Solutions for Pathways to Astronomy 6th Edition by Schneider

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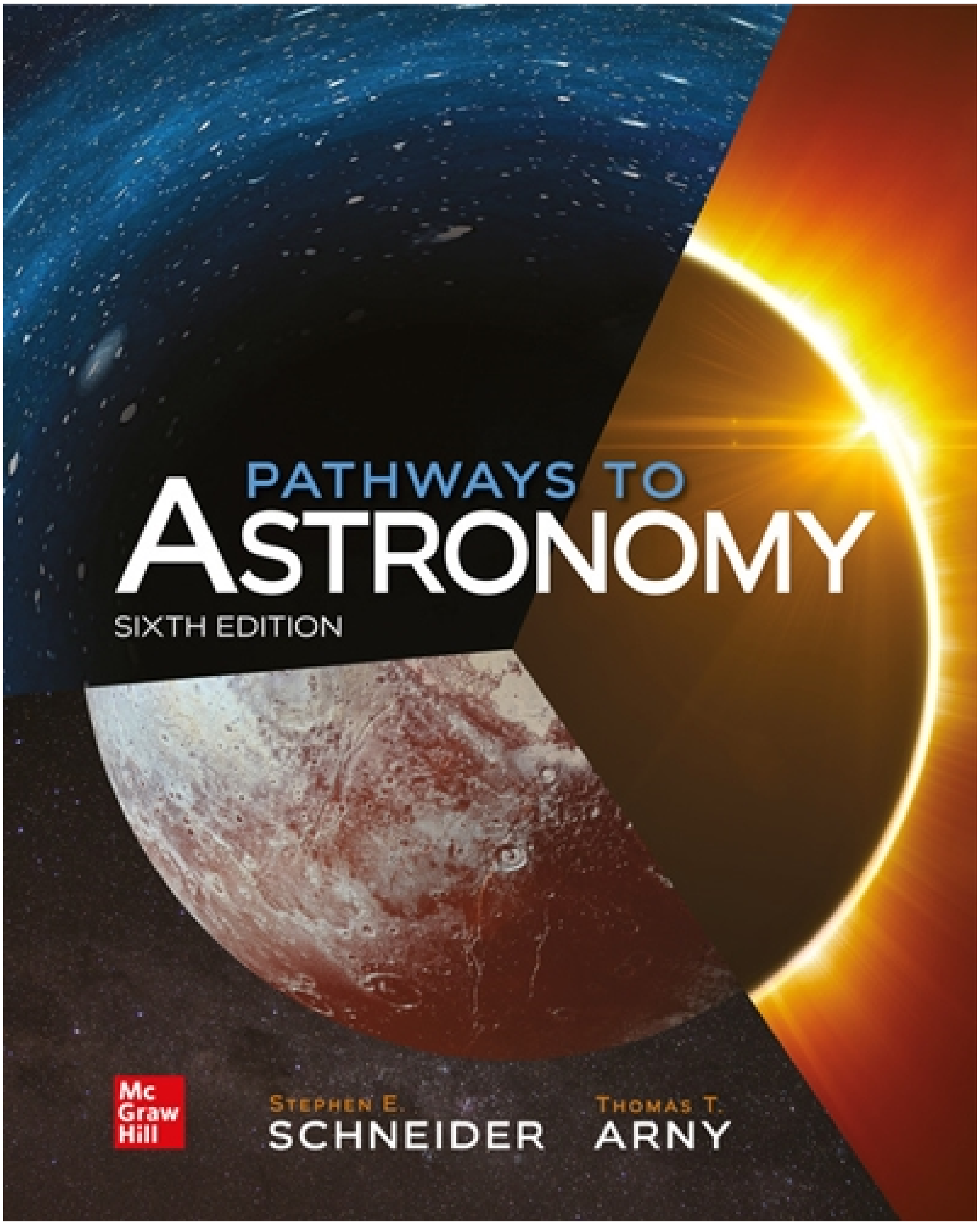


Solutions

Pathways to Astronomy, 6/e

Stephen Schneider and Thomas Arny

Instructor's Manual

Solutions to End of the Unit Quantitative Problems
Part I: The Cosmic Landscape

Unit 1

10. Using the value of the circumference of Earth given in the chapter,
Circumference (Volleyball) / *Circumference* (Real Earth) = 68 cm / 40,000 km = 0.0017 cm/km
1 km would be 0.0017 cm or 0.017 mm. This is about the diameter of extremely fine hair.

11. There are several ways to solve this problem. One easy way is to compare Earth's radius or diameter to the Moon's radius or diameter. The chapter notes the Moon's diameter is about ¼ Earth's. Since $C = \pi \times D$, then the circumference is also ¼ Earth's, so in the model where Earth is a volleyball, the Moon must have a circumference 0.25 × 68 cm = 17 cm. The Moon's diameter is then C/π = 17 cm / π = 5.4 cm.

A slightly more accurate calculation using the values of Earth and the Moon's size from the Appendix (the Moon's radius is 1738 km; Earth is 6378) gives the Moon's radius is 0.273 times Earth's; therefore the diameter and circumference are also 0.273 times Earth's; this gives a circumference for the model of the Moon of 18.6 cm and a diameter of 5.9 cm.

Either way, the model of the Moon would be a little smaller than a tennis ball or about the size of a small orange.

12. The volleyball is about 22 cm across ($D = C/\pi$ = 68 cm /π = 21.6 cm). The diameter of the Sun is about 109 times that of Earth (R_{Sun}/R_{Earth} = 696,000 km/6378 km = 109) so the model of the Sun would be 22 cm × 109 = 2398 cm = 23.98 m, or about 24 meters. This would be roughly the size of a house. (Also okay to use R_{Sun}/R_{Earth} ~ 100 as given in chapter, for 2200 cm).

13. An AU is approximately 1.5×10^8 km, while the Moon is d = 384,400 km away from Earth (Appendix Value). Performing a standard unit conversion gives a distance of

$$d = (384{,}400\ \cancel{\text{km}}) \times (1\ \text{AU}/1.5 \times 10^8\ \cancel{\text{km}}) = 0.0026\ \text{AU}.$$

14. The Moon is 384,400 km away from Earth (Appendix value). A three-day (72-hour) flight gives an average speed of 384,400 km/3 day = 128,000 km/day (= 5339 km/hr). A trip to Mars

on a trajectory 2 AU long would cover a distance $2 \times 1.5 \times 10^{11}$ m = 3.0×10^{11} m = 3.0×10^{8} km. At the speed of an *Apollo* spacecraft, a trip to Mars would therefore take

$$time = distance/speed = 3.0 \times 10^{8} \text{ km} / (1.28 \times 10^{5} \text{ km/day}) = 2.34 \times 10^{3} \text{ days}$$

This is about 6.4 years to reach Mars. (Note: if using the rounded value of 400,000 km distance to the Moon in the chapter, the speed is about 130,000 km/day, which yields about 6 yr.)

15. Based on the speed calculated in the last problem, a 2 AU flight took 6.4 years. Pluto is 20 times farther away, so the flight would take 20 times longer: 20×6.4 yr = 128 yr.

Unit 2

10. Model scale: *Diameter*(nickel) / *Diameter*(Milky Way) = 2 cm / 100,000 ly = 2×10^{-5} cm/ly.

Using the sizes in table 2.1:

a) The Local Group is about 3 million ly in diameter, which in the model is:

$$3 \times 10^{6} \text{ ly} \times 2 \times 10^{-5} \text{ cm/ly} = 60 \text{ cm.}$$

60 cm is about the size of a beach ball.

b) The Local Supercluster is 50 million ly $\times$ 2 = 100 million ly in diameter, scaled to the model this is:

$$100 \times 10^{6} \text{ ly} \times 2 \times 10^{-5} \text{ cm/ly} = 2000 \text{ cm} = 20 \text{ m.}$$

20 m is about the size of a house.

c) The visible universe would be about 13.7 billion ly $\times$ 2 = 27.4 billion ly in diameter, which in the model is:

$$27.4 \times 10^{9} \text{ ly} \times 2 \times 10^{-5} \text{ cm/ly} = 5.5 \times 10^{5} \text{ cm} = 5500 \text{ m} = 5.5 \text{ km}$$

5.5 km is about the size of a town or the height of Mt. McKinley.

11. Radio waves, like all forms of electromagnetic radiation, travel at the speed of light. We'd have to wait for the message to get to Andromeda, and for the response to make it back to us—twice the distance (2.5 million light years), divided by the speed of light. Because light travels 1 light year in a year, so:

$$time = distance / speed = (2 \times 2.5 \text{ million ly}) / (1 \text{ ly/yr}) = 5 \text{ million years.}$$

There is an introduction to solving distance-velocity-time problems at the beginning of the appendix.

12. An AU is approximately 1.5×10^8 km, and the speed of light is about 3.0×10^5 km/sec. Therefore, the time it takes light to travel from the Sun to Earth is

$$\textit{time} = \textit{distance} / \textit{speed} = 1.5 \times 10^8 \text{ km} / 3.0\times 10^5 \text{ km/sec} = 500 \text{ sec},$$

which is about 8.3 minutes.

13. This is another distance-velocity-time problem: $d = 1$ ly $= 9.46 \times 10^{15}$ m $= 9.46 \times 10^{12}$ km; $V = 1000$ km/sec. Therefore, we find the time for the distance to increase by 1 light-year is

$$t = d/V = 9.46 \times 10^{12} \text{ km} / (1000 \text{ km/sec}) = 9.46 \times 10^9 \text{ sec}.$$

Converting this to years:

$$9.46 \times 10^9 \text{ sec} \times 1\text{hr}/(3600 \text{ sec}) \times 1 \text{ day} / (24 \text{ hr}) \times 1 \text{ yr}/(365.25 \text{ day}) = 300 \text{ yr}.$$

14. This problem is like the last one, but with d = 2.5×10^6 ly and V = 100 km/sec:

$$\underline{t} = (2.5\times10^6 \text{ ly} \times 9.46 \times 10^{12} \text{ km/ly}) / (100 \text{ km/sec}) = 2.37 \times 10^{17} \text{ sec}.$$

Converting this to years gives

$$1.89 \times 10^{17} \text{ sec} \times 1\text{hr}/(3600 \text{ sec}) \times 1 \text{ day} / (24 \text{ hr}) \times 1 \text{ yr}/(365.25 \text{ day}) = 7.5 \times 10^9 \text{ yr}.$$

So the Milky Way and Andromeda will collide in 7.5 billion years, or sooner with acceleration.

15. At a scale of Figure 2.4, 1 light year = 1 meter, so 12 billion light years = 12 billion meters: 12×10^9 m $= 12 \times 10^6$ km = 12 million km. So on the scale where the Milky Way is about the size of a large metropolitan area, the most distant galaxies we can see are about 30 times the Moon's distance [12×10^6 km/384,000 km = 31], or about a tenth of an AU distant [12×10^9 m /(1.5×10^{11} m/AU) = 0.8 AU].

Unit 3

9. The ratio of the Sun's radius to Earth's radius is 7×10^5 km / (6.4×10^3 km) = $7/6.4 \times 10^{5-3} \approx 1 \times 10^2$ or about 100 times larger.

10. From Table 3.3 a solar radius is 6.97×10^8 m, or in kilometers 6.97×10^5 km. The radius of a hypergiant star would be about $1500 \times 6.97 \times 10^5$ km $= 1.05 \times 10^9$ km.

An astronomical unit is 1.50×10^8 km making the radius of the hypergiant star (1.05×10^9 km) $\times$ (1 AU/1.50×10^8 km) = 6.97 AU $\approx$ 7.0 AU, which is larger than Jupiter's orbit!

11. The light travel time to Earth from the Sun can be calculated from the distance-speed-time formula $t = d/V$, where $V = c = 3.0 \times 10^5$ km sec^{-1}, and $d = 1$ AU $= 1.496 \times 10^8$ km:

$t = 1.496 \times 10^8$ km/ $(3.0 \times 10^5$ km sec$^{-1}) = (1.5/3.0) \times 10^{8-5}$ sec $= 0.50 \times 10^3$ sec $= 5.0 \times 10^2$ sec

Next, we convert this to minutes, also using scientific notation:

$t = 5.0 \times 10^1$ sec $\times$ 1min / $(6 \times 10^1$ sec$) = 50/6$ min $= 8.3$ min (about 8 1/2 min).

12. Sun's luminosity is 3.86×10^{26} W $= 3.86 \times 10^{26}$ J/sec. Divide the by the energy output of a 1 kiloton bomb to get the equivalent number of these explosions each second:

$(3.86 \times 10^{26}$ J/sec$)/(4.18 \times 10^{12}$ J/kt$) = 9.23 \times 10^{13}$ kt per second.

13. The Andromeda galaxy is 2.5 million light years away. The Sun is 25,000 light years ($2.5 \times 10^4 = 0.025 \times 10^6 = 0.025$ million light years) from the center of the Milky Way galaxy. Since $2.5 \times 10^6 - 0.025 \times 10^6 = 2.475 \times 10^6 \approx 2.5 \times 10^6$, it would not affect the distance estimate to within the 2-digit precision of the distance of the Andromeda galaxy.

14. The time for the galaxies to move this distance is given by the distance-speed-time equation:

$t = d/V = (3 \times 10^8$ ly$)/(6000$ km/sec$) = (3 \times 10^8$ ly $\times 9.46 \times 10^{12}$ km/ly$)/(6000$ km/sec$)$

$= 4.73 \times 10^{17}$ sec $= 4.73 \times 10^{17}$ sec $\times$ 1y$/(3.16 \times 10^7$ sec$) = 1.50 \times 10^{10}$ years.

This time of 15 billion years assumes the galaxies have moved at a constant speed.

15. To get the units to work out properly in the MKS system, the 3.10-gram mass of the penny must be expressed in kilograms:

$E = m\,c^2 = (3.10 \times 10^{-3}$ kg$) \times (3.00 \times 10^8$ m/sec$)^2 = 2.79 \times 10^{14}$ kg m^2/sec$^2 = 2.79 \times 10^{14}$ J

Note: this means the conversion of a penny to pure energy is equivalent to a 66.7 kiloton bomb.

16. Using scientific notation:

$(1.4 \times 10^9)^3 / (9.3 \times 10^8)^2 = (1.4^3 \times 10^{9\times3}) / (9.3^2 \times 10^{8\times2})$

$= 2.74 \times 10^{27} / 86.5 \times 10^{16} = 2.74/86.5 \times 10^{27-16} = 0.0317 \times 10^{11} = 3.2 \times 10^9$

17. Paris: 5 ft(P) 2 in(P) $= 5 \times 12 + 2 = 62$ in(P). Since the Parisian units are 6.63% larger, 1 Parisian inch = 1.0663 English inches. To convert this:

62 in(P) $\times$ 1.0663 in / 1 in(P) = 66 in $= (5 \times 12 + 6)$ in

Thus in the English system, Bonaparte was 5 ft 6 in tall. To convert to the Metric system from the English measurement of 66 in and the fact that 1 in = 2.54 cm we calculate:

66 in × (2.54 cm / 1 in) = 168 cm = 1.68 m.

Unit 4

11. A hydrogen atom is 10^{-10} m in diameter while a proton is about 10^{-15} m, so the atom is about 10^{5} times larger than the size of the proton. If the proton were blown up in size of a large apple (10 cm), then the size of the atom would become $(10 \times 10^{-2}\ \text{m}) \times 10^{5} = 10^{4}$ m = 10 km, about the size of a city.

12. The force of gravity is 10^{-36} times weaker than the force of electromagnetism (see Table in chapter). So only 10^{-36} as much matter is needed for the electromagnetic force as for the gravitational force, for them to be equal. The mass of Earth is 5.974×10^{24} kg, so only ~ 6×10^{24} kg × $10^{-36} = 6 \times 10^{-12}$ kg of mass needs to be charged! A quarter of this for the Moon.

Note that this is about the mass of a single cell in your body, so if all the electrons could somehow disappear from a single cell, the electrical repulsion would rival the whole Earth's gravitational pull.

13. While the atoms in your clothes typically are electrically neutral, meaning that they have an equal number of positive and negative charges, friction between tumbling clothes can allow certain materials to capture electrons from other materials. When this happens, one material becomes more negative and the other more positive. This is what we mean when we say something has a static charge. Since opposite charges attract, a sock that has gained a negative charge in this process is attracted to and clings to a sweater that has developed a positive charge. The crackling sound is that of charges jumping from one fabric to the other in tiny sparks as you pull them apart (you may be able to see these in the dark).

Under humid conditions, surfaces become covered with water molecules that are conductive and allow electrical charges to flow away relatively easily, so large charges rarely build up. That's why the static charge builds up on clothes in the dryer and not in the wash. Dryer sheets often also contain chemicals that are conductive and coat the clothes, thereby reducing the ability of tumbled clothes to build up a large electric charge.

14. The probability that a neutrino passing through an atom will interact is about one out of 10^{27}! Explanation: Assume that the atom is a sphere and the 12 nuclear particles are each spheres with

circular cross-sections like circular targets. Using the given radii, calculate the cross-sectional areas for the atom as a whole (A_1) and for the nuclear particles (A_2). Each area = $\pi \times r^2$, so the ratio of areas is:

$$12 \times A_2 / A_1 = 12 \times \pi \times (10^{-24}\text{m})^2 / (\pi \times (10^{-10}\text{m})^2) = 12 \times (10^{-24})^2 / (10^{-10})^2$$

Note that the pi's (and meters) cancel out, so the fraction of the area that the neutrino might hit is

$$= 12 \times 10^{-48} / 10^{-20} = 1.2 \times 10^{-27}.$$

Thus, a neutrino might be expected to pass through something in the order of 10^{27} atoms before there is a strong likelihood of it interacting! This means that a neutrino has a high probability of passing through a solid layer of material that is even a light year (about 10^{16} meters) thick, since that's "only" 10^{26} atoms thick.

Unit 5

10. (Adjust answer to match your location). Method: If your latitude and longitude are 40° N and 100° W, then the points on the opposite side of Earth would have to be somewhere on 40° S (reflected through the center of Earth). The longitude is slightly trickier, because it is 180° away on the other side of the Prime Meridian, so it is (180° - 100°) E = 80° E. [Look at a globe or a 360° protractor to understand why it's (180° - value) in the opposite hemisphere.]

11. At a latitude of 45° N, stars at declination +45° pass through your zenith, so the horizon blocks off stars more than 90° north or south of that. You can therefore observe declinations from –45° and up to +90°. To see the most stars you would want to build your observatory on the equator, and then you would be able to observe all the declinations.

12. In the Northern hemisphere, the end of the "bowl" of the Big Dipper "points" at the north celestial pole and the north star, Polaris (itself at the handle end of Ursa Minor or the Little Dipper). Continuing the line made by Merak and Dubhe (going "up" out of the bowl) leads the eye to Polaris about 30° away.

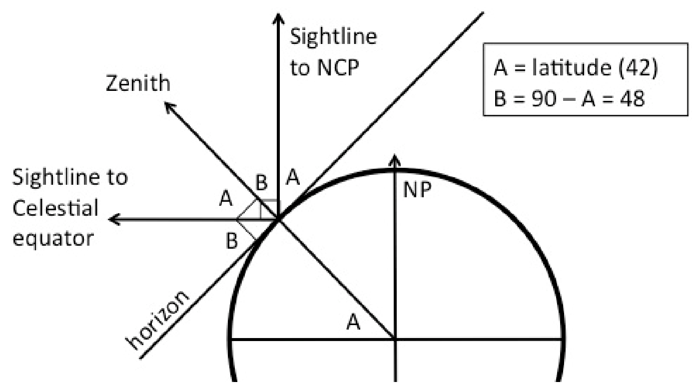
In the Southern hemisphere, the two bright stars on the longer arm of the "Southern Cross" (the constellation Crux) also point toward the south pole about 30° away, however there are no naked-eye stars close to the pole, so finding the position of the celestial pole is trickier. The distance from Acrux (the brightest star in Crux) to the pole is about four times the distance between Gamma Crucis and Acrux, or about 2/3rds the distance from Acrux to Beta Hydri, the first relatively bright star encountered along the line on the other side of the pole. The south celestial pole might also be pictured as the missing point needed to make a trapezoid out of the three brightest stars in the constellation Octans.

13. At 34°S, a star with a declination of –34° will pass through the zenith. Some examples you can find in the charts in the back of the book are ε Scorpii (Wei), ε Sagittarii (Kaus Australis), or α Columbae (Phaet). As Earth turns, the star will pass over Buenos Aires at 58° W, the rest of South America, the Pacific Ocean, the 180° line of longitude separating the western and eastern hemispheres, and then on to Sydney, Australia at 151° E. The separation between these cities and longitude 180° is:

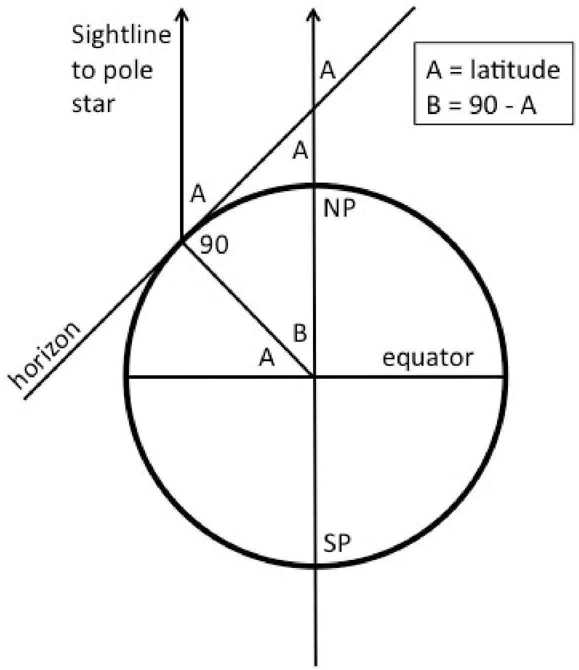
Buenos Aires to 180° = 180° – 58° = 122° 180° to Sydney = 180° – 151° = 29°

The total change in longitude is therefore 122° + 29° = 151°. Since Earth turns 15° per hour, it will take 151°/(15°/hr) or just a bit over 10 hours between the star being overhead in Buenos Aires and being overhead in Sydney.

14. At 31° N, a star at declination +31° will pass through your zenith, so the celestial equator is 31° south of your zenith. (This is illustrated as angle A in the figure at right for latitude 42° N.) Likewise, at 15° S, the celestial equator is 15° north of your zenith.



15. The drawing should look like this: (Northern hemisphere location; reverse NP and SP for Southern hemisphere.).



Note that this geometric demonstration makes use of several principles: a line (in this case the horizon) crossing parallel lines makes the same angle A to each, the sum of the angles in a triangle is 180°, and the tangent line to a point on a circle is at a 90° angle to the radius line to that point.

Some students are concerned that the different sightlines to the pole star are not exactly parallel for a star that is at a finite distance. While true for any physical star, the difference is extremely small. For example, the star Polaris is about 50 times larger than the Sun, so the difference from being parallel is thousands of times smaller than the seemingly pointlike appearance of Polaris in the night sky.

16. From a latitude of 39° N, the north celestial pole is 39° above the northern horizon. Therefore, stars within 39° of the pole (which is at declination +90°) never set. This makes all stars north of declination (+90° – 39°) = +51° circumpolar.

Unit 6

12. If Earth's axis had no tilt instead of 23.5°, the tropic and arctic regions would shrink to their smallest possible size. In the tropics the Sun passes directly overhead at least once during the year. With 0° tilt, the Sun would always be directly over just the equator. In arctic regions the Sun remains below the horizon for more than 24 hours during some parts of the year, but with 0° tilt, observers at the north and south pole would find that the Sun always remained right on the horizon. Without a tilt there would not be the seasonal changes we experience as the angle of sunlight to the ground changes.

13. If Earth's axis had a 50° tilt, geographically the tropics would extend to 50° N and S latitudes. The arctic regions would reach all the way to 40° N and S latitudes, giving a 10° overlap between the two. If you lived in the overlap region, there would be times of the year when the Sun would pass straight overhead as in the tropics, but half a year later, there would be days when the Sun never rose. This would lead to much greater variations in seasonal temperatures than we experience on Earth.

14. If Earth's axis was tilted by 90°, the Sun would appear to lie directly over the North Pole once a year, then move down toward the equator and eventually lie directly over the South Pole 6 months later before moving back to the North Pole over the course of a year. In this situation (which is similar to what the planet Uranus experiences), there would be no tropics or arctic regions, or you might say they were both everywhere. The polar regions would sometimes be warmer than the equator, and the seasons would be extreme, varying between "North Pole hot and in constant sunlight, equator cool with the Sun on the northern horizon all day long, South Pole dark for months and extremely cold," "equator warm with 12 hour days and nights, and both poles cool" and "South Pole hot and in constant sunlight, equator cool, North Pole cold."

15. On the Arctic Circle (latitude 66.5° N), it remains true on the equinoxes that night and day would both be about 12 hours long, and the Sun rises due east and sets due west. The Sun would not get very high in the sky, reaching a maximum altitude of 23.5° above the southern horizon at noon. On the December solstice, the Sun would barely skim the southern horizon around noon, with an hour or two of twilight before and after. It would be fully dark from about mid-afternoon to mid-morning the following day. On the June Solstice, the Sun would be up 24 hours, reaching a height of 47 degrees in the South at noon, and just flirting with the northern horizon at midnight.

16. For the best opportunity to observe a star with a right ascension (R.A.) of 12 h, you would wish the Sun to be as far away from it as possible, at R.A. = 0 h (see also Unit 5.5). This would occur near March 20 (although much of the year would also be acceptable, as well). For the star at R.A. = 6 h, it's best if the Sun was at R.A. = 18h. This happens ¾ of the year after March 21 – around the winter solstice (Dec. 21).

Unit 7

10. To find how the 5° longitude difference affects time measurement, we need to know how much time it takes Earth to turn each degree. Since Earth takes 24 hr to rotate 360°, the time per degree is: 24 hr / 360° = 1 hr / 15° = 60 min / 15° = 4 min / 1°.

Therefore, back in the days when clocks were set using a sundial, Philadelphia's clocks were $5° \times 4\text{min}/1° = 20$ minutes ahead the clocks in Pittsburgh.

11. Siberia is in the +12h time zone; Moscow is in the +3h. They appear to be 9h apart but are actually on opposite ends of their time zones—based on longitude, Siberia is nearly at what would be +13h (and in fact Moscow is very close to the start of +3h, although it is not obvious on the map). If the Sun rose at 6 am local time, the Moscow time would be 10h earlier, 8pm the previous evening.

For the second part of the question, local noon moves from east to west across the map (or right to left; it's noon in England before it's noon in America). Time zones are accurate to local solar time in the middle of the time zone—the middle of "0" runs through Greenwich, England (except for political zig-zags). So if one is at the eastern (or right side) edge of a time zone, the Sun crosses the meridian (local solar noon) at 11:30 am, half an hour before the clock reads noon. In the middle, it crosses at the same time, and at the western edge (left on map) it crosses the meridian (local solar noon) when the clock reads 12:30 pm. Looking carefully at the map, in some places the time zones have been moved from being centered on the lines of longitude, and stretch east and west over other time zones. All of Greenland is -3h, but the easternmost edge is nearly in the middle of the -1h time zone based strictly on longitude. That means that the Sun will cross the meridian there 1 hour after it crosses the meridian in Greenwich, but the clock will be set to 3 hours earlier than Greenwich—it will be "noon" at 10:00 am! This is one of the places where the Sun crosses the meridian at the earliest local (clock) time. In China, there is one of the latest crossings. All of China, for example, is in the +8h time zone, but the westernmost edge of China is actually in line with the middle of the +5h time zone based on longitude alone.

Therefore, in Western China, the clock will read 3h later than local solar time (noon); it will read 3pm when the Sun crosses the meridian!

12. For cities at 21° E and 104° W, the longitude difference = 21° + 104° = 125°. A star that passes overhead in the eastern city first, next goes overhead at 0° longitude, and then continue on to the western city. The amount of time between meridian crossings = 125° × 24 hours/360° = 8.267 hours = 8 hours, 16 minutes.

The eastern city is +21°/(15°/hr) = +1.4hr ahead of the prime meridian, so it is located in +1hr time zone. The second city is located -104°/(15°/h) = -6.9hr behind the prime meridian, so it is in the –7 hr time zone. The clock at 104°W is set 8h earlier than the clock at the 21°E, so 8h after it is midnight at 21°E (and the star is overhead there), it will be midnight at 104°W—but the star will not yet be overhead because only 8hr have passed, and the star won't be overhead for another 16 minutes (part 1). The star will be overhead at 104°W 16 minutes past midnight, at 12:16 am.

13. At present there are 8766 hr in a year (365.25day × 24hr/day). This number of hours divided into 180 solar days is 8766 hr / 180 day = 48.7 hr/day, or 48 hours 42 minutes. For each of these new solar days, Earth would move 2° so that it completed a full revolution around the Sun in 180 days. This means that Earth must be rotating an extra 2° compared to the stars during each solar day. Therefore Earth takes 48.7 hr to rotate 362° relative to the stars. The length of the sidereal day is then 360° × (48.7hr / 362°) = 48.4 hr.

14. The Sun would be 3.5° lower in summer, 3.5° higher in winter. For example, in Lafayette, Colorado (exactly 40° N latitude), on the June solstice the Sun rises to 73.5° above the southern horizon; on the December solstice, it rises to just 26.5°. If the axial tilt changed to 20°, the Sun would get only 70° high as a June maximum, and 30° high for the December maximum.

15. Example: Dodge City, KS, is located at almost exactly 100° West longitude in the Central Time Zone. This time zone is defined for 90° West Latitude. Therefore, Dodge City is 10° West of the 90° West longitude. Earth turns at about 15° an hour, so 10° represents about 10/15 of an hour, or 40 minutes. So if the Sun crossed the meridian at 12 noon at 90° West longitude, it would cross the meridian at about 12:40 p.m. in Dodge City. (Note this is more than the maximum 30-minute time difference that time zones were initially designed to encompass because the edges of the Central Time Zone have been adjusted to match political boundaries).

Unit 8

13. If the Moon is currently at third quarter (day 22 of the lunar month). You have to wait for ¾ of a lunar month (approximately 22 days) until the next full moon

14. Since the Moon is in the same phase and rises at the same local time once every 29.5 days (on average), the Moon must rise 1/29.5 of a day later each day (on average). This results in a shift of 24 hr / 29.5 = 0.814 hr × 60 min/hr = 49 min later each day.

Note that this will not be exactly correct primarily because of two factors. First, the Moon changes declination each day, so just as the Sun rises earlier in summer than winter, moonrise will be earlier when the Moon is farther north (for a northern observer). Second, the Moon's orbit is quite elliptical, so it speeds up and slows down in its orbit over the course of the month (Unit 12.2).

15. The ratio of the Moon's and Sun's diameters is $(2 \times 1738 \text{ km})/(2 \times 6.96 \times 10^5 \text{ km}) = 0.00250$. The ratio of Moon's and Sun's average distances: $(384.4 \times 10^3 \text{ km})/(1.496 \times 10^8 \text{ km}) = 0.00257$.

16. A very similar total solar eclipse to the August 2, 2027 eclipse occurs a *saros* later. Looking at the map of eclipse shadows, we see that this eclipse follows the northern coast of Africa, around 30 degrees latitude. First, we estimate the location of the eclipse. The added 8 hours means that the eclipse shadow falls 1/3 of a day, or 120°, further west than Africa on Earth. This places it near the Gulf of Mexico and up into the USA. 18 years is 18*365 = 6570 days (not accounting for leap years), so 6585 days is 18 years, 15 days. Between 2027 and (2027 + 18 = 2045) are 5 leap years, (2028, 2032, 2036, 2040, 2044), so we need to subtract a day for each of these. That leaves us with 18 years, 10 days, which we add to August 2, 2027, giving us the date August 12, 2045. More information about this eclipse can be found at the NASA Goddard Spaceflight Center's Eclipse Web Site, http://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2045Aug12Tgoogle.html

17. First we need the scale of the diagram. In Figure 8.12B, Earth's diameter is almost exactly 2 mm, and its radius therefore 1mm. The actual radius of Earth in Appendix Table 1 is 6378 km, so the scale of the image is 1mm = 6378 km. You can also determine the scale by measuring the distance to the Moon, which measures about 63 mm; if we assume it's at its average distance of 384,400 km from Earth given in Appendix Table 7 this gives a scale of 384,400 km/63 mm =

6102 km/mm. (These numbers are very close, so the sizes and distances are about at the same scale in the drawing, but there is some uncertainty given the size of the figure, and we don't know for sure what the Moon's distance is in the drawing. An answer based on either number should be acceptable and both are about the same.)

From Appendix Table 1, the radius of the Sun is 6.96×10^8 m = 6.96×10^5 km, and it is at a distance of 1.5×10^{11} m = 1.5×10^8 km from Earth. With the Earth-determined scale, for the drawing the Sun would be 6.96×10^5 km × 1mm/6378 km = 109 mm in radius or 218 mm (21.8 cm) in diameter, and you would have to locate it 1.5×10^8 km × 1mm/6378 km = 23,518 mm = 23.5 meters away! (For the Moon distance-determined scale, the Sun would be 228 mm in diameter and 24.6 m away.)

Unit 9

10. The system in Europe before 532 C.E. was based on the founding of Rome in 753 B.C.E., and the year 532 corresponds to the year 1285 using that system. So the present year plus 753 will give the answer. The other system mentioned in the text is based on when Diocletian became emperor of Rome; in that system, 532 C.E. is year 248; so there is a difference of 284 years (= 532 – 248) from the present C.E. year. For example, 2015 C.E. gives 2015 + 753 = 2768 since the founding of Rome, and 2015 – 248 = 1767 in the reign of Diocletian.

11. In September 2000, the Jewish calendar started the year 5761 with Rosh Hashanah; in 2020 it will be the year 5780 before Rosh Hashanah and 5781 after it.

From Figure 9.2, the Islamic year 1426 began on February 10, 2005. Since the Islamic year is 11 days shorter on average, after 15 years, the Islamic year 1441 will begin about 11 × 15=165 days (or about 5 months) earlier on the Gregorian calendar, placing the first day of 1441 at the end of August 2019. This means the year 2020 C.E. will begin with 1441 and end in 1442 of the Islamic calendar. Note that the Islamic calendar picks up an extra year compared to the common calendar once every 33 or 34 years. The extra year here was gained in 2008, which saw the beginning of two Islamic years.

In the Chinese system, the 79th sixty-year cycle began in early 1984 C.E. and will end in early 2044 C.E. That means in early 1984 C.E., 78 cycles or 78 × 60 = 4680 years were completed, and the year 4681 began. There are 36 years between 2020 and 1984 C.E., which means that in early 2020 C.E. the Chinese year 4681 + 36 = 4717 will begin. Note that some authorities begin the count a year earlier (which would make it the Chinese year 4618), but in either case it is agreed to be the year of the Metal Rat.

12. A lunar calendar year is shorter than a solar year by 11 days, so each year the "lunar new year" begins 11 days earlier on average in the common solar calendar. For example, if the first day of the lunar calendar was Jan 1, then 12 lunar months would be completed around Dec 21 later that year, and by about Dec 10 the following year. We would have to wait a number of years until the missing time accumulated to a full year. Since 365.25/11 = 33.2, 33 lunar calendar years should accumulate the necessary difference.

Checking this, after 33 lunar calendar years the date will have shifted earlier by 33 × 11 = 363 days—this is less than 7 days short of 365.25 days, as expected. One fewer solar years has gone by in the same interval.

Note that in a more detailed calculation with a lunar month of 29.53 days, a lunar calendar year adds up to 354.36 days. Compared to a more precise value of the solar year of 365.24 days, the difference is actually 10.88 days. The ratio 365.24/10.88 = 33.57, and in fact depending on the number of leap years spanned in the common calendar over the intervening years, there may be 33 or 34 lunar calendar years corresponding to 32 or 33 solar years to get the closest match.

13. The Moon takes 29.5 days to move 360° relative to the Sun. Since 29.5 days × 24 hr/day = 708 hr, the Moon moves 360° / 708 hr ≈ 0.5°/hr relative to the Sun. Therefore 16 hours after the new moon, the Moon will have moved about 16hr × 0.5°/hr = 8° from the Sun, and because the sky turns at 15°/hr, it will set 8°/(15°/hr) = 0.53 hr = 32 minutes later. (Note that these results are approximate since the Moon may be off the ecliptic by several degrees, and moonset timing depends on the angle between Sun and Moon relative to the horizon.)

14. In the Julian calendar, there are 365.25d/y × 400 y = 146100 days in 400 years. The Gregorian calendar removes leap years in centuries not divisible by 400. In 400 years, there are three centuries not divisible by 400, so the Gregorian calendar would have 146097 days, and average 365.2425 days per year. To correct the calendar today, we need to remove the 10 days needed in 1582, plus any extra days that would have been in a Julian calendar since then: the leap years from 1700, 1800, and 1900, for 13 days total.

15. If a year had 365.170 days, over 1000 years there would be 365.170 × 1000 = 365,170 days. If all 1000 years had 365 days, there would be 365,000 days leaving an extra 170 days. These can be made up with 170 leap years of 366 days each, and the other 830 (= 1000 – 170) would have 365 days.

Since 1000/170 = 5.88, a leap year is needed every five or six years. The question is how to distribute these years with an extra day that is easy to remember. If there was a leap year every five years, there would be 200 in 1000 years, which is 30 too many. If every six years, there would only be 166 of them, four too few. One scheme that would work would be a leap year every five years, skipping 3 each century—for example, every five years except for years that end in 25, 50, and 75.

Unit 10

10. At the smallest separation between Earth and Jupiter of 588 million km, Jupiter (diameter = 140,000 km) has an angular diameter of:

$\alpha = 57.3° \times \text{diameter/distance} = 57.3° \times 1.4{\times}10^5 / 5.88{\times}10^8 = 0.0136°$.

At the largest separation of 968 million km, Jupiter has an angular diameter of

$\alpha = 57.3° \times \text{diameter/distance} = 57.3° \times 1.4{\times}10^5 / 9.68{\times}10^8 = 0.0083°$.

11. Use Eratosthenes' method to find the size of the planet Myrmidon. From the observations we know that 1000 miles on the surface spans an angle of 36°, so Myrmidon's circumference must satisfy:

circumference/1000 miles = 360°/36° = 10.

Hence,

circumference = 10 × 1000 miles = 10,000 miles.

And since circumference = $2\pi R$, we find its radius R = 10,000 miles / 2π = 1592 miles.

12. The size of a cloud that is 10° across and 2200 m away is:

$\ell = d \times \alpha/57.3° = 2200 \text{ m} \times 10°/57.3° = 380 \text{ m}$.

13. From the linear and angular diameters of the Andromeda galaxy, we can find its distance:

$d = \ell \times (57.3°/\alpha) = (140{,}000 \text{ light-years}) \times (57.3°/3.18°) = 2.5 \times 10^6$ light-years

This "nearby" galaxy is about 2.5 million light-years distant.

14. A person 1.8 m tall who has an angular size of 2° must be standing at a distance:
$d = \ell \times (57.3°/\alpha) = 1.8 \text{ m} \times 57.3°/2° = 51.6 \text{ m}$

15. If the Moon has an angular size of 0.500° when it is near the horizon, it will be *larger* when it is overhead later that night because it will be closer to you—by Earth's radius. The ratio of the distances is 398,000 km / (398,000 km – 6378 km) = 398,000/391622 = 1.0163. Since you are closer, and angular size-distance is an inverse relationship, the Moon will appear bigger by that factor and have an angular size of 0.500° × 1.0163 = 0.508°. (Note that this is the opposite of what most people expect to be true because of the Moon illusion.)

16. If two stars are 10 ly from the Sun, then their distance from Earth can vary by plus or minus 1 AU as Earth orbits the Sun. Expressing light years in AU: 1 ly = 63,240 AU. (from Appendix) so the distance varies from 632,401 AU to 632,399 AU. If the stars are 3 ly = 189,720 AU apart, we can calculate their angular separation from the formula:
Closest: $\alpha = 57.3° \times \ell / d = 57.3° \times 189{,}720 \text{ AU} / 632{,}399 \text{ AU} = 17.1900272°$
Farthest: $\alpha = 57.3° \times \ell / d = 57.3° \times 189{,}720 \text{ AU} / 632{,}401 \text{ AU} = 17.1899728°$

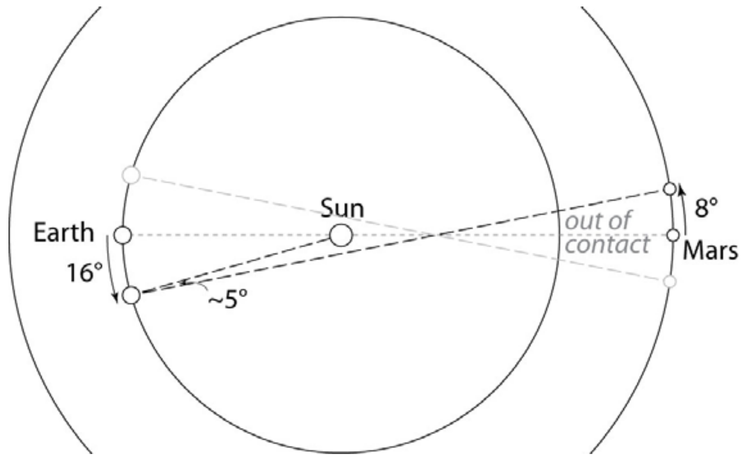
The difference is 0.000054°, much smaller than the 0.02° difference the eye can distinguish.

Unit 11

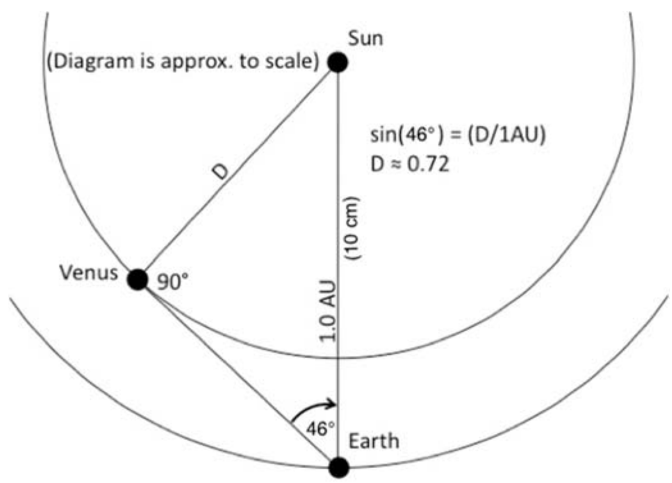
10. If a planet was in opposition once every 366 days, that would imply it shifts by less than about 1° in its orbit each year, indicating that it must take more than 360 years to complete an orbit. (If you use 365.25 days as the length of the year, you might estimate an orbital period as large as 487 years.) Given that this orbit is slower than any of the other planets, the new planet must lie in a very large, slow orbit, far from the Sun.

11. At the smallest separation between Earth and Jupiter of 588 million km, Jupiter (diameter = 140,000 km) has an angular diameter of:
$\alpha = 57.3° \times \text{diameter/distance} = 57.3° \times 1.4 \times 10^5 / 5.88 \times 10^8 = 0.0136°$.
At the largest separation of 968 million km, Jupiter has an angular diameter of
$\alpha = 57.3° \times \text{diameter/distance} = 57.3° \times 1.4 \times 10^5 / 9.68 \times 10^8 = 0.0083°$.

12. Starting from when Mars is in conjunction, Earth's and Mars's motions on opposite sides of the Sun partly cancel out, keeping Mars hidden longer than if only one of them was moving. Earth's more rapid motion eventually overtakes Mars bringing it back into view. The diagram at right shows a scale construction of the two orbits (with Mars's orbit 1.52 times larger than Earth's and ignoring the ellipticity.) By testing several angles with a protractor, shifting Earth by 1° per day and Mars ½° per day in their orbits around the Sun, it appears that Mars reaches an angle of ~5° from the Sun (as seen from Earth) about 16–18 days after conjunction. In total, then Mars is difficult to contact for about 32 to 36 days, counting the time before and after conjunction.



13. First, we draw a line from Venus to Earth as shown in the diagram. Then 46° off of that, we draw a 10 cm line from Earth towards the Sun. Starting at the end of that line, we draw the circle that represents the orbit of Venus, so that it just touches our first line. We now have a line tangent to a circle, so the angle between our Venus-Earth line and the Venus-Sun line (D) is 90°. The length of D divided by the length of 1 AU measured in the figure gives the value of D, the orbital distance of Venus, in AU. Alternatively, we can use the law of sines and the right triangle we have just created to solve for D. The right angle is at Venus when Venus appears to be farthest from the Sun (at greatest elongation). If the angle between Venus and the Sun is 46° as seen from Earth, then from trigonometry:

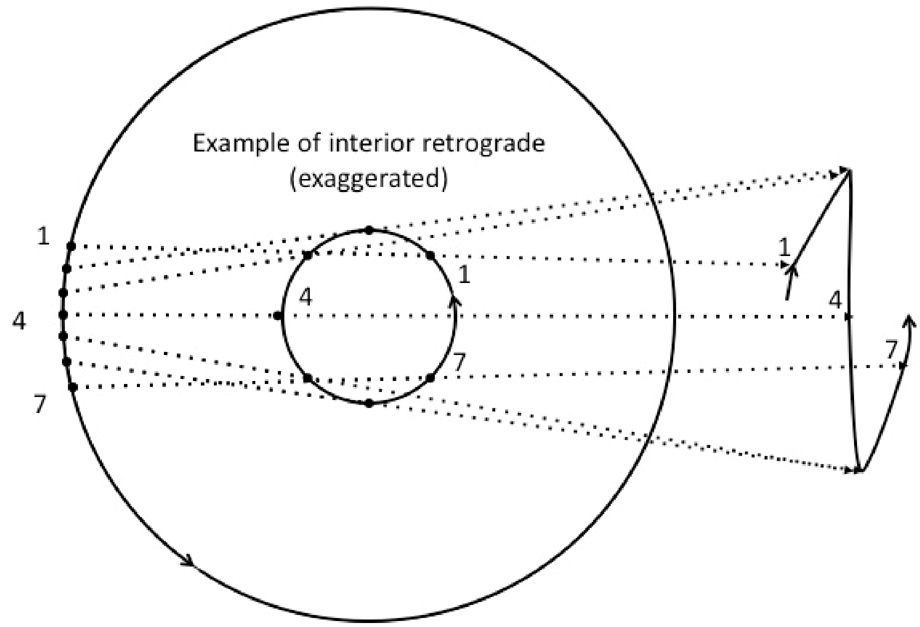


sin(46°) = Venus Distance / 1.0 AU

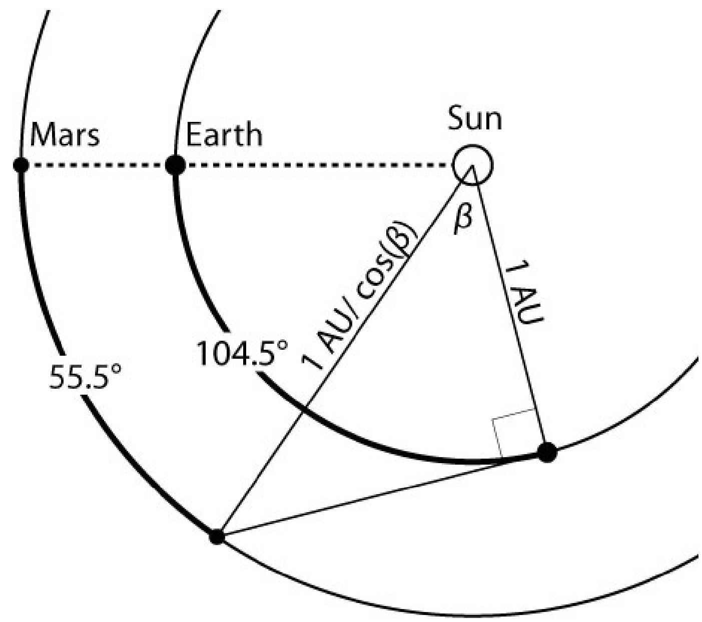
= D / 1 AU.

So D = 1AU × sin(46°) = 0.72 AU.

14. The retrograde motion for a planet closer to the Sun occurs around inferior conjunction as the planet passes Earth between Earth and the Sun. An observer on this planet during this time would also see Earth, near opposition, going through retrograde motion.



15. Mars spends, on average, about 106 days (15.4% of its orbit) moving from opposition to quadrature. This is illustrated in the figure at right. To draw this, we need to know how much of their orbits the planets move through. In the 106 days from opposition to quadrature, Earth travels 106/365 × 360° = 104.5° along its orbit. During the same time, Mars travels 106/687 × 360° = 55.5° along its orbit. Mars must be 1.52 times farther from the Sun than Earth along the line at 55.5° in order for Mars to be 90° away from the Sun when viewed from Earth. If Mars were anywhere else along that line from the Sun, the angle at Earth would be different.



Using trigonometry it is possible to solve for the size of Mars's orbit more directly. The difference between the angles the two planets move is $\beta = 104.5° - 55.5° = 49°$ as shown in the diagram. The distance from the Sun to Mars is the hypotenuse of the right triangle, therefore cos(β) = 1AU / (Mars distance from Sun). Since β = 49°, we get Mars's distance from the Sun equal to 1 AU / cos(49°) = 1.52 AU.

The eccentricity of Mars's orbit is sufficient that the results of this calculation vary depending on the portion of the orbit where Mars is traveling—neither Mars nor Earth travels at constant speed, so the time between opposition and quadrature can vary significantly.

Unit 12

10. From Ceres' orbital period of 4.6 yr, use Kepler's 3rd Law, $\alpha^3 = P^2$ to solve for the semimajor axis. For P= 4.6 yr, we find $\alpha^3 = 4.6^2 = 21.6$, so taking the cube root, we find α = 2.8 AU. This is between the orbits of Mars and Jupiter, placing Ceres in the asteroid belt.

11. From Sedna's semimajor axis of α = 526 AU, we can use Kepler's 3rd Law to solve for the period. $P^2 = \alpha^3 = (526)^3 = 1.4553 \times 10^8$, so taking the square root we find P = 12,063 years. The orbital period of Sedna is almost 50 times greater than Pluto's period.

12. The semimajor axis is half the sum of the closest and farthest distance from the Sun, so for this asteroid the semimajor axis a = (0.5 AU + 5.5 AU)/2 = 3.0 AU. We can solve the asteroid's period using Kepler's 3rd Law $P^2 = a^3 = 3^3 = 27$, so taking the square root we find P = 5.2 years.

13. A comet with an orbital period of 27 years has a semimajor axis that can be found from Kepler's 3rd Law: $\alpha^3 = P^2 = 27^2 = 729$; taking the cube root, we find α = 9 AU. Since the semimajor axis is the average of the maximum and minimum distance from the Sun, we know that (max + min)/2 = α or (max + min) = 2 α = 18 AU. Therefore, if the minimum distance to the Sun is 1 AU, the maximum distance from the Sun must be 18 AU – 1 AU = 17 AU.

14. For an asteroid orbit with a = 4 AU, the period is given by Kepler's 3rd Law as $P = 4^{3/2} = 8$ yr. A circular orbit of R = 4 AU has a circumference = 2πR. The speed of the asteroid is then:

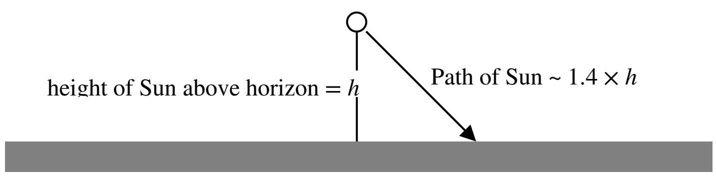
v = circumference / period
= 2πR / P
= 2π(4 AU * 149,598,000 km/AU) / (8 yr * 60 sec/min * 60 min/hr * 24 hr/day * 365 day/yr)
= 15 km/sec

15. The ratio of distances at Neptune's versus Venus's distance is (30.0 AU/0.723 AU) = 41.5. When the comet is closest to the Sun, its motion over a fixed amount of time can be pictured as the base of a triangle with the height of the triangle equal to the distance to the Sun. When the comet is farthest from the Sun, we can imagine the same kind of triangle, but it now has a much greater "height" so the base of the triangle must be proportionately shorter. Thus, the ratio of speeds is inversely related to the ratio of the distances. Therefore the comet travels 41.5 times faster when it is closest to the Sun than when it is farthest.

Unit 13

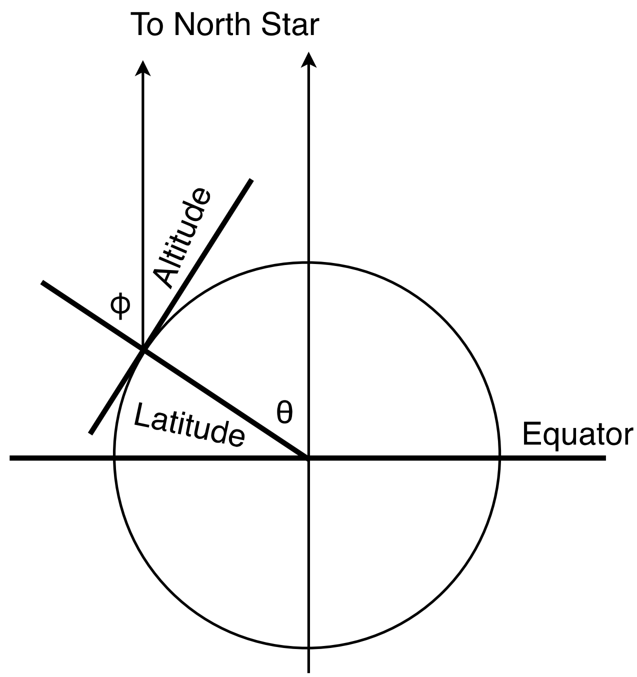
10. The main part of Orion, for example, is about 20° tall and 10° wide. (Sizes can be estimated from sky charts, but there is a lot of distortion at the edges because of the spherical projection.)

11. Typically the width of a finger is similar to the width of a thumbnail, which is about 2° wide when held at arm's length. Earth turns at about 1 degree every 4 minutes, so if the Sun were "one finger" above the western horizon at the equator, sunset would be in about 8 minutes. (The little finger might be a little less, the middle finger a little more.) At about 45° latitude, the Sun sets at a 45° angle, and hence its path to the horizon is longer. To figure out the length of the path, you can sketch the path and measure the difference:



The length of the Sun's path may also be recognized as the hypotenuse of a 45°-45°-90° triangle, which is $\sqrt{2}$ times the length of a side. (Or using trigonometry, we find that the longer distance is $h/\sin(45°) = h/0.707 = 1.41\ h$, where h is the vertical height of the Sun above the horizon.) A finger's width above the horizon translates to a motion of the Sun by about $2° \times 1.4 = 2.8°$, so the Sun will take about 8 min $\times$ 1.4 $\approx$ 11 minutes per finger before it sets at 45° latitude.

12. The picture at right shows Earth as viewed in profile and above the equator. By inspection of the figure we note that the two arrows pointing toward the North Star are parallel lines. This implies that the angles θ and ϕ are equal. Moreover, since the latitude angle + θ = 90° = Altitude + ϕ it follows that the altitude must also equal the latitude angle.

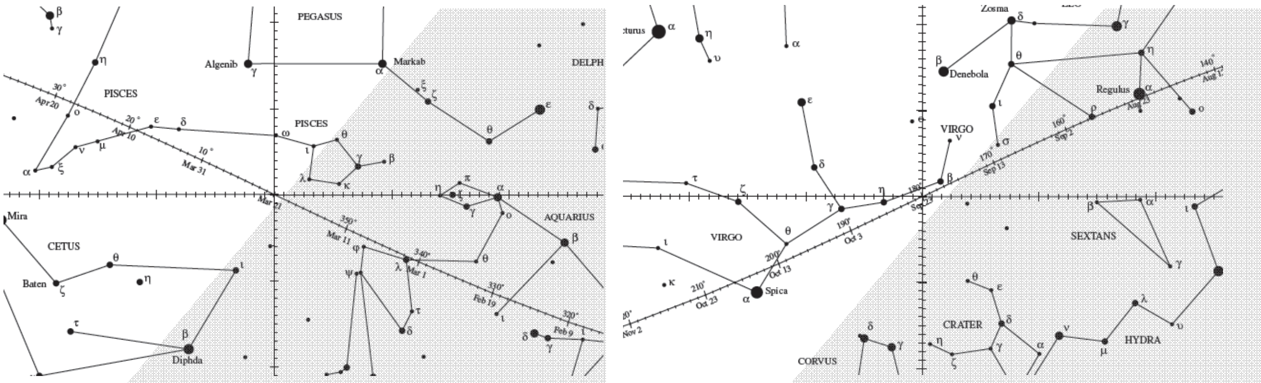


As a side note, students are often reluctant to accept that lines toward the North Star from different parts of Earth are effectively parallel. For some it is helpful to remind them that Polaris is far bigger than the entire Earth. In fact it is about 50 times larger than the Sun, so the difference in direction from different spots on Earth is a tiny fraction of the point of light we see in the night sky.

13. The Moon revolves (360°/29.53 days = 12.19°/day) around Earth each day, and during that day Earth has revolved (360°/365.25 days = 0.99°/day) around the Sun in the same direction, so the Moon revolves 12.19°/day + 0.99°/day = 13.18°/day relative to the stars. (Note this is the same answer as you get dividing 360° by the sidereal lunar month of 27.3 days).

14. The angle of the horizon at sunset depends on the observer's latitude. On the equator the horizon is perpendicular to the celestial equator (running north-south on the celestial sphere), so on the equator the ecliptic runs most nearly perpendicular to the horizon at the solstices.

At other latitudes, the horizon at sunset is tilted from north-south by an angle equal to the latitude. This is illustrated below for latitude 40°N, with the grayed-out area beneath the horizon for sunset on the March equinox (left) and the September equinox (right). As can be seen in the illustrations, the path of the ecliptic is most nearly perpendicular to the horizon in the evening sky near the beginning of spring, which is when it would be easiest to see Mercury as an evening star. The pre-dawn horizon is tilted 40° in the other direction, so Mercury is easiest to see as a morning star near the beginning of autumn for northern observers. These answers would be reversed for an observer at mid-southern-hemisphere latitudes.



15. The Equation of Time shows the offset between sundial time and mean solar time. These are not the same because of Earth's changing speed in its elliptical orbit and the tilt of Earth's axis (as discussed in Unit 13.5). If we measure the shadow cast by the top of the flagpole once every 24 hours as measured by a standard clock, the Sun will east of its mean position when the sundial is behind clock time, or west when the sundial is ahead as given by the Equation of Time. The shadow therefore reaches farthest to the west in February and July, and farthest to the east in May and November. Because the Sun also moves north and south of the celestial equator during the course of the year, so the east-west motions over each half year produce an S-shaped pattern that join to make a figure-eight-shaped pattern.