

Test Your Understanding

Does It Make Sense?

Decide whether the statement makes sense (or is clearly true) or does not make sense (or is clearly false). Explain clearly; not all of these have definitive answers, so your explanation is more important than your chosen answer.

Example: I walked east from our base camp at the North Pole.

Solution: The statement does not make sense because *east* has no meaning at the North Pole—all directions are south from the North Pole.

15. Our solar system is bigger than some galaxies.
16. The universe is billions of light-years in age.
17. It will take me light-years to complete this homework assignment!
18. Someday we may build spaceships capable of traveling a light-year in only a decade.
19. Astronomers recently discovered a moon that does not orbit a planet.
20. NASA plans soon to launch a spaceship that will photograph our Milky Way Galaxy from beyond its halo.
21. The observable universe is the same size today as it was a few billion years ago.
22. Photographs of distant galaxies show them as they were when they were much younger than they are today.
23. At a nearby park, I built a scale model of our solar system in which I used a basketball to represent Earth.
24. Because nearly all galaxies are moving away from us, we must be located at the center of the universe.

Quick Quiz

Choose the best answer to each of the following. Explain your reasoning with one or more complete sentences.

25. Which of the following correctly lists our “cosmic address” from small to large? (a) Earth, solar system, Milky Way Galaxy, Local Group, Local Supercluster, universe (b) Earth, solar system, Local Group, Local Supercluster, Milky Way Galaxy, universe (c) Earth, Milky Way Galaxy, solar system, Local Group, Local Supercluster, universe
26. When we say the universe is *expanding*, we mean that (a) everything in the universe is growing in size. (b) the average distance between galaxies is growing with time. (c) the universe is getting older.
27. If stars existed but galaxies did not, (a) we would probably still exist anyway. (b) we would not exist because life on Earth depends on the light produced by galaxies. (c) we would not exist because we are made of material that required recycling in galaxies.
28. Could we see a galaxy that is 20 billion light-years away? (a) Yes, if we had a big enough telescope. (b) No, because it would be beyond the bounds of our observable universe. (c) No, because a galaxy could not possibly be that far away.
29. The star Betelgeuse is about 425 light-years away. If it explodes tonight, (a) we’ll know because it will be brighter than the full Moon in the sky. (b) we’ll know because debris from the explosion will rain down on us from space. (c) we won’t know about it until 425 years from now.
30. If we represent the solar system on a scale that allows us to walk from the Sun to Pluto in a few minutes, then (a) the planets would be the size of basketballs and the nearest stars would be a few miles away. (b) the planets would all be marble-size or smaller and the nearest stars would be thousands of

miles away. (c) the planets would be microscopic and the stars would be light-years away.

31. The total number of stars in the observable universe is roughly equivalent to (a) the number of grains of sand on all the beaches on Earth. (b) the number of grains of sand on Miami Beach. (c) infinity.
32. The age of our solar system is about (a) one-third of the age of the universe. (b) three-fourths of the age of the universe. (c) two billion years less than the age of the universe.
33. An astronomical unit is (a) any planet’s average distance from the Sun. (b) Earth’s average distance from the Sun. (c) any large astronomical distance.
34. The fact that nearly all galaxies are moving away from us, with more distant ones moving faster, helped us to conclude that (a) the universe is expanding. (b) galaxies repel each other like magnets. (c) our galaxy lies near the center of the universe.

Process of Science

Examining How Science Works

35. *Earth as a Planet.* For most of human history, scholars assumed Earth was the center of the universe. That view began to change about 400 years ago, when scientists showed that Earth orbits the Sun. Today, we know that our Sun is just one star in a vast universe. In a general sense, what is it about science that made it possible for scientists to accept such a dramatic change in viewpoint on our place in the universe?
36. *Thinking About Scale.* Whether you are a student or a professional, one of the keys to success in science is finding simple ways to evaluate new ideas, and making a simple scale model is often helpful. Suppose someone tells you that the reason it is warmer during the day than at night is that the day side of Earth is closer to the Sun than the night side. Evaluate this idea by thinking about the size of Earth and its distance from the Sun in a scale model of the solar system.
37. *Looking for Evidence.* In this first chapter, we have discussed the scientific story of the universe but have not yet discussed most of the evidence that backs it up. Choose one idea presented in this chapter—such as the idea that there are billions of galaxies in the universe, or that the universe was born in the Big Bang, or that the galaxy contains more dark matter than ordinary matter—and briefly discuss the type of evidence you would like to see before accepting the idea. (*Hint:* It’s okay to look ahead in the book to see the evidence presented in later chapters.)

Investigate Further

In-Depth Questions to Increase Your Understanding

Short-Answer/Essay Questions

38. *Our Cosmic Origins.* Write one to three paragraphs summarizing why we could not be here if the universe did not contain both stars and galaxies.
39. *Alien Technology.* Some people believe that Earth is regularly visited by aliens who travel here from other star systems. For this to be true, how much more advanced than our own technology would the space travel technology of the aliens have to be? Write one to two paragraphs to give a sense of the technological difference. (*Hint:* The ideas of scale in this chapter can help you contrast the distance the aliens would have to travel easily with the distances we are now capable of traveling.)

40. *Stellar Collisions.* Is there any danger that another star will crash through our solar system in the near future? Explain.
41. *Raisin Cake Universe.* Suppose that all the raisins in a cake are 1 centimeter apart before baking and 4 centimeters apart after baking.
- Draw diagrams to represent the cake before and after baking.
 - Identify one raisin as the Local Raisin on your diagrams. Construct a table showing the distances and speeds of other raisins as seen from the Local Raisin.
 - Briefly explain how your expanding cake is similar to the expansion of the universe.
42. *Scaling the Local Group of Galaxies.* Both the Milky Way Galaxy and the Andromeda Galaxy (M31) have a diameter of about 100,000 light-years. The distance between the two galaxies is about 2.5 million light-years.
- Using a scale on which 1 centimeter represents 100,000 light-years, draw a sketch showing both galaxies and the distance between them to scale.
 - How does the separation between galaxies compare to the separation between stars? Based on your answer, discuss the likelihood of galactic collisions in comparison to the likelihood of stellar collisions.
43. *The Cosmic Perspective.* Write a short essay describing how the ideas presented in this chapter affect your perspectives on your own life and on human civilization.

Quantitative Problems

Be sure to show all calculations clearly and state your final answers in complete sentences.

44. *Distances by Light.* Just as a light-year is the distance that light can travel in 1 year, we define a light-second as the distance that light can travel in 1 second, a light-minute as the distance that light can travel in 1 minute, and so on. Calculate the distance in both kilometers and miles represented by each of the following:
- 1 light-second
 - 1 light-minute
 - 1 light-hour
 - 1 light-day
45. *Moonlight and Sunlight.* How long does it take light to travel from
- the Moon to Earth?
 - the Sun to Earth?
46. *Spacecraft Communication.* We use radio waves, which travel at the speed of light, to communicate with robotic spacecraft. How long does it take a message to travel from Earth to a spacecraft
- on Mars at its closest to Earth (about 56 million km)?
 - on Mars at its farthest from Earth (about 400 million km)?
 - Pluto at its average distance from Earth (about 5.9 billion km)?
47. *Moon to Stars.* How many times greater is the distance from Earth to Alpha Centauri (4.4 light-years) than the distance from Earth to the Moon?
48. *Saturn vs. the Milky Way.* Photos of Saturn and photos of galaxies can look so similar that children often think the photos show similar objects. (After all, like Saturn, at least some galaxies have a large, round center surrounded by a disk that looks like rings.) In reality, a galaxy is far larger than any planet. About how many times larger is the diameter of the Milky Way Galaxy than the diameter of Saturn's rings? (*Data:* Saturn's rings are about 270,000 km in diameter; the Milky Way is 100,000 light-years in diameter.)
49. *Galaxy Scale.* Consider the 1-to- 10^{19} scale on which the disk of the Milky Way Galaxy fits on a football field. On this scale, how far is it from the Sun to Alpha Centauri (real distance: 4.4 light-years)? How big is the Sun itself on this scale? Compare the Sun's size on this scale to the actual size of a typical atom (about 10^{-10} m in diameter).
50. *Universal Scale.* Suppose we wanted to make a scale model of the Local Group of galaxies, in which the Milky Way Galaxy was the size of a marble (about 1 cm in diameter).
- How far from the Milky Way Galaxy would the Andromeda Galaxy be on this scale?
 - How far would the Sun be from Alpha Centauri on this scale?
 - How far would it be from the Milky Way Galaxy to the most distant galaxies in the observable universe on this scale?
51. *Driving Trips.* Imagine that you could drive your car at a constant speed of 100 km/hr (62 mi/hr), even across oceans and in space. (In reality, the law of gravity would make driving through space at a constant speed all but impossible.) How long would it take to drive
- around Earth's equator?
 - from the Sun to Earth?
 - from the Sun to Pluto?
 - to Alpha Centauri (4.4 light-years away)?
52. *Faster Trip.* Suppose you wanted to reach Alpha Centauri in 100 years.
- How fast would you have to go, in km/hr?
 - How many times faster is the speed you found in (a) than the speeds of our fastest current spacecraft (around 50,000 km/hr)?
53. *Galactic Rotation Speed.* We are located about 28,000 light-years from the galactic center and we orbit the center once every 230 million years. How fast are we traveling around the galaxy? Give your answer in both km/hr and mi/hr.
54. *Earth Rotation Speed.* Mathematical Insight 1.3 shows how to find Earth's equatorial rotation speed. To find the rotation speed at any other latitude, you need the following fact: The radial distance from Earth's axis at any latitude is equal to the equatorial radius times the *cosine* of the latitude. Use this fact to find the rotation speed at the following latitudes. (*Hint:* When using the cosine (cos) function, be sure your calculator is set to recognize angles in degree mode, not in radian or gradient mode.)
- 30°N
 - 60°N
 - your latitude

Discussion Questions

55. *Eliot Quote.* Think carefully about the chapter-opening quotation from T. S. Eliot. What do you think he means? Explain clearly.
56. *Infant Species.* In the last few tenths of a second before midnight on December 31 of the cosmic calendar, we have developed an incredible civilization and learned a great deal about the universe, but we also have developed technology with which we could destroy ourselves. The midnight bell is striking, and the choice for the future is ours. How far into the next cosmic year do you think our civilization will survive? Defend your opinion.
57. *A Human Adventure.* Astronomical discoveries clearly are important to science, but are they also important to our personal lives? Defend your opinion.

19. Last night the Moon was so big that it stretched for a mile across the sky.
20. I live in the United States, and during my first trip to Argentina I saw many constellations that I'd never seen before.
21. Last night I saw Jupiter right in the middle of the Big Dipper. (*Hint: Is the Big Dipper part of the zodiac?*)
22. Last night I saw Mars move westward through the sky in its apparent retrograde motion.
23. Although all the known stars appear to rise in the east and set in the west, we might someday discover a star that will appear to rise in the west and set in the east.
24. If Earth's orbit were a perfect circle, we would not have seasons.
25. Because of precession, someday it will be summer everywhere on Earth at the same time.
26. This morning I saw the full moon setting at about the same time the Sun was rising.

Quick Quiz

Choose the best answer to each of the following. Explain your reasoning with one or more complete sentences.

27. Two stars that are in the same constellation (a) must both be part of the same cluster of stars in space. (b) must both have been discovered at about the same time. (c) may actually be very far away from each other.
28. The north celestial pole is 35° above your northern horizon. This tells you that (a) you are at latitude 35°N . (b) you are at longitude 35°E . (c) it is the winter solstice.
29. Beijing and Philadelphia have about the same latitude but very different longitudes. Therefore, tonight's night sky in these two places (a) will look about the same. (b) will have completely different sets of constellations. (c) will have partially different sets of constellations.
30. In winter, Earth's axis points toward the star Polaris. In spring, (a) the axis also points toward Polaris. (b) the axis points toward Vega. (c) the axis points toward the Sun.
31. When it is summer in Australia, it is (a) winter in the United States. (b) summer in the United States. (c) spring in the United States.
32. If the Sun rises precisely due east, (a) you must be located at Earth's equator. (b) it must be the day of either the spring or fall equinox. (c) it must be the day of the summer solstice.
33. A week after full moon, the Moon's phase is (a) first quarter. (b) third quarter. (c) new.
34. The fact that we always see the same face of the Moon tells us that (a) the Moon does not rotate. (b) the Moon's rotation period is the same as its orbital period. (c) the Moon looks the same on both sides.
35. If there is going to be a total lunar eclipse tonight, then you know that (a) the Moon's phase is full. (b) the Moon's phase is new. (c) the Moon is unusually close to Earth.
36. When we see Saturn going through a period of apparent retrograde motion, it means (a) Saturn is temporarily moving backward in its orbit of the Sun. (b) Earth is passing Saturn in its orbit, with both planets on the same side of the Sun. (c) Saturn and Earth must be on opposite sides of the Sun.

Process of Science

Examining How Science Works

37. *Earth-Centered or Sun-Centered?* The phenomena discussed in this chapter are all visible to the naked eye and therefore have been known throughout human history, including dur-

ing the thousands of years when Earth was assumed to be at the center of the universe. For each of the following, decide whether the phenomenon is consistent or inconsistent with a belief in an Earth-centered system. If consistent, describe how. If inconsistent, explain why, and also explain why the inconsistency did not immediately lead people to abandon the Earth-centered belief.

- a. The daily paths of stars through the sky
 - b. Seasons
 - c. Phases of the Moon
 - d. Eclipses
 - e. Apparent retrograde motion of the planets
38. *Shadow Phases.* Many people incorrectly guess that the phases of the Moon are caused by Earth's shadow falling on the Moon. How would you go about convincing a friend that the phases of the Moon have nothing to do with Earth's shadow? Describe the observations you would perform to show that Earth's shadow can't be the cause of phases.

Investigate Further

In-Depth Questions to Increase Your Understanding

Short-Answer/Essay Questions

39. *New Planet.* Suppose we discover a planet in another solar system that has a circular orbit and an axis tilt of 35° . Would you expect this planet to have seasons? If so, would you expect them to be more extreme than the seasons on Earth? If not, why not?
40. *Your View.*
 - a. Find your latitude and longitude, and state the source of your information.
 - b. Describe the altitude and direction in your sky at which the north or south celestial pole appears.
 - c. Is Polaris a circumpolar star in your sky? Explain.
41. *View from the Moon.* Assume you live on the Moon near the center of the face that looks toward Earth.
 - a. Suppose you see a full Earth in your sky. What phase of the Moon would people on Earth see? Explain.
 - b. Suppose people on Earth see a full moon. What phase would you see for Earth? Explain.
 - c. Suppose people on Earth see a waxing gibbous moon. What phase would you see for Earth? Explain.
 - d. Suppose people on Earth are viewing a total lunar eclipse. What would you see from your home on the Moon? Explain.
42. *View from the Sun.* Suppose you lived on the Sun (and could ignore the heat). Would you still see the Moon go through phases as it orbits Earth? Why or why not?
43. *A Farther Moon.* Suppose the distance to the Moon were twice its actual value. Would it still be possible to have a total solar eclipse? Why or why not?
44. *A Smaller Earth.* Suppose Earth were smaller. Would solar eclipses be any different? If so, how? What about lunar eclipses? Explain.
45. *Observing Planetary Motion.* Find out what planets are currently visible in your evening sky. At least once a week, observe the planets and draw a diagram showing the position of each visible planet relative to stars in a zodiac constellation. From week to week, note how the planets are moving relative to the stars. Can you see any of the apparently wandering features of planetary motion? Explain.

46. *A Connecticut Yankee*. Find the book *A Connecticut Yankee in King Arthur's Court* by Mark Twain. Read the portion that deals with the Connecticut Yankee's prediction of an eclipse (or read the entire book). In a one- to two-page essay, summarize the episode and explain how it helped the Connecticut Yankee gain power.

Quantitative Problems

Be sure to show all calculations clearly and state your final answers in complete sentences.

47. *Arcminutes and Arcseconds*. There are 360° in a full circle.
- How many arcminutes are in a full circle?
 - How many arcseconds are in a full circle?
 - The Moon's angular size is about $\frac{1}{2}^\circ$. What is this in arcminutes? In arcseconds?
48. *Latitude Distance*. Earth's radius is approximately 6,370 km.
- What is Earth's circumference?
 - What distance is represented by each degree of latitude?
 - What distance is represented by each arcminute of latitude?
 - Can you give similar answers for the distances represented by a degree or arcminute of longitude? Why or why not?
49. *Angular Conversions I*. The following angles are given in degrees and fractions of degrees. Rewrite them in degrees, arcminutes, and arcseconds.
- 24.3°
 - 1.59°
 - 0.1°
 - 0.01°
 - 0.001°
50. *Angular Conversions II*. The following angles are given in degrees, arcminutes, and arcseconds. Rewrite them in degrees and fractions of degrees.
- $7^\circ 38' 42''$
 - $12' 54''$
 - $1^\circ 59' 59''$
 - $1'$
 - $1''$
51. *Moon Speed*. The Moon takes about $27\frac{1}{3}$ days to complete each orbit of Earth. About how fast is the Moon going as it orbits Earth? Give your answer in km/hr.
52. *Scale of the Moon*. The Moon's diameter is about 3,500 km and its average distance from Earth is about 380,000 km. How big and how far from Earth is the Moon on the 1-to-10-billion scale used in Chapter 1? Compare the size of the Moon's orbit to the size of the Sun on this scale.
53. *Angular Size of Your Finger*. Measure the width of your index finger and the length of your arm. Based on your measurements, calculate the angular width of your index finger at arm's length. Does your result agree with the approximations shown in Figure 2.7c? Explain.
54. *Find the Sun's Diameter*. The Sun has an angular diameter of about 0.5° and an average distance of about 150 million km. What is the Sun's approximate physical diameter? Compare your answer to the actual value of 1,390,000 km.
55. *Find a Star's Diameter*. The supergiant star Betelgeuse (in the constellation Orion) has a measured angular diameter of 0.044 arcsecond. Its distance has been measured to be 427 light-years. What is the actual diameter of Betelgeuse? Compare your answer to the size of our Sun and the Earth-Sun distance.
56. *Eclipse Conditions*. The Moon's precise equatorial diameter is 3,476 km, and its orbital distance from Earth varies between 356,400 km and 406,700 km. The Sun's diameter is 1,390,000 km, and its distance from Earth ranges between 147.5 and 152.6 million km.
- Find the Moon's angular size at its minimum and maximum distances from Earth.
 - Find the Sun's angular size at its minimum and maximum distances from Earth.
 - Based on your answers to (a) and (b), is it possible to have a total solar eclipse when the Moon and Sun are both at their maximum distances? Explain.

Discussion Questions

57. *Earth-Centered Language*. Many common phrases reflect the ancient Earth-centered view of our universe. For example, the phrase "the Sun rises each day" implies that the Sun is really moving over Earth. We know that the Sun only *appears* to rise as the rotation of Earth carries us to a place where we can see the Sun in our sky. Identify other common phrases that imply an Earth-centered viewpoint.
58. *Flat Earth Society*. Believe it or not, there is an organization called the Flat Earth Society. Its members hold that Earth is flat and that all indications to the contrary (such as pictures of Earth from space) are fabrications made as part of a conspiracy to hide the truth from the public. Discuss the evidence for a round Earth and how you can check it for yourself. In light of the evidence, is it possible that the Flat Earth Society is correct? Defend your opinion.