Answers to Chapter Review Questions and Problems for The Amateur Astronomer's Introduction to the Celestial Sphere

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Chapter 1

The lure of the sky

There are no review questions in this chapter.

Chapter 2

Location and coordinates

Questions for review and further thought

1. What do we mean by a coordinate system's origin?

   Answer: The origin is the point at which all distance measurements along the reference lines begin. While the origin is usually labeled with a zero (0) and located at the center of the coordinate space, these conditions are not required.

2. How many dimensions (coordinates) are required to map the sky, as seen from Earth?

   Answer: Two. We treat the sky as if it were mapped onto the inside of a two-dimensional surface we call the *celestial sphere*. We know that space is three dimensional, that is, there is a distance to the stars, but we do not need to know the distance to a star in order to point our telescopes at it.

3. What are the three basic units of measure for angles, and how are they related to each other?

   Answer: The three basic units are degrees, minutes and seconds. There are 360 degrees in a circle, 60 minutes in a degree and 60 seconds in a minute. These relations originated in ancient Babylon.

4. Describe the position and orientation of the celestial sphere relative to the Earth.

   Answer: The celestial sphere is positioned concentric with the Earth and oriented such that they share a common axis of rotation (and thus have aligned poles and equators).

5. What are the names of the two coordinates used in the horizon coordinate system? Describe the measurement made by each coordinate.

   Answer: *Azimuth* is measured in degrees along the horizon starting with due north at $0°$. *Altitude* is measured along a zenith meridian, in degrees from the horizon at $0°$ to the zenith at $+90°$.

6. What is the meaning of negative altitude?

   Answer: When the altitude is negative, the object of interest is below the observer's horizon.

7. Where (at what altitude) is the zenith? Describe its location relative to the observer.

   Answer: The zenith is at altitude $+90°$, straight above the observer's head. A plumb-line would extend from the zenith to the nadir (ignoring the effects of the Earth's rotation).

8. What is the range of possible values for altitude?

   Answer: Altitude may range from $-90°$ at the nadir, to $0°$ at the horizon, to $+90°$ at the zenith.

9. Describe a quadrant. What coordinate does it measure?

   Answer: A quadrant is a device that uses a sight-guide (perhaps a simple wooden stick) with a quarter-circle (hence the name) angle measure (such as a protractor). It is used to measure the altitude of an object (in the horizon coordinate system).

10. What is the possible range of values for azimuth? Along what line is it measured?

    Answer: Azimuth ranges from $0°$ (due north) to $360°$ (returned to due north) increasing eastward, along the observer's horizon. Although in some situations it may be more convenient to use due south as the origin of the system.

11. What are the azimuth angles for the eight major compass points?

    Answer: When using due north as the origin, north = $0°$, north-east = $45°$, east = $90°$, south-east = $135°$, south = $180°$, south-west = $225°$, west = $270°$, north-west = $315°$. When using due south as the origin, south = $0°$, south-west = $45°$, west = $90°$, north-west = $135°$, north = $180°$, north-east = $225°$, east = $270°$, south-east = $315°$.

12. Why do the altitude and azimuth of a star depend on the date, time and location of the observer?

    Answer: They depend on time because the Earth is rotating, causing the sky to appear to move from east to west on a minute to minute basis. They depend on date because the Earth is orbiting the Sun, causing the positions of all objects to migrate from east to west on a daily basis. They depend on (Earthly) location because the horizon determines the object's azimuth and altitude, and the horizon is unique to each observer (because the horizon is defined by the zenith, which is unique to each observer).

13. Describe an observer's *local meridian*. Why is every observer's local meridian unique?

    Answer: The local meridian is a line drawn from due north on the horizon, through the observer's zenith, to due south on the horizon. Every observer's local meridian is unique because every observer's zenith is unique.

14. What are the names of the coordinates of the equatorial coordinate system and how are they measured?

    Answer: *Right ascension* is measured in units of time (hours, minutes and seconds) along the celestial equator. *Declination* is measured in degrees, minutes and seconds along a celestial sphere meridian (passing through the object).

15. How is the altitude of a celestial pole (north or south) related to an observer's latitude? (Discuss both hemispheres.)

    Answer: In the northern hemisphere, the altitude of the north celestial pole is equal to the observer's latitude and the altitude of the south celestial pole is equal to the negative of the observer's latitude. In the southern hemisphere, the altitude of the south celestial pole is equal to the observer's latitude and the altitude of the north celestial pole is equal to the negative of the observer's latitude.

16. Describe the imagined view of the celestial equator for a naked-eye observer. (Discuss both hemispheres and both poles.)

    Answer: For northern hemisphere observers, the celestial equator rises off the horizon from due east, crosses the local meridian in the southern sky, and sets on the horizon due west. For southern hemisphere observers, the celestial equator rises off the horizon from due east, crosses the local meridian in the northern sky, and sets on the horizon due west. At either pole, the celestial equator matches the horizon.

17. How is the altitude of the celestial equator (on the local meridian) related to an observer's latitude? (Discuss both hemispheres.)

    Answer: In either hemisphere, the altitude of the celestial equator as it crosses the local meridian is equal to 90° minus the observer's latitude. In the northern hemisphere this altitude is measured off due south on the horizon. In the southern hemisphere this altitude is measured off due north on the horizon.

18. In what region of the Earth would an observer be if the altitude of Polaris is negative?

    Answer: In the southern hemisphere.

19. Why does the *equatorial chart*s declination stop at ±60°?

    Answer: Because with this type of (rectangular) plot, the polar region constellations would be too distorted to be recognizable. Polaris, being so close to the celestial pole, would be stretched out to a large ellipse. It is better to use a polar plot when near the celestial poles.

20. What is a sidereal clock?

    Answer: A sidereal clock keeps time with reference to the stars. If the sky were observed every 24 sidereal hours, the stars would not have a seasonal motion (but the Sun would).

21. What are the equatorial system's advantages over the horizon system?

    Answer: It is nearly independent of time or date of the observation and of the observer's location (latitude and longitude). It is not completely independent because of the Earth's precessional motion and because of the stars' proper motion.

22. What is the meaning of "Epoch 2000.0" on a star chart?

    Answer: It means that the equatorial coordinates of the objects shown on the chart have been updated to 1 January of the year 2000.

Review problems

1. If Polaris has an altitude of +32°, what is the observer's latitude?

   Answer: Because Polaris is near the north celestial pole, the altitude of Polaris is approximately equal to the observer's latitude, 32° N.

2. An observer is located at latitude 38° N and longitude 79° W. Calculate the altitude of Polaris (the altitude of the north celestial pole), the altitude of the south celestial pole and the altitude of the celestial equator for this observer.

   Answer: The altitude of Polaris is nearly equal to that altitude of the north celestial pole which is equal to the observer's latitude, 38°. The altitude of the south celestial pole is equal to the observer's latitude but negative, −38°. The altitude of the celestial equator is 90° − the observer's latitude, $90° - 38° = 52°$ off the southern horizon. The longitude is irrelevant.

3. Rework problem 2 for an observer located at latitude 38° N and longitude 92° W. How do the results compare?

   Answer: The altitude of Polaris is nearly equal to that altitude of the north celestial pole which is equal to the observer's latitude, 38°. The altitude of the south celestial pole is equal to the observer's latitude but negative, −38°. The altitude of the celestial equator is 90° − the observer's latitude, $90° - 38° = 52°$ off the southern horizon. The results are the same, longitude is irrelevant.

4. Rework problem 2 for an observer located at latitude 46° N and longitude 95° E. How do the results compare?

   Answer: The altitude of Polaris is nearly equal to that altitude of the north celestial pole which is equal to the observer's latitude, 46°. The altitude of the south celestial pole is equal to the observer's latitude but negative, $-46°$. The altitude of the celestial equator is 90° $-$ the observer's latitude, $90° - 46° = 44°$ off the southern horizon. The longitude is irrelevant. The observer is farther north so Polaris is higher in the sky and the celestial equator is lower.

5. Rework problem 2 for an observer located at latitude 38° S and longitude 30° E. How do the results compare?

   Answer: In the southern hemisphere, the altitude of Polaris is nearly equal to that altitude of the north celestial pole which is equal to the observer's latitude, but is negative, $-38°$. The altitude of the south celestial pole is equal to the observer's latitude, 38°. The altitude of the celestial equator is 90° $-$ the observer's latitude, $90° - 38° = 52°$ off the northern horizon. The longitude is irrelevant. For southern hemisphere observers, the celestial equator crosses the northern sky.

6. Calculate the altitude of the celestial equator for an observer at either of the Earth's poles. Which important skyline does the celestial equator match when standing on the poles?

   Answer: The altitude of the celestial equator is $90°-$ the observer's latitude. At the poles, the latitude is 90° N or 90° S. So, $90°-90° = 0°$. The celestial equator matches the horizon. Because the intersection of the celestial equator with the horizon is in this case, continuous rather than (duo)valued, there is no east or west when standing on the Earth's poles.

Chapter 3

Stars and constellations

Questions for review and further thought

1. What are stars and how do they relate to our sun?

   Answer: Stars are other suns. Our sun is a star. A longer definition of a star is that it is a self-luminous sphere of gas (or plasma) deriving its energy from nuclear reactions in its core.

2. What are constellations? How are they defined?

   Answer: Constellations are recognizable patterns of stars usually named for important elements of a culture. In modern astronomy, they are defined by their borders.

3. How many official constellations are there?

   Answer: There are 88 constellations as declared and defined by the International Astronomical Union.

4. How are constellations named?

   Answer: They are named for things that are important to our cultures.

5. What are the ancient constellations? Where did they come from?

   Answer: The ancient constellations are those 48 constellations that are named in Claudius Ptolemy's *Almagest*. Most of them are linked to Greek Mythology, but their true origins are mostly unknown.

6. Where are most of the modern constellations found?

   Answer: Most of the modern constellations are found in the southern hemisphere – at declinations where the Greeks could not see.

7. What is the original intent of constellations?

   Answer: To honor or represent people, deities, animals or things important to a culture.

8. How does modern Astronomy use constellations?

   Answer: To designate regions of the sky, making it easier to label and find specific objects such as stars, nebulae and galaxies.

9. How many stars do not belong to a constellation?

   Answer: Every star belongs to a constellation. There are no stars that do not belong to a constellation, although there are a couple of stars that are on the border and thus shared by two constellations.

10. What is an asterism? How does it differ from a constellation?

    Answer: An asterism is a recognizable pattern of stars, but not one of the 88 defined constellations. Constellations are defined by their boundary and asterisms are defined (and named) by their stick figures.

11. What do we mean by a star's *proper* name?

    Answer: This is the name given to a star by the ancient Greek or Arabic astronomers, such as, "Rigel" or "Betelgeuse."

12. What problems are created by using proper names for stars?

    Answer: First, there is a limited number of proper names available. Second, some stars were given the same name or very similar names, leading to the obvious kinds of confusion. Third, some names became too long to be practical for star maps.

13. How are Greek letters assigned to the stars within the Bayer designation system of star naming?

    Answer: The letters are assigned alphabetically in order of the apparent brightness of the stars within the constellation.

14. Describe a binary or double star system.

    Answer: A binary or double star system is one where two stars are orbiting each other, gravitationally bound to each other.

15. What is *apparent magnitude*?

    Answer: Apparent magnitude (symbol, m) is a comparative measure of a star's brightness as seen from Earth.

16. Who invented the apparent magnitude scale? When did he invent it?

    Answer: The ancient Greek astronomer, Hipparchus invented the apparent magnitude scale in about 150BC as part of his new star catalog.

17. How is the relationship between apparent magnitude and apparent brightness defined?

    Answer: A difference of five magnitudes corresponds to a ratio in brightness of 100. A star whose apparent magnitude is 1 provides 100 times more energy to our eyes that a star whose apparent magnitude is 6.

18. List the three kinds of twilight, describe the observation conditions they create, and describe the position of the Sun that defines them.

    Answer: The tree types are civil, nautical and astronomical. Civil twilight is that period where the center of the Sun is between $0°$ and $-6°$ in altitude. The brightest stars can be seen and the sea horizon is clearly defined. Nautical twilight is that period where the center of the Sun is between $-6°$ and $-12°$. The sea horizon can no longer be seen and altitude measurements with reference to the horizon for navigation can no longer be made. Astronomical twilight is that period where the Sun is between $-12°$ and $-18°$. The scattered sunlight is less than the average starlight and is about the same brightness as the aurora or zodiacal light.

19. List and describe the terms we use for the description of observation conditions.

    Answer: Probably should have used the term "atmospheric conditions" rather than "observation conditions." The three are: sky brightness, transparency and seeing. These are usually used with telescopic observation rather than naked-eye observation. Sky brightness is caused by aurora, moonlight and light pollution. It interferes with deep sky observations. Transparency is the optical clarity of the atmosphere − it is determined by clouds, humidity and particulates. Seeing is a description of our ability to see finer details in extended objects, such as the Moon or the planets.

20. What is a star catalog? What general information does it provide?

    Answer: A star catalog is an orderly listing of the stars, usually ordered by position but not necessarily, describing their characteristics such as apparent magnitude, color and so forth.

Review problems

1. Star A has $m = +4$ and star B has $m = +3$. Which is brighter? What is the ratio of their brightness?

   Answer: Star B has the lower magnitude number so it is the brighter. The difference in their magnitudes is 1, and from table 3.4, the ratio of their brightness is 2.512.

2. Star A has $m = +5$ and Star B has $m = +1$. Which is brighter? What is the ratio of their brightness?

   Answer: Star B has the lower magnitude number so it is the brighter. The difference in their magnitudes is 4, and from table 3.4, the ratio of their brightness is 39.81.

3. Star A has $m = +2$ and Star B has $m = -1$. Which is brighter? What is the ratio of the brightness?

   Answer: Star B has the lower magnitude number so it is the brighter. The difference in their magnitudes is 3, and from table 3.4, the ratio of their brightness is 15.85.

4. Star A has $m = -1$ and star B has $m = +6$. Which is brighter? What is the ratio of their brightness?

   Answer: Star A has the lower magnitude number so it is the brighter. The difference in their magnitudes is 7, and from table 3.4, the ratio of their brightness is 631.

5. Star A has $m = +2.3$ and star B has $m = +3.6$. What is the ratio of the brightness?

   Answer: See Appendix A, p. 230 for the formula (A.5) to solve this problem. Using star A as star 1 and star B as star 2 in the formula, we have

   $$\frac{f_1}{f_2} = 2.512^{-(m_1-m_2)} = 2.512^{-[+2.3-(+3.6)]} = 2.512^{1.3} = 3.3$$

   This means that star A is 3.3 times brighter than star B.

6. Star A has $m = -0.7$ and star B has $m = +2.62$. What is the ratio of their brightness?

   Answer: See Appendix A, p. 230 for the formula (A.5) to solve this problem. Using star A as star 1 and star B as star 2 in the formula, we have

   $$\frac{f_1}{f_2} = 2.512^{-(m_1-m_2)} = 2.512^{-[(-0.7)-(+2.63)]} = 2.512^{3.33} = 21.5$$

   This means that star A is 21.5 times brighter than star B.

7. Verify the calculation of energy flux for an $m = 0$ magnitude star given in the simplistic calibration section on p. 53.

   Answer: See Appendix A, p. 230 for the formula (A.5) to solve this problem. Using the zero magnitude star as star 1 and the Sun as star 2 in the formula, we have

$$\frac{f_1}{1340\ \mathrm{W/m^2}} = 2.512^{-[0-(-26.73)]} = 2.512^{-26.73} = 2.03 \times 10^{-11}$$

   Then,

$$f_1 = 1340\ \mathrm{W/m^2}\ (2.03 \times 10^{-11}) = 2.7 \times 10^{-8}\ \mathrm{W/m^2}$$

   .

Chapter 4

Motions of the Earth

1. Why do the constellations not change their shape (stick figure) over a year's time?

   Answer: Any change in the shape of a constellation is due to the proper motion of the stars. This motion is so slow, that it requires hundreds of years for any noticeable change (by naked-eye) in the constellations.

2. List and briefly describe the four major motions of the Earth.

   Answer: The four major motions are: diurnal – the daily rotation of the Earth on its axis; annual – the orbital motion of the Earth around the Sun; precession – the "wobble motion" of the Earth caused mainly by the tidal forces of the Moon; and nutation – a "bobbing motion" caused by many factors in the Earth's structure and other gravitational interactions.

3. Describe the basic diurnal motion of the stars in the night sky, particularly for your latitude.

   Answer: The stars, along with all other celestial objects, rise in the east and set in the west each day. Further details are linked to the observer's latitude. In the northern hemisphere the observer sees circumpolar stars in the northern sky and southern hemisphere observers see circumpolar stars in the southern sky. Observers on the Equator do not see any circumpolar stars.

4. For regions north or south of the equator, there are some stars that never set (go below the horizon). What are these stars (as a class) called? Describe their motion.

   Answer: They are called "circumpolar stars." Their diurnal paths are parallel to the celestial equator but appear as circles centered on the celestial pole.

5. Describe and compare the diurnal motion of the stars as observed when standing at latitudes 45° N and 45° S. Include a description of the appearance of the celestial equator.

   Answer: At 45° N: In the northern sky, the circumpolar stars rotate around the NCP counterclockwise. In the eastern sky, the stars rise on paths parallel to the celestial equator, slanting to the right. The celestial equator meets the horizon at an angle of 45°. In the southern sky the stars rise in the southeast and set in the southwest, traveling paths parallel to the celestial equator. The transit altitude of the celestial equator is 45°. In the western sky, the stars set on paths parallel to the celestial equator, which meets the horizon at a 45° angle slanting to the left.

   At 45° S: In the northern sky, the stars rise in the northeast and set in the northwest, traveling paths parallel to the celestial equator. The transit altitude of the celestial equator is 45°. In the eastern sky, the stars rise on paths parallel to the celestial equator, slanting to the left. The celestial equator meets the horizon at an angle of 45° slanting to the left. In the southern sky the circumpolar stars rotate around the SCP clockwise. In the western sky, the stars set on paths parallel to the celestial equator, which meets the horizon at a 45° angle slanting to the right.

When comparing northern and southern hemisphere views, the circumpolar stars are on opposite horizons and move in opposite directions. The star paths on the eastern and western horizons are slanted in opposite ways, relative to the horizon.

6. What are we talking about when discussing an object's upper and lower culmination?

   Answer: The upper culmination is the object's altitude when it crosses that half of the meridian which contains the zenith. The lower culmination is the object's altitude when it crosses that half of the meridian which contains the nadir. The division points between these meridian halves are the celestial poles.

7. Describe the procedure for finding the upper and lower culminations of a circumpolar object for northern hemisphere observers.

   Answer: First verify that the object is indeed circumpolar. For this, the distance between the object and the celestial pole (the polar distance, D_{polar}) must be less than the distance between the celestial pole and the observer's horizon (A_{NCP}). Calculate the polar distance of the object by subtracting its declination (δ_{object}) from the declination of the NCP (+90°).

   $$D_{polar} = +90^\circ - \delta_{object}$$

   The polar distance must be less than the polar altitude. The altitude of the NCP is equal to the observer's latitude (λ).

   $$D_{polar} < A_{NCP} \quad or \quad D_{polar} < \lambda$$

   If this inequality is true, the object is circumpolar.

   Both culminations are measured from the north point of the horizon. The upper culmination (A_{UC}) is found by adding the polar distance to the altitude of the NCP.

   $$A_{UC} = A_{NCP} + D_{polar}$$

   The lower culmination (A_{LC}) is found by subtracting the polar distance from the altitude of the NCP.

   $$A_{LC} = A_{NCP} - D_{polar}$$

   If the upper culmination is greater than 90° then subtract the result from 180° and measure the altitude from the southern horizon.

8. Describe the procedure for finding the transit altitude of objects for an observer at the Equator.

   Answer: The celestial equator transits the local meridian at the zenith. Subtract the absolute value of the object's declination from 90°.

   $$A_{object} = 90^\circ - \mid \delta_{object} \mid$$

   If the object's declination is positive, then the result is its transit altitude as measured from the northern horizon. If the declination is negative, the altitude is measured from the southern horizon.

9. Describe the procedure for finding the upper and lower culminations of a circumpolar object for southern hemisphere observers.

   Answer: First verify that the object is indeed circumpolar. For this, the distance between the object and the celestial pole (the polar distance, D_{polar}) must be less than the distance between the celestial pole and the observer's horizon (A_{SCP}). Recalling that objects located south of the celestial equator have negative declination, calculate the polar distance of the object by subtracting the declination of the SCP ($-90°$) from its declination (δ_{object}).

$$D_{polar} = \delta_{object} - (-90°) = \delta_{object} + 90°$$

The polar distance must be less than the polar altitude. The altitude of the SCP is equal to the observer's latitude (λ).

$$D_{polar} < A_{SCP} \quad or \quad D_{polar} < \lambda$$

If this inequality is true, the object is circumpolar.

Both culminations are measured from the south point of the horizon. The upper culmination (A_{UC}) is found by adding the polar distance to the altitude of the SCP.

$$A_{UC} = A_{SCP} + D_{polar}$$

The lower culmination (A_{LC}) is found by subtracting the polar distance from the altitude of the SCP.

$$A_{LC} = A_{SCP} - D_{polar}$$

If the upper culmination is greater than 90° then subtract the result from 180° and measure the altitude from the northern horizon.

10. Describe the annual motion of the stars. What direction do they move? How fast do they move?

    Answer: The annual motion of the stars requires time to be measured relative to the Sun. This causes the stars (apparently) to move from east to west at the rate of approximately one degree per day.

11. Compare the annual motion of the Big Dipper with the annual motion of the Southern Cross.

    Answer: Because they are both part of the celestial sphere, their motions are identical except for the (apparent) direction. The Big Dipper orbits the NCP counterclockwise (east to west) while the Southern Cross orbits the SCP in the clockwise (east to west) direction (because the observer turned around).

12. Describe the diurnal motion of the Sun.

    Answer: The apparent daily motion of all celestial objects is caused by the actual daily motion of the Earth. Therefore the daily motion of the Sun is the same as for all objects. It rises in the east and sets in the west each day, moving on a path that is parallel to the celestial equator. The only exception to this general description is at certain latitudes near the Earth's poles, where for some period of the year the Sun becomes circumpolar and then has a daily path similar to other circumpolar objects.

13. Define one *solar day*.

    Answer: The time it takes for the Sun to move from the local (or time zone) meridian, "around the Earth" and back to the local meridian.

14. Why is there a 30 minute variation in the duration of the solar day during the year?

    Answer: This variation is called the equation of time. It is caused by the variation in the Earth's orbital speed compared to its (almost) constant rotational speed and the obliquity of the ecliptic.

15. Describe the Sun's annual motion.

    Answer: Based in sidereal time, the Sun's apparent motion against the background stars is approximately one degree per day along the ecliptic line from west to east.

16. What is the apparent path of the Sun called?

    Answer: The ecliptic line.

17. At what rate does the Sun's position change along its apparent path?

    Answer: Based in sidereal time, approximately one degree per day.

18. Describe the location (on the celestial sphere) of the vernal equinox. On what date is the Sun found there?

    Answer: The vernal equinox is the point in the sky where the Sun crosses the celestial equator, from south (negative declination) to north (positive declination), during its annual motion, on or about 21 March.

19. What are those constellations through which the ecliptic passes called?

    Answer: The zodiac constellations.

20. What is the difference between a zodiac sign and a zodiac constellation?

    Answer: Each zodiac sign is a 30° segment measured from west to east along the ecliptic line, starting from the vernal equinox. A zodiac constellation is a region of the sky, defined by its borders, which happens to contain a segment of the ecliptic line.

21. Why do the dates of the Sun's entry into the zodiac constellations not match with the dates of its entry into the zodiac signs?

    Answer: The Earth's precessional motion has caused them to become misaligned. Three thousand years ago, when the zodiac was established, the signs and constellations were relatively well aligned.

22. How do we define our measure of the day or the year?

    Answer: These time periods are defined in terms of the Earth's rotation and orbital motion. Because these can change, we must constantly adjust our (constant) clocks to compensate.

23. What is universal time? Describe

    Answer: Universal Time (UT) is time kept according to the average time of the Sun's transit of the local meridian at Greenwich, England. Because the Sun's transit is ultimately due to the motion of the Earth, UT includes both the erratic rotation and the effects of any slight changes in the orbital motion of the Earth.

24. When and why were time zones established?

    Answer: They were needed because of our increasing ability to communicate and travel over long distances in short times. It was mainly the telegraph and railroad companies that brought the change to our way of keeping common time. By 1893, most of the world adopted Greenwich as the prime meridian and time zones as the standard of time keeping.

25. Describe the analemma.

    Answer: It is a plot of the equation of time against the declination of the Sun. It appears as a slightly misshapen figure 8 graphic on many world globes.

26. How is precession sometimes described?

    Answer: Precession is sometimes described as a "wobble motion."

27. What is *polar flattening*? How does it relate to equatorial bulge?

    Answer: Polar flattening is a result of the Earth's rotation. The polar diameter of a rotating planet or star is less than its equatorial diameter. It is equivalent to equatorial bulge.

28. What is the period of the Earth's precessional motion?

    Answer: The period is 25 982 years.

29. Define the north and south ecliptic poles.

    Answer: The north and south ecliptic poles are those points where the line perpendicular to the ecliptic plane passes through the celestial sphere.

30. Why hasn't Polaris always been our North Star?

    Answer: One of the results of the Earth's precessional motion is the movement of the position of the north celestial pole on the celestial sphere. As the pole moves on the sphere it comes closer to and moves away from various stars. It just happens to be near Polaris at the present.

31. Along which line of the celestial sphere are the equinoxes moving?

    Answer: They are moving from west to east along the ecliptic line.

32. List the effects of the motion of the vernal equinox.

    Answer: The right ascension and declination of all objects must be periodically updated. The calendar must be adjusted to keep the date of the vernal equinox from moving toward the beginning of March. The zodiac signs and constellations no longer match.

33. Explain the term *epoch*.

    Answer: Epoch, along with a year number, is used at the top of star charts (or star catalogs) to indicate the date for which the right ascension and declination of objects on the chart have been plotted.

Review problems

1. Determine if the following are circumpolar for latitudes higher than 40° N.

   Answer: In table form for clarity.

Object	**Declination**	**Test**	**Circumpolar?**
Polaris	$+89°$	$+89° >^? 90° - 40°$	Yes
Thuban	$+64°$	$+64° >^? 90° - 40°$	Yes
Mizar	$+55°$	$+55° >^? 90° - 40°$	Yes
Capella	$+46°$	$+46° >^? 90° - 40°$	No
Alberio	$+28°$	$+28° >^? 90° - 40°$	No
Altair	$+9°$	$+9° >^? 90° - 40°$	No

2. Determine if the following are circumpolar for latitudes lower than 40° S.

   Answer: In table form for clarity.

Object	Declination	Test	Circumpolar?
β Octantis	$-82°$	$-82° <^? 40° - 90°$	Yes
Volans	$-69°$	$-69° <^? 40° - 90°$	Yes
Achernar	$-57°$	$-57° <^? 40° - 90°$	Yes
Canopus	$-53°$	$-53° <^? 40° - 90°$	Yes
Columba	$-38°$	$-38° <^? 40° - 90°$	No
α Centauri	$-61°$	$-61° <^? 40° - 90°$	Yes

3. Calculate the upper (A_{UC}) and lower culmination (A_{LC}) of Altair for your latitude.

   Answer: The answer to this problem depends on the reader's latitude. Therefore, example calculations are shown.

   If the reader's latitude is 38° N: The altitude of the north celestial pole is 38° off the northern horizon. The declination of Altair is +9°. Altair's polar distance is then

$$D^{Altair}_{polar,38°N} = 90° - 9° = 81°$$

   The upper culmination is

$$A^{Altair}_{UC,38°N} = 38° + 81° = 119°$$

   from the northern horizon. This is greater than the maximum allowed value for altitude, which means we need to turn around to see Altair. Thus we have

$$A^{Altair}_{UC,38°N} = 180° - 119° = 61°$$

   from the southern horizon. This is also what we termed the *transit altitude* of Altair for this latitude ($90° - 38° + 9° = 61°$). The lower culmination is given by

$$A^{Altair}_{LC,38°N} = 38° - 81° = -43°$$

   from the northern horizon. Because this altitude is negative, the lower culmination of Altair is not visible at this latitude. Altair is not circumpolar.

   If the reader's latitude is 38° S: The altitude of the south celestial pole is 38° off the southern horizon. Altair's polar distance is then

$$D^{Altair}_{polar,38°S} = 9° - (-90°) = 99°$$

   The upper culmination is

$$A^{Altair}_{UC,38°S} = 38° + 99° = 138°$$

   from the southern horizon. This is greater than the maximum allowed value for altitude, which means we need to turn around to see Altair. Thus we have

$$A^{Altair}_{UC,38°S} = 180° - 138° = 42°$$

   from the northern horizon. This is also what we termed the *transit altitude* of Altair for this latitude ($90° - 38° - 9° = 42°$). The lower culmination is given by

$$A^{Altair}_{LC,38°S} = 38° - 99° = -61°$$

   from the southern horizon. Because this altitude is negative, the lower culmination of Altair is not visible at this latitude. Altair is not circumpolar.

   Note: The only way to get Altair to be circumpolar is to be at a latitude within 9° of the North Pole.

4. Calculate the transit altitude of Sirius for your latitude.

   Answer: The answer to this problem depends on the reader's latitude. Therefore, example calculations are shown.

   If the reader's latitude is 38° N: The altitude of the north celestial pole is 38° off the northern horizon. The declination of Sirius is $-17°$. Sirius' polar distance is then

   $$D^{Sirius}_{polar,38^\circ N} = 90^\circ - (-17)^\circ = 107^\circ$$

   The upper culmination is

   $$A^{Sirius}_{UC,38^\circ N} = 38^\circ + 107^\circ = 145^\circ$$

   from the northern horizon. This is greater than the maximum allowed value for altitude, which means we need to turn around to see Sirius. Thus we have

   $$A^{Sirius}_{UC,38^\circ N} = 180^\circ - 145^\circ = 35^\circ$$

   from the southern horizon. This is also what we termed the *transit altitude* of Sirius for this latitude ($90^\circ - 38^\circ - 17^\circ = 35^\circ$). The lower culmination is given by

   $$A^{Sirius}_{LC,38^\circ N} = 38^\circ - 99^\circ = -61^\circ$$

   from the northern horizon. Because this altitude is negative, the lower culmination of Sirius is not visible at this latitude. Sirius is not circumpolar.

   If the reader's latitude is 38° S: The altitude of the south celestial pole is 38° off the southern horizon. Sirius' polar distance is then

   $$D^{Sirius}_{polar,38^\circ S} = -17^\circ - (-90^\circ) = 73^\circ$$

   The upper culmination is

   $$A^{Sirius}_{UC,38^\circ S} = 38^\circ + 73^\circ = 111^\circ$$

   from the southern horizon. This is greater than the maximum allowed value for altitude, which means we need to turn around to see Sirius. Thus we have

   $$A^{Sirius}_{UC,38^\circ S} = 180^\circ - 111^\circ = 69^\circ$$

   from the northern horizon. This is also what we termed the *transit altitude* of Sirius for this latitude ($90^\circ - 38^\circ - (-17^\circ) = 69^\circ$). The lower culmination is given by

   $$A^{Sirius}_{LC,38^\circ S} = 38^\circ - 73^\circ = -35^\circ$$

   from the southern horizon. Because this altitude is negative, the lower culmination of Sirius is not visible at this latitude. Sirius is not circumpolar.

   Note: The only way to get Sirius to be circumpolar is to be at a latitude within 17° of the South Pole.

5. Calculate the transit altitude of the following objects for your latitude: Regulus, Arcturus, Great Square, Antares, Canopus, Achernar, Thuban, Fomalhout, Capricornus, Mizar. If the object is circumpolar, calculate its upper (A_{UC}) and lower culminations (A_{LC}).

   Answer: The answers are again dependant on the reader's latitude. The declinations are estimated off the charts.

   Example calculations for 38° N.

Object	**Circumpolar?**	**Transit Altitude or Upper Culmination**	**Lower Culmination**
Regulus	$+12° > 90° - 38°$, No	$52° + (+12°) = 64°$	N/A
Arcturus	$+19° > 90° - 38°$, No	$52° + (+19°) = 71°$	N/A
Great Square	$+22° > 90° - 38°$, No	$52° + (+22°) = 74°$	N/A
Antares	$-26° > 90° - 38°$, No	$52° + (-26°) = 26°$	N/A
Canopus	$-54° > 90° - 38°$, No	$52° + (-54°) = -2°$ (Not visible)	N/A
Achernar	$-57° > 90° - 38°$, No	$52° + (-57°) = -5°$ (Not visible)	N/A
Thuban	$+64° > 90° - 38°$, Yes	$38° + (90° - (+64°)) = 64°$	$38° - (90° - (+64°)) = 12°$
Fomalhaut	$-29° > 90° - 38°$, No	$52° + (-29°) = 23°$	N/A
Capricornus	$-20° > 90° - 38°$, No	$52° + (-20°) = 32°$	N/A
Mizar	$+55° > 90° - 38°$, Yes	$38° + (90° - (+55°)) = 73°$	$38° - (90° - (+55°)) = 3°$

   Example calculations for 38° S.

Object	**Circumpolar?**	**Transit Altitude or Upper Culmination**	**Lower Culmination**
Regulus	$+12° < 38° - 90°$, No	$52° - (+12°) = 40°$	N/A
Arcturus	$+19° < 38° - 90°$, No	$52° - (+19°) = 33°$	N/A
Great Square	$+22° < 38° - 90°$, No	$52° - (+22°) = 30°$	N/A
Antares	$-26° < 38° - 90°$, No	$52° - (-26°) = 78°$	N/A
Canopus	$-54° < 38° - 90°$, Yes	$38° + (90° + (-54°)) = 74°$	$38° - (90° + (-54°)) = 2°$
Achernar	$-57° < 38° - 90°$, Yes	$38° + (90° + (-57°)) = 71°$	$38° - (90° + (-57°)) = 5°$
Thuban	$+64° < 38° - 90°$, No	$52° - (+64°) = -12°$ (Not visible)	N/A
Fomalhaut	$-29° < 38° - 90°$, No	$52° - (-29°) = 81°$	N/A
Capricornus	$-20° < 38° - 90°$, No	$52° - (-20°) = 72°$	N/A
Mizar	$+55° < 38° - 90°$, No	$52° - (+55°) = -3°$ (Not visible)	N/A

6. Currently, it is 20:00 hours and the star Procyon is on the local meridian. What does the sidereal clock read? When (about) will Spica be on the local meridian?

   Answer: The right ascension of Procyon is about $7^{h}\,40'$. Thus the reading of the sidereal clock is 7:40. Spica's right ascension is about $13^{h}\,30'$. Because sidereal and solar hours are nearly the same, Spica will be on the local meridian in about 5 hours and 50 minutes, or at about 01:50 hours.

Chapter 5

The seasons

1. On what date (approximately) is the Earth farthest from the Sun?

   Answer: On or about 4 July.

2. In one sentence, why do we have seasons?

   Answer: Because the Earth's axis of rotation is tilted. Further discussion: The seasons occur because of two effects – the efficiency with which the Sun heats the earth and the length of daylight at the observer's latitude. Both of these effects are ultimately caused by the tilt of the Earth's rotational axis and so, the reason we have seasons is that the Earth's axis of rotation is tilted.

3. List the four important dates for the seasons.

   Answer: The four dates are the equinox and solstice dates: 21 March, 21 June, 21 September and 21 December.

4. What is the meaning of the term *equinox*?

   Answer: It means those days on which the duration of daylight and night are equal, for latitudes other than the Equator. It also means those points along the ecliptic where the Sun crosses the celestial equator.

5. Why does it happen that the date on which there is 12 hours of daylight and night (ignoring refraction) occur on the same date that the Sun is on the celestial equator?

   Answer: On these dates, the Sun is on the celestial equator and the diurnal motion of the Sun must (as always) be a path parallel to the celestial equator. The equator's passage through the horizon line defines the compass points, east and west. These are also the points where the "12-hour circle" passes through the celestial equator (by definition of the 12-hour circle). That is, only those objects with $0°$ declination are above the horizon for 12 hours (for all observer's except polar). When the Sun is at an equinox point, it is also above the observer's horizon for 12 hours. (Note: Not only are we ignoring refraction effects here, but we are also ignoring geocentric parallax.)

6. What is the origin and meaning of the word *solstice*?

   Answer: It is Latin for "Sun stand still."

7. Describe the main process by which the atmosphere is heated.

   Answer: Sunlight heats the ground and the ground heats the air.

8. At what (optical) angle does sunlight heat the ground most efficiently?

   Answer: At zero degrees to the normal. (The word "optical" was to prompt you to think of angular measure with respect to the normal, as is done in optics.) At this angle sunlight strikes the ground straight down.

9. Explain how ground heating causes the northern and southern hemispheres to have opposite seasons.

   Answer: The efficiency of ground heating is the result of the angle at which sunlight strikes the ground. The smaller the angle (with the normal to the ground) the greater the efficiency. When the Sun is high in the sky in the northern hemisphere (June) it is low in the sky in the southern hemisphere. This creates different angles with respect to the ground normal. The northern hemisphere is warmed and the southern hemisphere cools, creating opposite seasons.

10. What role does duration of daylight play in the seasons?

    Answer: The longer the duration of daylight, the longer the sun has to heat the ground. During the summer days the Sun is above the horizon for longer than 12 hours, giving the Sun more time to heat the ground as compared to the winter days when the Sun is above the horizon for less than 12 hours.

11. What other factors, besides the angle of the sunlight, affect the rate at which the Sun may heat the ground?

    Answer: Snow cover will affect efficiency because snow is very reflective. The composition of the ground itself also affects efficiency. Some earth materials (minerals) absorb more sunlight-energy than others. There are others.

12. Explain why people living at the Equator have 12-hour days throughout the year.

    Answer: At the Equator, the 12-hour circle matches the horizon. Thus, no matter what the declination of an object, it takes the object 12 hours to move from the eastern horizon to the western horizon. This is true for the Sun as well. Even though the Sun's declination is changing through the year, it always takes 12-hours to move from the eastern to the western horizon for observers standing on the Equator. The only effect the Sun's changing declination has for equatorial observers is to change the azimuth of sunrise/set.

13. Explain how solar altitude and daylight duration are related to the seasons.

    Answer: In either hemisphere, during the summer months, the duration of daylight is long and the Sun is high in the sky. This combination warms the earth efficiently and causes the long, warm summer days. During the winter months, the Sun is low in the sky and the duration of daylight is shorter. This combination does not heat the ground very well, creating the colder, winter weather.

14. Explain the effect called *seasonal lag*.

    Answer: Seasonal lag is the delay between the beginning of a season and the intensity of the type of weather associated with that season. It is caused by the fact that, for any given region on Earth, it takes time for heat to build up or to dissipate.

15. What is an *orbital plane*?

    Answer: An orbital plane is a mathematical plane containing the paths of two bodies in orbit about each other.

16. What is the *ecliptic plane*?

    Answer: The orbital plane of the Earth.

17. Explain how the ecliptic plane is used to define "up" and "down" in the solar system.

    Answer: If we are located above the ecliptic plane, then we can look "down" to see the Earth's north pole. If we are below the ecliptic plane, we can look "up" to see the Earth's south pole. The line, perpendicular to the ecliptic plane defines the vertical (up and down) of the solar system. This perpendicular line passes through the north and south ecliptic poles (NEP and SEP).

18. Explain how the Earth's axial tilt is related to (measured with reference to) the ecliptic plane.

    Answer: The Earth's rotational axis makes a $23^\circ.5$ angle with the line perpendicular to the ecliptic plane. This is also known as the "obliquity of the ecliptic."

19. Describe and explain the Tropic of Cancer and the Tropic of Capricorn.

    Answer: The Tropic of Cancer is a line drawn parallel to the Earth's equator at latitude $23^\circ.5$ N. The Tropic of Capricorn is a line drawn parallel to the Earth's equator at latitude $23^\circ.5$ S. These lines represent the farthest latitude, north or south, at which the Sun passes through the zenith at least once during the year.

20. Describe and explain the Arctic Circle and the Antarctic Circle.

    Answer: The Arctic Circle and the Antarctic Circle are located at $66^\circ.5$ N and $66^\circ.5$ S, respectively. The Arctic Circle designates the latitude above which the Sun never sets on the June solstice. This has also been called "the land of the midnight Sun." During the December solstice, this same region is in 24 hours of darkness – the Sun never rises. The Antarctic Circle represents the same events for the south polar regions, but for the opposite solstice dates.

21. Explain the phrase, "land of the midnight sun."

    Answer: It is the region above the Arctic Circle where during the June solstice the Sun never sets. That is, the Sun is above the horizon at midnight. Although this fanciful name is usually applied to the northern latitudes, it also describes the scene at latitudes below the Antarctic Circle during the December solstice.

22. Describe possible climate zones of the Earth, if the Earth's axis were not tilted.

    Answer: The equatorial regions would remain as hot as they are now. The polar regions would be somewhat colder, because they would never receive any solar radiation. The polar ice sheets would probably be larger. The temperate zones would not see the changes in weather patterns associated with the seasons. They would probably have weather similar to that currently associated with the spring or fall seasons – for any particular latitude, a mix of the typical weather seen on the equinox dates.

Review problems

1. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 75° N latitude.

    Answer: For this observer, the transit altitude of the celestial equator is $90^\circ - 75^\circ = 15^\circ$ off the southern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$15^\circ + 0^\circ = 15^\circ$	$15^\circ + (+23^\circ.5) = 38^\circ.5$	$15^\circ + 0^\circ = 15^\circ$	$15^\circ + (-23^\circ.5) = -8^\circ.5$ (The Sun is below the horizon all day.)

2. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 35° N latitude.

   Answer: For this observer, the transit altitude of the celestial equator is $90° - 35° = 55°$ off the southern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$55° + 0° = 55°$	$55° + (+23°.5) = 78°.5$	$55° + 0° = 55°$	$55° + (-23°.5) = 31°.5$

3. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 15° N latitude.

   Answer: For this observer, the transit altitude of the celestial equator is $90° - 15° = 75°$ off the southern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$75° + 0° = 75°$	$75° + (+23°.5) = 98°.5 \rightarrow 81°.5$ from northern horizon	$75° + 0° = 75°$	$75° + (-23°.5) = 31°.5$

4. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 15° S latitude.

   Answer: For this observer, the transit altitude of the celestial equator is $90° - 15° = 75°$ off the northern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$75° - 0° = 75°$	$75° - (+23°.5) = 31°.5$	$75° - 0° = 75°$	$75° - (-23°.5) = 98°.5 \rightarrow 81°.5$ from the southern horizon.

5. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 35° S latitude.

   Answer: For this observer, the transit altitude of the celestial equator is $90° - 35° = 55°$ off the northern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$55° - 0° = 55°$	$55° - (+23°.5) = 31°.5$	$55° - 0° = 55°$	$55° - (-23°.5) = 78°.5$

6. Calculate the transit altitude of the Sun on the four seasonal dates for an observer at 75° S latitude.

   Answer: For this observer, the transit altitude of the celestial equator is $90° - 75° = 15°$ off the southern horizon. A table shows the transit altitude for the Sun on each date.

21 March	21 June	21 September	21 December
$15° - 0° = 15°$	$15° - (+23°.5) = -8°.5$ (The Sun is below the horizon all day.)	$15° - 0° = 15°$	$15° - (-23°.5) = 38°.5$

7. Calculate the transit altitude of the Sun on the four seasonal dates for your latitude.

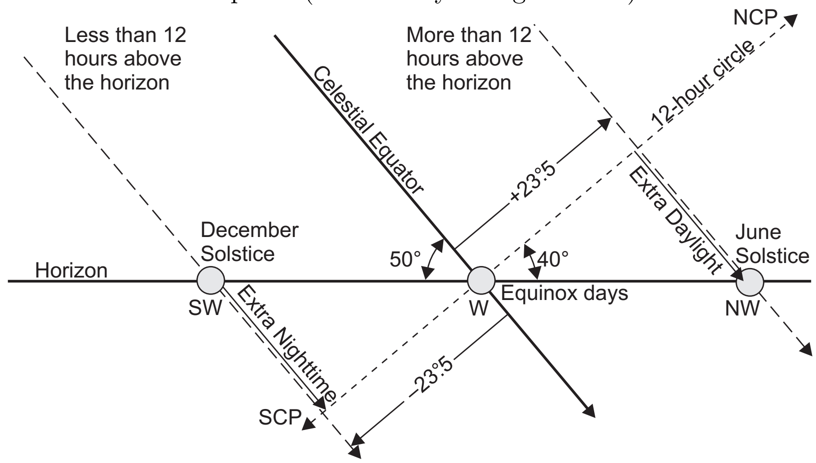
   Answer: This problem has unique solutions for each reader. Set up a table like those shown above.

8. Make a set of diagrams similar to Figures 5.2 through 5.12 for your city's latitude.

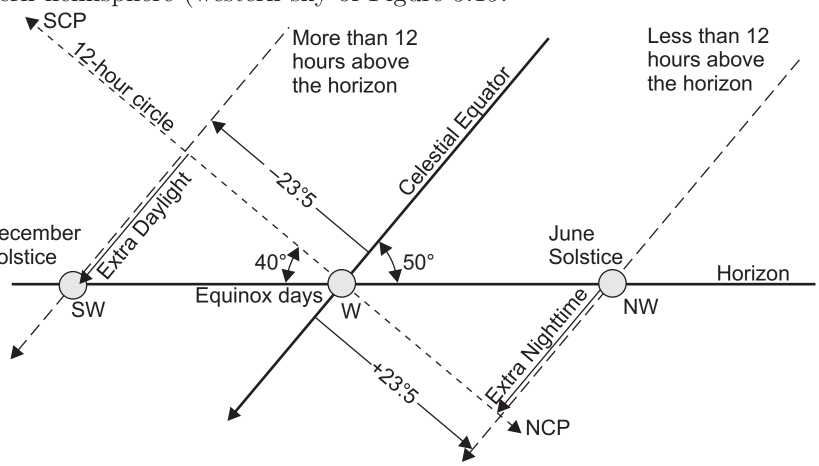
   Answer: This problem has unique solutions for each reader. Study the specified drawings carefully.

9. Make a drawing similar to Figures 5.18 and 5.19 for the western horizon.

   Answer: For the northern hemisphere (western sky of Figure 5.18:)



For the southern hemisphere (western sky of Figure 5.19:



Chapter 6

The phases of the Moon

Questions for review and further thought

1. What is the apparent diameter of the Moon?

   Answer: About one-half of one degree.

2. Describe the difference between terra and maria, as seen by naked-eye observation.

   Answer: Terra are the lighter colored areas: rocky, mountainous regions. Maria are the dark areas: flat-plains regions.

3. What type of event caused most of the craters?

   Answer: The impact of space debris (lunar meteorites).

4. Why does the Moon appear to be larger when near the horizon than when high in the sky?

   Answer: It is a mental illusion. Its size does not change.

5. Why does the Moon have a red/orange tint when it is near the horizon?

   Answer: This is an effect caused by the Earth's atmosphere, which removes most of the blue light from the image of the Moon, leaving the Moon with a reddish tint. It is the same process as that which causes a blue sky and a red sunset/rise – Rayleigh scattering.

6. Describe the diurnal motion of the Moon.

   Answer: The Moon has the same diurnal motion as all the other objects in the sky. It rises in the east and sets in the west traveling on a (daily) path that is parallel to the celestial equator. In the northern hemisphere its path lies mainly in the southern sky and in the southern hemisphere its path lies mainly in the northern sky. It could be argued that its daily path is not truly parallel to the celestial equator because its motion carries it about 12° along its orbital path, and its orbital path is inclined to the celestial equator. This generally small effect is being ignored here.

7. Why do we not see the Moon during the daytime as often as we see it during the night?

   Answer: This holds true even though the Moon is in the daytime day as much as it is in the nighttime sky (averaged across the year). As the Moon comes closer to the Sun it becomes a narrow crescent that is easily out shined by the glaring Sun. Also, the new Moon phase – when the Moon is in the same position as the Sun – can not be seen at all. Therefore, although the Moon is in the daytime sky as long as in the nighttime sky, its proximity to the Sun will not allow us to view the Moon during this entire time.

8. Why do we always see the same side of the Moon?

   Answer: Because the Moon is in a one-to-one synchronous orbit. Its rotational motion is synchronized to its orbital motion, thus keeping the same face toward Earth.

9. What is a synchronous orbit? Why did the Moon's orbital motion become synchronous?

   Answer: When the rotational motion of a moon (or planet) is synchronized to its orbital motion. This happens because of the tidal forces (studied in future book in this series) of the parent body acting on the moon. These tidal forces cause the rotational motion of the moon to decrease while the orbital path radius increases. Eventually the rotational motion and orbital motion become synchronous. The Moon's tidal forces are acting on the Earth. Many years from now the Earth's rotational motion will be synchronized to the Moon's orbital motion.

10. How much of the Moon's surface can we actually see form Earth?

    Answer: Because of the Moon's orbital characteristics, we can see about 59% of its total surface area.

11. Describe the apparent monthly motion of the Moon.

    Answer: The Moon's orbital motion makes it appear to move in our sky from west to east, close to the ecliptic line. Its orbital path carries it off the ecliptic by $5^\circ.1$ at most. Because the Moon is always so close to the ecliptic, we can see it only within the zodiac constellations (and because of the inclination of its orbit to the ecliptic, in a few neighboring constellations), taking on average slightly more than two days to pass through each constellation. The Moon crosses the ecliptic twice during each orbit around the Earth. The points where the Moon's path crosses the ecliptic are called nodes. They are 180° apart, on opposite sides of the sky.

12. How fast does the Moon move through the constellations? Through what set of constellations does the Moon move?

    Answer: On average, slightly more than two days for each constellation. Through mainly the zodiac constellations, but because of the slight inclination of its path to the ecliptic it also passes through a few neighboring constellations.

13. What is the length of the Moon's sidereal period?

    Answer: 27.32 days.

14. Define the sidereal period of the Moon.

    Answer: The sidereal period of the Moon is the length of time it takes to orbit the Earth, with reference to the stars.

15. What is the length of the Moon's synodic period?

    Answer: 29.53 days.

16. Define the synodic period of the Moon.

    Answer: The Moon's synodic period is the time between two successive new Moon phases (or any other particular phase, such as full).

17. About how quickly does the Moon move along its path (both sidereal and solar rates)?

    Answer: Its position changes by $13^\circ.18$ per day on average by sidereal reckoning, or $12^\circ.2$ per day on average by solar reckoning.

18. What is the average time difference between lunar risings on succeeding days?

    Answer: About 50 minutes.

19. What is a *lunar phase*?

    Answer: A lunar phase refers to the apparent shape of the Moon as seen from Earth.

20. Describe the lunar phases. Include the appearance from Earth, its rise/set times, its duration, the general time and sky location for best observation and a description of its orbital position.

    Answer: In list form:

    New Moon: As seen from Earth, the Sun and the Moon are in the same direction in the sky. This phase cannot normally be seen. The new Moon rises at sunrise and sets at sunset. It lasts about four hours. There is no best observation time because it can not be seen, except during a solar eclipse. In its orbit, the Moon is located on the Earth-Sun line.

    Waxing crescent Moon: Crescent shaped, sunlit on the west side with the "horns" of the crescent pointing away from the Sun. The waxing crescent rises just after sunrise and it sets just after sunset, but it is most easily seen just after sunset in the west. It lasts a little less than seven days. In its orbit, the Moon is located anywhere from 1° to 89° counterclockwise (seen from above the ecliptic plane) from the Earth-Sun line.

    First quarter Moon: Has the west half of the Moon sunlit. The first quarter Moon rises at noon and sets at midnight, lasting for a few hours. In the northern latitudes, this phase is seen close to the local meridian in the southern sky at sunset. In the southern latitudes, it is seen in the northern sky at sunset. The Moon is 90° counterclockwise (seen from above the ecliptic plane) away from the Sun.

    Waxing gibbous Moon: Has more than half of the west side of the Moon sunlit. The waxing gibbous rises in the afternoon and sets in the early morning. It is best seen in the evening to early morning western sky. It lasts a little less than seven days. In its orbit, the Moon is located anywhere from 91° to 179° counterclockwise (seen from above the ecliptic plane) from the Earth-Sun line.

    Full Moon: Has the face of the Moon fully sunlit. We can see "the man's entire face." When the Sun is setting in the west, the full Moon is rising in the east. As the full Moon sets in the west, the Sun rises in the east. The full Moon lasts only a few hours. This phase can only be seen at night, because we must be on the night-side of the Earth to see the Moon. In its orbit, the Moon is located 180° away from the Sun or, on the opposite side of the Earth from the Sun.

    Waning gibbous Moon: Has more than half of the east side of the Moon sunlit. The waning gibbous rises in the east before midnight and sets in the west after sunrise, but before noon. It is best seen in the late evening to morning eastern sky. It can also be seen in the western sky during the morning hours of daylight. It lasts a little less than seven days. In its orbit, the Moon is located anywhere from 181° to 269° counterclockwise (seen from above the ecliptic plane) from the Earth-Sun line.

    Third (or last) quarter Moon: Has the east half of the Moon sunlit. It rises at midnight and sets at noon. In the northern latitudes, this phase is seen close to the local meridian in the southern sky at sunrise. In the southern latitudes, it is seen in the northern sky at sunrise. It is probably best observed two hours before sunrise. This phase lasts only a few hours. The third quarter Moon is 270° ahead (or 90° behind) the Sun.

    Waning crescent Moon: Has less than half of the eastern side of the Moon sunlit. The Moon has a crescent shape. The "horns" of the crescent point away from the Sun. It lasts about seven days. This phase is best seen in the eastern sky in the morning hours. The waxing crescent is located anywhere from 271° to 359° ahead of the Sun (or 1° to 89° behind the Sun).

21. What is a *true new Moon*?

    Answer: The new Moon seen during a total solar eclipse.

22. When do we see a true full Moon?

    Answer: During a total lunar eclipse.

23. What is a blue Moon (in the calendrical sense)? How often do blue moons occur?

    Answer: The second full moon of the calendar month. Roughly every 2.5 to 3 years.

24. How long (how many days) is the lunar cycle of phases and how is the lunar cycle of phases related to the orbital period of the Moon?

    Answer: The cycle of phases takes a little less 30 days. The cycle of phases is related to the synodic period of the Moon's orbit around the Earth.

25. What group of people within most societies or cultures have been most responsible for the creation of calendars?

    Answer: Politicians and priests.

26. Who is the Julian calendar named for and what changes did he bring to calendars?

    Answer: Julius Caesar. It started on the day Roman magistrates took office, on 1 January. It had twelve months with each month alternating in length of 30 and 31 days except February, which had only 29, giving a total of 365 days. A leap day was added to the end of February every four years.

27. Describe the procedure for determining if a year is a leap year, under the Gregorian calendar.

    Answer: For any year except a century year (any year which is a multiple of 100), if the year is divisible by four, it is a leap year. For century years, the year must be divisible by 400.

28. What do the calendar designations CE and BCE mean and why are they used?

    Answer: CE means "common era" and BCE means "before the common era." These are used in cultures or situations where the calendar link with the birth of Christ is not made explicit.

29. Why does the calendar begin with the year one instead of zero?

    Answer: Because when the calendars were created they used the Roman numbering system which does not have zero.

30. What is the most probable reason for there being seven days in the week?

    Answer: They are named for the seven wandering stars (or planets). In the ancient world, the Sun and Moon were considered planets along with Mercury through Saturn. They were also thought to be gods and the days were named for these gods.

31. Describe the need for the International Dateline.

    Answer: To avoid confusion about the date when marking out time zones with increasing (or decreasing) hour counts. When one returns to the starting point when counting the hours, the date should return to the same value, as does the clock.

32. Describe the need for the Julian Day calendar.

    Answer: Determining the number of days between two dates on the civil calendar is not an easy task. The Julian Date, or Julian Day number (JD) is a continuous count of days starting from January 1, 4713 BC on the Julian proleptic calendar. The integral portion of the Julian Day refers to the instant of Greenwich mean noon, and the decimal portion is a partial of one day. Hours, minutes and seconds are not used. Using day numbers instead of dates makes the calculation between to days (and times) a simple matter of subtraction.

Review problems

1. Determine the sidereal rotation period of the Moon.

   Answer: Because the Moon is in a synchronized orbit, it sidereal rotation period is (nearly) equal to its sidereal orbital period – 27.32 days. There is a slight (periodic) difference that helps us to see a little more than 50% of the Moon's surface.

2. If the Moon happens to be at its positive maximum inclination from the ecliptic when its right ascension is $6^{h}\,0'$, calculate its transit altitude for an observer at latitude 35° N.

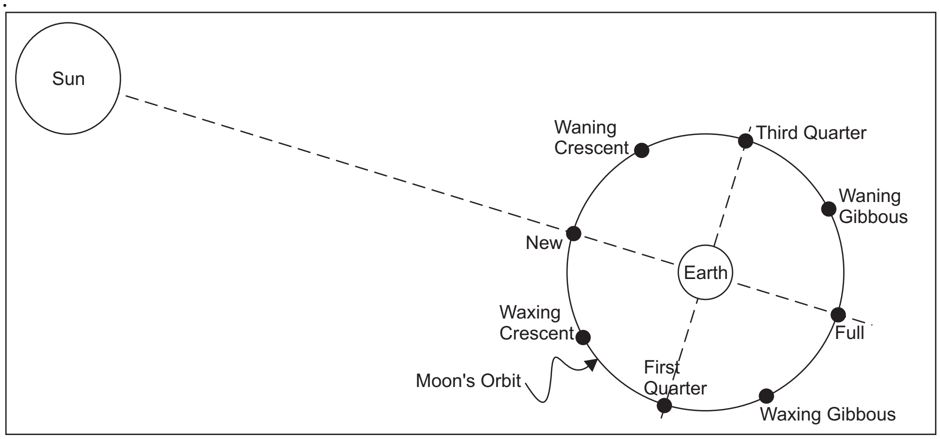
   Answer: For an observer at 35° N, the transit altitude of the celestial equator is $90° - 35° = 55°$. At maximum positive inclination, the Moon is 5°.1 above the ecliptic. The 6^{h} point on the ecliptic is the June solstice, which is 23°.5 above the celestial equator. Thus, the Moon's transit altitude for this case is $55° + 23°.5 + 5°.1 = 83°.6$ above the southern horizon.

3. If the Moon happens to be at a node when its right ascension is $18^{h}\,0'$, calculate its transit altitude for an observer at latitude 38°.5 S.

   Answer: If the Moon is at a node in its orbit, it is crossing the ecliptic. Therefore its transit altitude is the same as the ecliptic's transit altitude. Because this node happens to be at 18^{h}, which is also the December solstice, the transit altitude of the Moon is equal to the transit altitude of the December solstice. At 38°.5 S, the altitude of the celestial equator is $90° - 38°.5 = 51°.5$. The declination of the December solstice is $-23°.5$. Therefore, the transit altitude of the Moon for this scenario is $51°.5 - (-23°.5) = 75°$ off the northern horizon.

4. Using the figure shown below, draw the appropriate orbital position of the Moon for each of its phases and label each position with the phase name.

   Answer:



5. Determine which of the century years are leap years on the Gregorian calendar, between its inception and the year AD 4000.

   Answer: Those years divisible by 400: 1600, 2000, 2400, 2800, 3200, 3600, 4000.

Chapter 7

Eclipses

Questions for review and further thought

1. What causes eclipses?

   Answer: Eclipses are caused by the Moon passing through the Earth's shadow or the Earth passing through the Moon's shadow. In general, eclipses are cause by one object passing through the shadow of another object.

2. What are the two parts of a shadow? Describe them.

   Answer: The umbra and penumbra. The umbra is a region of total darkness, having a cone shape, coming to a point "behind" the object. The penumbra is a region of partial darkness, also with a cone shape, but spreads outward behind the object until gradually, the shadow no longer exists because the size of the blocking object is too small compared to the light source.

3. Why does a shadow have two parts?

   Answer: When the light source is not a point-sized light source, the shadow will have an umbra and penumbra.

4. What object disappears during a lunar eclipse?

   Answer: The Moon.

5. What object disappears during a solar eclipse?

   Answer: The Sun.

6. Describe the arrangement of the Sun, Moon and Earth during a lunar eclipse.

   Answer: The Moon is on the opposite side of the Earth from the Sun, passing through the Earth's umbra. They lie in a true, straight line.

7. Describe penumbral, partial and total lunar eclipses. Include a description of the path of the Moon and its appearance during the eclipse.

   Answer: Penumbral: The Moon passes through only the penumbral portion of the Earth's shadow. These lunar eclipses are barely noticeable. If all or a significant portion of the Moon is immersed in the penumbra, the Moon may lose a partial magnitude in brightness.

   Partial: Part of the Moon passes into the Earth's umbra. The curved shape of the Earth's shadow on the face of the Moon can easily be seen. The part of the Moon not inside the umbra is in the penumbra and has nearly the normal brightness of the full Moon.

Total: The Moon passes completely into the Earth's umbra, turning to a "coppery red color" during totality. It does not completely disappear.

8. Explain why the Moon turns red during a total lunar eclipse.

   Answer: The color comes from the refractive and scattering effects of the Earth's atmosphere. The sunlight glancing the Earth passes through the Earth's atmosphere (and particulate pollutants in the atmosphere). The atmosphere scatters the blue portion of the sunlight and allows the red sunlight through. This is the same atmospheric effect that causes the red/orange moonrise, but the effect is being used in a different way. This time the light passing through the atmosphere on its way to the Moon is scattered, where as with the moonrise it is the light coming from the Moon that is affected. The red and yellow portion of the spectrum that does make it through the atmosphere is refracted and dispersed just like a prism breaks sunlight into the visible spectrum. Because of this combination of scattering and refraction the Earth's umbra is not completely black at the Moon's distance from the Earth, but is actually red with slightly yellow edges. The Moon passes into the red light and this is the reason for its coppery-red color during a total lunar eclipse.

9. List and describe the stages of a lunar eclipse.

   Answer: The penumbra entry and exit points are generally the least important. First contact is when the eastern limb of the Moon first touches the western limb of the umbra and is the beginning of a total eclipse. Second contact is when the western limb of the Moon touches the western limb of the umbra and is the beginning of totality for the eclipse. The center point is when the Moon is at its darkest. Third contact is when the eastern limb of the Moon touches the eastern limb of the umbra and is the end of totality. Fourth contact is when the western limb of the Moon touches the eastern limb of the shadow and is the end of the total lunar eclipse.

10. There will come a time when total solar eclipses will no longer happen. Why?

    Answer: Because of the Moon's tidal forces acting on the Earth, the Earth's rotation rate is slowing down and this is causing the Moon to slowly recede from the Earth. Thus, its apparent size is gradually decreasing with time. Eventually, its apparent size will not be large enough to cover the entire solar disk and total solar eclipses will never occur again.

11. When is it safe to look directly at the Sun?

    Answer: Only during the totality portion of a total solar eclipse.

12. Why is it not safe to use a "homemade" solar filter?

    Answer: While these "filters" may darken the Sun to a comfortable level in visible light, they may allow non-visible light (infrared or ultraviolet) to pass through to your eyes. At the Sun's intensity, these light wavelengths will burn your eyes just as fast, or faster than visible light.

13. Describe the relationship between an observer's location in the shadow path and the observed solar eclipse.

    Answer: The observer will see either a partial or total solar eclipse, depending on where the observer is located relative to the path of totality. In the partial (penumbral) zone, a partial solar eclipse is observed. In the zone (or path) of totality (the umbra), a total solar eclipse is observed.

14. Why are astronomers so interested in total solar eclipses?

    Answer: Because they allow us to study the thin atmosphere of the Sun in detail – at least for a few minutes.

15. What do we mean by the "path of totality"? Describe it.

    Answer: This is the path the tip of the Moon's umbra makes across the Earth's surface. It is never greater than about 270 km (170 mi) wide.

16. Describe the diamond ring. How is it created?

    Answer: Just as totality ends, we see the diamond ring. It is best seen in a short time-exposure photograph which brings out the faint part of the Sun's atmosphere surrounding the Moon, while the part of the Sun peaking through a valley on the Moon's limb is slightly overexposed.

17. Why would a solar eclipse be annular instead of total?

    Answer: There are two ways to state the answer. 1) The Moon's umbral shadow is too short to reach the Earth's surface. 2) The Moon's apparent diameter is smaller than the Sun's. In either case the solar disk is not entirely covered.

18. What is the longest duration (of totality) for total solar eclipse?

    Answer: The longest possible is 7 minutes, 40 seconds.

19. How long is totality for a typical total solar eclipse?

    Answer: Three to five minutes.

20. What is a saros and what is the saros cycle?

    Answer: The period of 223 lunar cycles is called the saros. The saros cycle is a near repetition in the pattern of eclipses and contributes to our ability to predict the occurrence of eclipses. If a total eclipse occurs at a given Earth location, then 6585.32 days later there will be another total (or nearly total, because of the slight difference in the anomalistic period) eclipse at almost the same latitude, but slightly north or south of the original depending on the particular saros.

21. How close to the ecliptic must the Moon come to have at least a partial lunar eclipse?

    Answer: The center of the Moon must come to at most one degree of the ecliptic line.

22. During the average calendar year, how many lunar eclipses occur? (Minimum, maximum and typical.)

    Answer: Minimum count, 0. Maximum count, equal to the number of eclipse seasons for the calendar year (2 or 3). Typically, one.

23. Why must a solar eclipse occur every eclipse season?

    Answer: Because even the minor solar ecliptic period (shortest solar eclipse season) is longer than the synodic period of the Moon. Therefor there must be a new Moon phase and at least a partial solar eclipse during every eclipse season.

24. How many solar eclipses are there in a calendar year? (Minimum, average and maximum.)

    Answer: Minimum, two. Maximum, five. On average, a little more than two. The average takes into account the occasional three eclipse season calendar year.

Review problems

1. Verify the relationships between the angular diameter and distance diameter (kilometers) of the Earth's umbra and penumbra at the Moon's average distance.

   Answer: At the Moon's average distance of 384 500 km, the Earth's umbra and penumbra are $1^\circ.4$ and $2^\circ.4$ in diameter, respectively. Translating the angles into radian measure we get, 0.024 and 0.042 radians. Treating the Moon's orbit as circular, we then get $384\,500 \times 0.024 = 9200$ km for the umbra and 16 000 km for the penumbra.

2. What is the maximum and minimum size of the major lunar eclipse period?

   Answer: The eclipse periods are found by doubling the size of the ecliptic limits and using the rate of motion of the Sun as one degree per day. This gives a minimum of 19 days and a maximum of 25 days.

3. Given a lunar eclipse season of 24.5 days, calculate the probability of a lunar eclipse. *Hint*: Approach this problem as a simple ratio.

   Answer: The lunar synodic period is 29.5 days. Using the simple ratio of 24.5/29.5 we get a probability of 0.83 or 83%.

Chapter 8

Observation projects

This chapter is found in a separate file.