric reasoning and is communicated substantially through geometric representations. Yet, typical undergraduate students possess relatively undeveloped capacities for geometric visualization and manipulation, especially in three dimensions. Thus, the effectiveness of our introductory astronomy teaching is enhanced by any success in cultivating the geometry skills of our students. Finally, observational projects can be fun (especially if they involve group work) and are generally well received by the students. They have been used effectively in large classes and require only modest equipment and time.

A review of angular measurements is an excellent opportunity to emphasize that astronomy is an observational rather than an experimental science, principally because of the vast distances between celestial objects. While the space program is very important in the advancement of modern astronomy, humans have visited only one other celestial object (the Moon) and have landed spacecraft on only five others (Mars, Venus, Titan, and the asteroids Eros and Itokawa). Much of the space program has been devoted to using remote observatories that are still passive observers and that do not conduct active experiments beyond the solar system.

The distances between astronomical objects are vast, so their true sizes and distances from one another are frequently unknown or poorly known. Astronomers are able to measure angular separations and sizes directly. The presentation of light travel times to such celestial objects as our Moon, the Sun, the nearest star, the center of our galaxy, the nearest external galaxies, and the most remote quasars clearly illustrates these distances.

The introduction of scientific notation (Appendix A-1) can be justified by noting that the science of astronomy spans the entire dimensional scale from the truly vast to the truly minute. Most people recognize the large numbers of and the large sizes of celestial objects. It is helpful to remind students that the observational (passive) nature of astronomical investigations means that all direct information about the physical conditions existing on celestial objects and about their past and future conditions must be extracted from an understanding of the nature of atoms and the constituent parts of atoms, the smallest entities of the universe. Thus, astronomers must frequently deal with very small numbers as well as very large ones. This is a primary motivation for becoming familiar with scientific notation. The film *Powers of Ten* illustrates the range of astronomical sizes dramatically but very rapidly. Be sure to provide some time for mastery of the concepts of the powers-of-ten notation before expecting students to experience and interpret this film as a quantitative document.

The use of different systems of distance units in astronomy serves to emphasize the role of units in physical science and to illustrate the justification for establishing different systems of units. Many students fail to associate units with numbers. They have dealt with numbers in mathematics courses but have little experience with the measuring activities that lie at the heart of the physical sciences. Accordingly, a discussion of how units give meaning to numbers is important to aid student understanding. By using a variety of length units in astronomy, we are able to compare sizes and distances of the same order of magnitude with whole numbers and simple fractions. Although any system of units can be used with powers-of-ten notation, it is not as easy to visualize the relative magnitudes with very large or very small numbers. Comparisons of the sizes of and distances between objects of vastly different dimensions are more readily accomplished in powers-of-ten notation. It is useful to encourage students to view the exponent in the context of order-of-magnitude comparisons.

It is always a good idea to emphasize (repeatedly) that light-years are units of length and not units of time. During a topical overview, it is worthwhile to point out that astronomers must constantly deal with the past as they study remote objects. The light from celestial objects requires a finite amount of time to reach us. Astronomers thus see things not as they are, but as they were when the light left the object under study. We see the Moon as it was 1.5 seconds ago, the Sun as it was 8.3 minutes ago, Pluto as it was about 4 or 5 hours ago, the nearest star as it was 4 years ago, the center of our galaxy as it was 25,000 years ago, the Andromeda Galaxy as it was 2.6 million years ago, distant galaxies as they were 8 to 10 billion years ago, and remote quasars as they were 10 to 15 billion years ago. Astronomers can thus attempt to investigate systematic changes that occur with time and try to explain the results of those observations. The study of the impact of stellar evolution on the observable properties of stellar populations in galaxies is an example.

Constellations are used as aids in "navigating" the night sky. This discussion can be used as the basis for modest but very useful observing assignments designed to consolidate a student's understanding of angles and apparent positions in the sky.

The naked-eye observational focus of the chapter provides an important opportunity for those instructors who choose to highlight the character of scientific knowledge. Knowing little about the process of science, most students are able to recognize only the "incorrectness" of ancient astronomy but not its successes. Most are astounded to learn (for instance, in a discussion of Chapter 2) that it is possible to account for all naked-eye observations with a geocentric model of the universe. So, the immediate successors of Copernicus were confronted with two competing scientific models that were equally successful in matching the available observations. It is important for students to appreciate that a given set of data does not automatically specify a unique hypothesis; science, like art, requires creative leaps. That appreciation is most easily acquired through substantial experience with a concrete example. An instructor who hopes to use the comparison between Ptolemaic and Copernican models must develop the observational groundwork in Chapter 1. Useful resources for the instructor in this context include Kuhn, *The Copernican Revolution* (Harvard University Press, 1957) and Crowe, *Systems of the World from Ptolemy to Copernicus* (Dover, 1991).

The three primary motions of the Earth are rotation, revolution, and precession. Many of the geometric relationships among observed quantities are more easily displayed in the geocentric model (hence its use in celestial navigation texts). For example, the dependence of the time and azimuth of sunrise on the solar declination and latitude of observation is easily recognized on a celestial globe equipped with a horizon ring. The complementary use of heliocentric and geocentric models is initially surprising to many students, but it is an illuminating intellectual exercise. This example can be used to initiate a more general discussion of the use of conceptual models in our attempts to understand and describe nature. Such a discussion can help students to understand the role and limitations of models. The fact that a model has only a finite range of applicability does not detract from its usefulness within that range. (This theme is useful later in discussing the advances in our understanding of mechanics and the properties of light and matter.)

The rotation of the Earth on its axis is the basis for the geographic coordinate system (latitude and longitude), which is a natural tie-in to the celestial sphere and celestial coordinates. Most students have had some exposure to the geographic system. Students should be encouraged to go out at night and observe diurnal motion. The role of astronomers in the development of our time systems and their connection with the Earth's rotation should be noted here as an example of an early application of astronomy. Students who have used a GPS receiver may be familiar with the metric-based UTM/UPS coordinate system, an easier system to use than latitude and longitude. Consult the U.S. Naval Observatory Web site for the correct time. A GPS receiver will also report highly accurate time. Many clocks, watches, and home weather stations receive signals from WWVB and automatically synchronize to the correct time.

A planetarium presentation can be very helpful here, if one is available. Computer sky simulators provide an excellent vehicle for quantitative demonstrations and student exercises. It is critical to remember, however, that students' experiences of the real sky are very different from their experiences of a planetarium dome. A small flat sky map or computer screen is an even more abstract (arguably denatured) representation of the sky. To benefit from these learning aids, a student must develop a nontrivial mapping from an initially unfamiliar experience to an unfamiliar representation. This takes time. It is not difficult, however, to devise a set of observation exercises that span and complement several weeks of lecture material (see, for instance, the suggestions in later chapters). This strategy allows most students enough time to gain a satisfying level of understanding.

In our experience, the most rapid and substantial learning occurs if we are able to provide each student with access in lab or discussion class to a concrete "hands-on" model, such as a celestial globe, and to a computer program such as *Starry Night*™. (If student access to computers is limited, exercises can be built around carefully selected computer-generated diagrams. The loss of individual interactive experience is a significant but not a crippling limitation.)

When discussing time keeping, it should be emphasized that the calendar requires a whole number of days and that a day requires a whole number of hours. These are human needs, and the Earth is under no obligation to provide them. Therefore, we have to make adjustments to how we define these time periods so as to agree as closely as possible with the true astronomical year and the variable duration of the solar day throughout the year. For more information on calendars, consult the U.S. Naval Observatory Web site.

The causes of seasons are misunderstood by a very large number of students. The effects of the varying altitude of the Sun at noon can be demonstrated by using a flashlight held at different angles to a wall. The variation in the length of day is well known to everyone. However, many students look at elliptical orbits and conclude that seasons are caused by the varying distance of the Earth from the Sun. Be sure to point out that the Earth is closest to the Sun in January and farthest away in July. Also point out that the northern and southern hemispheres have opposite seasons and the names of the equinoxes and solstices reflect the northern hemispheric seasons only. Geometric links among day/night duration, observer's latitude, midday solar altitude, and the sunrise/sunset azimuths and solar ecliptic longitude are easily recognized by using a celestial globe or armillary sphere. A computerized sky simulator such as *Starry Night*™ can be used to represent the observations at different latitudes in each hemisphere.

A long-term project to observe the rising and setting azimuths of the Sun and/or its altitude at noon can help to make some of the patterns more clear. As a complementary observation, one can (once per month or so) make hourly observations of the length and azimuth of the shadow cast by a gnomon. Simulations of such gnomon observations at different seasons and latitudes can be done with a globe and a small square of cardboard perforated by a thumbtack. Tape the gnomon assembly to the globe at various latitudes and use the beam of a slide projector or overhead projector to cast the shadow of the thumbtack.

The underlying physics of precession is best demonstrated by the actions of a toy top. The necessity of rotation for precession is easy to show, and the precise nature of the motion is obvious. It can be instructive to discuss what summer and winter constellations are, how they are defined, and how they will appear in 13,000 years. It is also interesting to discuss the impact of the presence of a pole star on celestial navigation in the northern and southern hemispheres and the role astronomy has played in navigation in general. Until the past few years, during which satellite navigation has become common, transoceanic navigation was possible only on the basis of an understanding of the sky positions of celestial objects and the variation of those positions with time. This is another example of astronomy as an applied science. The applied nature of astronomy has dramatically diminished with time. Modern astronomers are generally more involved in basic research than with application.

The changing phases of the Moon are probably among the most familiar celestial variations for students, even though their cause is not well understood. The lunar phases can be demonstrated by illuminating a sphere with a flood lamp. One student then carries the sphere in orbit around other students who represent observers on the Earth. A surprising number of students require this kinesthetic experience to consolidate their geometric understanding. The concept of time can also be discussed by having the “Earthbound” students rotate once for each passing day during this demonstration. The location of the Moon in the sky relative to the Sun during its various phases should be noted. The concepts of synodic and sidereal period are also introduced in this section and can be demonstrated by having an assistant move the Sun.

When eclipses of the Sun and Moon are introduced, the line of nodes defined, and the concept of eclipse seasons described, colored tape can be used on the classroom walls to indicate the apparent paths of the Sun and Moon on the sky. The inclination of the lunar orbit is thus easily demonstrated. A piece of string or ribbon can be used to trace the line of nodes. Move a light source to demonstrate the apparent motion of the Sun each day (1° per day), and move a sphere representing the Moon (13° per day). Eclipse seasons occur only when both the Sun and Moon are lined up near the line of nodes. This alignment occurs twice each month for the Moon but only twice each year for the Sun. Thus, the Sun’s apparent motion (due to the revolution of the Earth) controls the frequency of eclipse seasons.

Eclipse classification is confusing for students. Remind them that eclipses are named for the object, which is supposed to be visible but disappears. In solar eclipses, the Sun disappears. In lunar eclipses, the Moon disappears. It might be interesting to note that, as a result of the angular size of the Sun and its apparent rate of motion along the ecliptic, at least one eclipse of each type must occur during each eclipse season. If only one eclipse occurs, it is likely to be a central eclipse (total or annular solar or total lunar). If more than one eclipse occurs during an eclipse season, it will probably be noncentral (partial solar or partial or penumbral lunar). Warn students about potential eye damage that can result from observing total solar eclipses without proper protection. Even though visible radiation is substantially reduced, harmful invisible radiation can still be intense. The resource list includes a number of useful videos and other references developed in connection with the 1991 total solar eclipse.

Starry Night™ contains several excellent simulations of these terrestrial, lunar and solar motions. On the menu bar, select Favorites-Observing Projects. Set the location to your current location. You could also change the location to higher or lower latitudes to show the effects of this change.

Class Discussion and Projects

1. Students can observe bright celestial objects over a period of a few hours to monitor diurnal motion. A simple altimeter can be constructed from a protractor, a soda straw or a plastic pipe, and a fishing weight on a piece of string. This instrument can be used to determine the altitude of Polaris, as well as stars or planets near the east and west points, as a function of time. Time-lapse photography showing star trails near the celestial equator and near the pole is also a good project.

2. Ask students to keep a notebook, showing the phase and location of the Moon relative to the horizon and/or relative to stars on a star chart at the same times of night (at 6-hour intervals perhaps) for a period of one lunar month. Records of meteorological data should be maintained also to develop some feeling for the limits imposed by weather conditions at your site.

3. Create your own Stonehenge during the quarter or semester by establishing a backsight and moving rocks (or posts) as foresights to represent the azimuths of sunrise or sunset for different dates.

4. Record positions of constellations relative to the horizon at a given time of night on about the same date each month for several months. Note and describe the changes that occur.

5. Have students compute the relative sizes of and distances between the Earth, Sun, and Moon, using a scale of 1 m for the diameter of the Sun. This project will clearly demonstrate why scale models of eclipses are not feasible. All objects will fit on a blackboard, but the distance of the Sun from the Earth-Moon system is much longer than a football field. This discovery will start to impress upon students that the distances between astronomical objects are much larger than the sizes of the objects themselves.

Review Questions

1. (c) The horizon divides the land from the sky.

2. There are 88 constellations.

3. The celestial equator is above the Earth's equator on the celestial sphere.

4. The Earth orbits the Sun in one year.

5. The Sun's path is the ecliptic.

6. Constellations (as regions of the sky) are useful because they make it easier to navigate the sky, just as maps with cities and the boundaries of states and countries do on Earth. Similarly, constellations (as asterisms) make it easier to locate objects in space. For example, following the arc of the handle of the Big Dipper takes you to the star Arcturus or "Arc to Arcturus."

7. The celestial sphere is the imaginary hollow shell surrounding the Earth that appears to us as the sky. Even though the stars are all moving relative to us and to each other, they are all so far away from Earth that they appear fixed on the celestial sphere over the span of a human lifetime. Just as a map with its cities and country boundaries makes it easier to find places on Earth, constellation boundaries on the celestial sphere help us navigate around the night sky.

8. The celestial equator is the line around the celestial sphere midway between the celestial poles. The celestial equator is directly above the Earth's equator. The north and south celestial poles are the intersection of the celestial sphere with the extension of the Earth's axis of rotation. Therefore, the north and south celestial poles are directly above the Earth's North and South Poles, respectively.

9. The ecliptic is the apparent annual path of the Sun around the celestial sphere. It is tilted relative to the celestial equator because the Earth's equator is tilted relative to the Earth's orbital plane. The ecliptic makes a circle on the celestial sphere. The plane piercing that circle is identical to the plane of the Earth's orbit around the Sun, also called the ecliptic.

10. The Sun moves approximately 1° per day along the ecliptic. Therefore, it makes a complete circuit of the celestial sphere in approximately 360 days. The number for one such circuit or sidereal period is closer to 365.26 days, which is the length of our year.

11. The Sun remains for many days in each of the constellations through which it moves. The amount of time it spends in each one depends on the size of the constellation.

12. The Sun moves through 13 constellations per year. These are the zodiac constellations. The least familiar zodiac constellation is Ophiuchus.

13. The Earth revolves around the Sun at a constant tilt. When the Sun is north of the celestial equator, it will rise higher in the sky in the northern hemisphere. This increased height of the Sun leads to a higher concentration of sunlight and longer days, resulting in warmer weather. While this is occurring in the northern hemisphere, the opposite is occurring in the southern hemisphere – the Sun is low in the sky, the sunlight is spread out more and the days are shorter, resulting in colder weather. As the Earth orbits the Sun, the Sun moves from north of the celestial equator to south of the celestial equator, thus causing the northern hemisphere to experience summer, fall, and winter and the southern hemisphere to experience winter, spring and summer. The seasons are always opposite to each other in the northern and southern hemispheres. See Figures 1-15 and 1-17.

14. The vernal and autumnal equinoxes are the points on the Earth's orbit where the Sun appears to cross the celestial equator. The vernal, spring equinox, (March for the northern hemisphere) occurs when the Sun crosses the celestial equator heading northward, while the autumnal (September for the northern hemisphere) equinox occurs when the Sun crosses it heading south. On these two days, the Sun is directly over the Earth's equator. The solstices are the points on the Earth's orbit where the Sun appears farthest north or south of the celestial equator. In both hemispheres, the summer solstice is when the Sun is highest in the sky at noon and the winter solstice is when it is lowest at noon. At the December solstice the Sun is directly above the Tropic of Capricorn (summer in the southern hemisphere) and at the June solstice it is directly above the Tropic of Cancer (summer in the northern hemisphere).

15. Precession is the wobbling motion of the Earth's axis, which moves as if it were a spinning top twirling on a table. This wobble means that the axis of rotation describes a cone. Precession causes the celestial poles to change position slowly on the celestial sphere as well as the Sun's position on the vernal equinox. This means that Polaris is not always directly above the North Pole and does not always indicate geographic North. One complete cycle of precession for the Earth takes about 26,000 years.

16. During the summer, the Sun rises earlier, crosses higher in the sky, and sets later than during any other season. Conversely, during the winter, the Sun rises later, crosses lower in the sky, and sets earlier than during any other season. In the northern hemisphere, the Sun appears farther north in summer and farther south in winter. In the southern hemisphere, the seasons are reversed.

17. Temperatures on Earth are not determined by the distance from the Earth to the Sun but by the angle at which the Sun's rays strike Earth. It is warmer in the summer because the Sun's rays strike the Earth's surface at a relatively steep angle and because the Sun is above the horizon longer during the summer than during other seasons. These two conditions mean that more of the Sun's energy reaches the hemisphere experiencing summer.

18. It is convenient to divide the Earth into time zones so that clocks in large regions of the Earth can be set to the same time which helps coordinate human affairs. In a world without time zones, you would have to reset your watch every time you went even short distances east or west.

19. The Moon exhibits phases because different amounts of the sunlit side of the Moon facing Earth are visible from the Earth as the Moon moves around our planet and both move around the Sun.

20. The sidereal month is the Moon's orbital period as measured with respect to the stars. It is one circuit of the Moon around the celestial sphere. The synodic month is the time it takes for the Moon to undergo a complete cycle of phases. The synodic month is longer because the Moon must revolve more than one sidereal orbit of the Earth to line up with the Sun again due to the Earth's revolution around the Sun during that time.

21. The Moon’s orbit is tilted about 5° from the plane of the ecliptic. The line created by the intersection of the ecliptic and the plane of the Moon’s orbit is called the line of nodes. When the Moon is on the line of nodes during the new phase (dark), a solar eclipse occurs, and when it is on the line of nodes during a full phase (fully illuminated), a lunar eclipse is the result.

22. In the umbra of a shadow, no part of the light source is visible, whereas in the penumbra, part of the light source is visible.

23. In a penumbral eclipse, the Moon passes only into the penumbra of the Earth’s shadow. It is easy to overlook such an eclipse because the Moon only grows slightly dimmer, while continuing to appear full.

24. More people have seen lunar eclipses because lunar eclipses occur more often than solar eclipses and because they are visible over larger geographical areas.

25. In an annular eclipse, the Sun’s disk is not entirely covered. A ring, or annulus, of the Sun is visible around the Moon’s edge. This occurs because the Moon’s apparent size is insufficient to completely obscure the Sun when the Moon is near apogee, that is, farthest from Earth. During a total solar eclipse the Sun is completely occulted by the Moon.

26. The next leap year will be 2016 followed by 2020.

27. Solar eclipses occur at the new Moon and lunar eclipses at the full Moon.

28. It is not safe to watch a solar eclipse without eye protection, but watching a lunar eclipse without eye protection is always safe.

29. The full Moon is not seen above the horizon in the daytime because the full Moon rises at sunset and sets at sunrise.

Advanced Questions

30. The waxing phases rise after sunrise and set after sunset. The waning phases rise before sunrise and set before sunset. The full Moon rises at sunset and sets at sunset. The new Moon rises at sunrise and sets at sunset.

31. The Big Dipper cannot be seen from the southern hemisphere as it is always below the horizon.

32. All stars are in at least one constellation. However, some stars are in two constellations. Elnath is at the tip of one of the horns of Taurus and also in the constellation Auriga. Alpheratz is in both Pegasus and Andromeda.

33. The north celestial pole is seen on the horizon from the Earth’s equator.

34. To see the Sun pass directly overhead, which is your zenith, you must be at or between latitudes 23.5° N, the Tropic of Cancer, and 23.5° S, the Tropic of Capricorn. Between these two latitudes, the Sun passes through the zenith twice each year. The Sun is above the Tropic of Cancer or the Tropic of Capricorn on only one day each year.

35. You must be at the South Pole to see the south celestial pole directly overhead. The south celestial pole is the location on the celestial sphere where the Earth’s rotation axis, passing through our planet’s South Pole, meets the celestial sphere. The Sun is never more than 23.5° above the horizon when you stand at the South Pole. The Sun’s maximum elevation occurs on about December

21, the date of the summer solstice in the southern hemisphere (and of the winter solstice in the northern hemisphere).

36. The Sun always rises due east at the time of the vernal equinox.

37. The star Canopus could someday be regarded as the "south star," although it would not be as close to the south celestial pole as Polaris is now.

38. Circumpolar stars, those that never go below the horizon, vary with latitude. At the poles, all visible stars are circumpolar, while at the equator, no stars are circumpolar. Every place in between has circumpolar stars. Some stars are never visible unless you live on the equator. In the northern hemisphere, the stars that are never visible are those with declinations equal to your latitude minus 90°. In the southern hemisphere, it is those stars with declinations of latitude plus 90°.

39. Because the north celestial pole is on the horizon (altitude = 0º) as seen from the equator, as one proceeds north, the north celestial pole's altitude will increase by the number of degrees moved, that is, the latitude.

40. Any bright star on the ecliptic will mark the vernal equinox someday. In the year 13,100 the very bright star Spica will be close to the position of the vernal equinox of the celestial sphere.

41. (a) Waning crescent (b) Waxing crescent (c) Sunrise (d) Noon

42. (a) New (b) First quarter (c) Full (d) Last quarter

43. There are 365.26/29.5 = 12.38 synodic months in a year, and 365.26/27.3 = 13.38 sidereal months in a year. Therefore, there is about one more sidereal month per year than synodic months.

44. Earth's shadow cannot create a gibbous Moon. As the Moon moves through the shadow, called the umbra, it appears that a bite is taken out of the Moon, creating a crescent Moon. Also, the Moon can move into the Earth's shadow only at full Moon. At other phases, it is not near the Earth's shadow.

45. Depending on the details of the Moon's orbit during an eclipse, the total solar eclipse paths can cross any part of the Earth facing the Sun. Total solar eclipses fall more frequently on oceans because the oceans cover about 75% of the Earth's surface.

46. There is never an annular eclipse of the Moon because the Earth's shadow, or umbra, is much larger than the Moon where the Moon crosses it and thus completely obscures it.

47. The Moon enters the Earth's shadow from the west because the Moon is moving eastward in its orbit.

48. Since the star trails are almost a half circle, the exposure was made from dusk to dawn.

49. Any star, up to double the distance from the horizon to the south celestial pole, will be circumpolar.

50. The photo was taken from the southern hemisphere, and there is no bright star as the center of the concentric circles.

51. We can see only half of the Moon's surface from the Earth. This is because the Moon's rotation is synchronous. The Moon's rotation is the same as its orbital period, which results in the same side of the Moon always facing us.

52. These are the views as seen from Earth for a northern hemisphere observer facing south. Because the Sun is to the east of the Moon during the waning phase, the illuminated portions are on the left side of the Moon's disk.

53. From Astronomer’s Toolbox 1-1, we have: physical diameter = distance × tan (angular diameter) or $D = (1.496 \times 10^{11}\ \mathrm{m}) \times \tan(0.5°) = (1.496 \times 10^{11}\ \mathrm{m}) \times (0.008727) = 1.306 \times 10^{9}\ \mathrm{m}$. Then, $R = 0.5D = 6.528 \times 10^{8}\ \mathrm{m}$. Our value for the angular diameter of the Sun is an approximate one.

54. Drawing

55. The top-most image is the first in the sequence and the upper most is the last. A solar eclipse will occur only at new Moon when the Moon and Sun are in the same part of the sky. As the Earth rotates, the Sun appears to set in the West, while the Moon moves toward the East creating the illusion that they pass by each other as seen in Figure1-29.

56. Light from the Sun reflected off the Earth can illuminate the Moon when it is in the new phase.

Discussion Questions

57. It is doubtful that the ancients knew of telescopes (*Telescopium*) and microscopes (*Microscopium*), to name two. These constellations are generally located too far south to be seen from the Mediterranean area. Various American Indian groups had their own unique names for the constellations, as did Chinese astronomers.

58. Eclipse paths move west to east as well as moving north and south. Since South Africa is nearly due south of the British Isles, an eclipse visible in England cannot be observed in South Africa, or vice versa. Starting at either location, the eclipse would pass much farther east of the other.

59. The reddish look of the Moon during a lunar eclipse is due to sunlight passing around the Earth's atmosphere and then scattering off the Moon. Without the atmosphere, we would see a gray Moon throughout the eclipse. The Earth's shadow would also be sharper if Earth lacked an atmosphere, so we would see the Moon passing from the penumbra to the umbra and back as more sharply defined events.

60. Many people never see an eclipse when the path is over sparsely populated areas, or over the oceans. The next widely visible eclipse in the United States is not until August 21, 2017.

What If . . .

61. You would still see phases. Eclipses would still be possible when the Moon crosses the ecliptic.

62. If the Earth had no tilt, there would be no seasons anywhere on the Earth. The Sun would be up for ½ the day everywhere except the poles, and daytime and nighttime would be of equal length. At the poles the Sun would never set and circle endlessly around the horizon. With a 45° tilt, the Sun would rise directly overhead for an observer at 45° north latitude on June 21 and directly overhead for an observer at 45°south latitude on December 21. More locations on the Earth would be Tropical and the increased tilt would increase the difference in the average temperatures between summer and winter. Similarly, at the poles, the seasons would be more severe. Aside from a shorter sunrise and sunset, the day-night cycle would remain the same.

63. As one side of the Moon always faces the Earth, the Earth will remain nearly motionless in the sky. You would see the Earth rotate nearly 15 times during the lunar day. The phases of Earth would be similar to the phases of the Moon, but they would be opposite to each other: when the Earth saw a full Moon, you would see a "new" Earth.

64. If the Moon did not rotate with respect to the celestial sphere, we would see the entire surface in the course of a lunar month. Since this isn't the case, we can conclude that the Moon must rotate with a period equal to the Moon's orbital period.

Web Questions

Answers will vary.

Got It? Questions

Answers provided in the back of the book.

Observing Projects

80. Answers in this question are specific to the observer's location and time of observation.

81.

(a) Angle between Merak and Dubhe is 5° 22'.

(b) Angle between Dubhe and the Pole Star is 28° 42'.

(c) Number of pointer-star spacings between Dubhe and the pole is about 5.4.

(d) Angle between NCP and Pole Star is about 40'.

(e) Angle between the pole and the horizon, (the Altitude of the pole star) is about 51°.

(f) This angle is equal to the latitude of the observer at Calgary.

(g) Angle between Gacrux and Acrux is 6°.

(h) Angle between Acrux and the S Pole is 26° 40'.

(i) Number of pointer-star spacings between Acrux and the S pole is approximately 4.4.

(j) Angle between the South Pole and the horizon at Brisbane is about 27°.

(k) This angle is equal to the latitude of the observer at Brisbane.

82.

(a) The zodiacal constellation Leo is flanked by Virgo to the east and Cancer to the west.

(b) The Sun's position on a specific day will depend upon time and date.

(c) The Sun will follow the zodiac on the following schedule: Sagittarius/ Jan 19/Capricorn/Feb 16/Aquarius/Mar 11/Pisces/Apr 18/Aries/Taurus/Jun 21/Gemini/Jul 20/Cancer/Aug 11/Leo/Sept 17/Virgo/Oct 31/Libra/Nov 23/Scorpius/Nov 29/Ophiuchus/Dec 18/Sagittarius.

(d) No, the Sun will be seen in the same constellations from both hemispheres.

83.

(a) Stars move counterclockwise.

(b) Answer is location-dependent. Observers at locations at mid-latitudes will see some circumpolar stars. Observers close to the equator will see very few if any circumpolar stars.

(c) Answer (ii). The limiting declination is equal to (90° – latitude).

(d) No circumpolar stars are seen in a direction opposite to the celestial pole in either hemisphere.

If your course meets in the wintertime when Orion is visible, look at the Orion Nebula with binoculars. Use *Starry Night*™ to visualize Orion from Australia. "Down Under" he stands on his head!

The USNO Web site has very useful information on time, calendars, seasons, and phases of the Moon. One could have an entire assignment or lab activity devoted to exploring this site. If your course has a Web page, you might want to include a link to the USNO Web site: aa.usno.navy.mil/

The current time is available at tycho.usno.navy.mil/cgi-bin/anim.

A reprint of *Calendars* from the *Explanatory Supplement to the Astronomical Almanac* by L. E. Doggett is available at astro.nmsu.edu/~lhuber/leaphist.html.

Fred Espenak's Web site is a superb source of detailed data on eclipses. Eclipse Home Page (Fred Espenak): eclipse.gsfc.nasa.gov/eclipse.html. The *Sky & Telescope* Web site also contains excellent information on future eclipses.

It may be necessary to go on an eclipse cruise to have a good view of an eclipse for the next several years.

U.S. Naval Observatory, Phases of the Moon: aa.usno.navy.mil/data/docs/MoonPhase.php

The Web site of the award-winning radio program *Earth & Sky*, earthsky.org/, is another good source of night sky information. Consult the *Earth & Sky* Web site for the location of radio stations broadcasting the program.

Notes