TT TEXTBOOK TESTBANKS

Test Bank for Essential Cosmic Perspective 9th Bennett

TEST BANK SAMPLE PREVIEW

PUBLISHER
Pearson

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2022

RESOURCE TYPE
Test Bank

ISBN
9780135794968

***The Essential Cosmic Perspective, 9e* (Bennett et al.)**
Chapter 1 A Modern View of the Universe

Section 1.1

1) About where is our solar system located within the Milky Way Galaxy?
A) at the center of the galaxy
B) about 10 percent of the way from the center of the galaxy to the edge of the galactic disk
C) about halfway from the center of the galaxy to the edge of the galactic disk
D) near the far edge of the galactic disk
E) in the halo of the galaxy above the galactic disk
Answer: C

2) When we speak of the entire universe (as opposed to the *observable* universe), we mean ________.
A) all the stars and galaxies that we can see with telescopes
B) all material located within about 14 billion light-years of Earth
C) the sum total of all matter and energy
D) all the matter in galaxies, but not the spaces between the galaxies
Answer: C

3) Which of the following is the smallest distance?
A) Diameter of a typical planet
B) 1 light-second
C) 1 AU
D) Diameter of a typical star
Answer: A

4) Which of the following is the largest distance?
A) Diameter of a typical galaxy
B) Diameter of Pluto's orbit
C) Distance to the nearest star (other than our Sun)
D) 1 light-year
Answer: A

5) Which of the following statements does *not* use the term *light-year* in an appropriate way?
A) It's about 4 light-years from here to Alpha Centauri.
B) It will take me light-years to complete this homework assignment.
C) A light-year is about 10 trillion kilometers.
D) It will take the Voyager spacecraft about 20,000 years to travel just 1 light-year.
E) The Milky Way Galaxy is about 100,000 light-years in diameter.
Answer: B

6) One *light-minute* is the distance that light travels in one minute. How far is this, in kilometers? (Recall that the speed of light is 300,000 km/s.)
A) 300,000 km
B) 18 million km
C) 100 million km
D) 1.08 billion km
E) 9.46 trillion km
Answer: B

7) One light-year is approximately ________.
A) the distance from the Sun to Earth
B) the speed at which Earth orbits the Sun
C) 10 trillion kilometers
D) the same as one regular year
Answer: C

8) Light takes approximately one second to travel from Earth to the Moon. This means that the Moon is approximately ________.
A) 1 astronomical unit from Earth
B) 1 light-year from Earth
C) 3000 kilometers from Earth
D) 300,000 kilometers from Earth
E) near the top of Earth's atmosphere
Answer: D

9) Sunlight takes about 8.4 minutes to travel from the Sun to Earth. When NASA's *New Horizons* Spacecraft passed Pluto in 2015, it was about 32 AU from Earth. About how long did it take for transmitted images of Pluto to travel from the spacecraft to Earth?
A) One Plutonian year
B) 4-1/2 hours
C) 2-1/4 days
D) 3 weeks
E) They arrived almost instantaneously.
Answer: C

10) The *Voyager 2* Spacecraft is currently on its way out of our solar system at a speed of about 50,000 kilometers per hour. It will reach the distance of the nearest star system (beyond our solar system) in about ________ years.
A) 100
B) 1000
C) 10,000
D) 100,000
E) 1,000,000
Answer: D

11) Suppose we look at a photograph of many galaxies. Assuming that all galaxies formed at about the same time, which galaxy in the picture is the youngest?
A) The one that is farthest away
B) The one that is reddest in color
C) The one that is bluest in color
D) The one that is closest to us
E) The one that appears smallest in size
Answer: A

12) Suppose we imagine the Sun to be about the size of a grapefruit. Which of the following best describes the size and distance of Earth on the same scale?
A) Earth is the size of a tip of a ballpoint pen about 1 meter from the Sun.
B) Earth is the size of a golf ball about 1 meter from the Sun.
C) Earth is the size of a tip of a ballpoint pen about 15 meters from the Sun.
D) Earth is the size of a golf ball about 15 meters from the Sun.
E) Earth is the size of a marble about 25 miles from the Sun.
Answer: C

13) Suppose we imagine the Sun to be about the size of a grapefruit. How big an area would the orbits of the eight planets of the solar system cover?
A) The size of a typical dorm room
B) The size of a typical campus building
C) The size of a typical campus
D) The size of a small city
E) The size of a western state (e.g., Colorado)
Answer: C

14) Which of the following best describes the Milky Way Galaxy?
A) A spiral galaxy with a disk about 100,000 light-years in diameter
B) A spiral galaxy with a disk about 1 billion kilometers in diameter
C) A spiral galaxy with a disk about 1000 light-years in diameter
D) A spherically shaped galaxy that is about 4 light-years in diameter
E) A spherically shaped galaxy that is about 100,000 light-years in diameter
Answer: A

15) If we use 1 millimeter to represent 1 light-year, about how large in diameter is the Milky Way Galaxy?
A) 100 millimeters
B) 100 meters
C) 1 kilometer
D) 100 kilometers
E) 1 million millimeters
Answer: B

16) How long would it take to count all the stars in the Milky Way Galaxy at a rate of one star per second?
A) Several days
B) Several weeks
C) Several years
D) Several thousand years
E) Hundreds of thousands of years
Answer: D

17) About how many galaxies are there in the observable universe?
A) Roughly (within about a factor of 10) the same as the number of stars in our galaxy
B) A few dozen
C) A few thousand
D) About as many as the number of grains of sand on all the beaches on Earth
E) An infinite number
Answer: A

18) If you represented each star by a grain of sand, about how much sand would it take to represent all the stars in the observable universe?
A) All the sand in a typical playground sandlot
B) All the sand on Miami Beach
C) All the sand on the beaches of California
D) One cubic meter of sand
E) All the sand on all the beaches on Earth
Answer: E

19) The distance of Mars from the Sun is about 1.5 AU. How far is this in kilometers? (You do not need a calculator to answer this question. You do need to know what an AU is, within a factor of 1000.)
A) 1.5 150,000,000 km
B) 1.5 150,000 km
C) 150,000,000,000 / 1.5 km
D) 150,000,000 / 1.5 km
E) 1.5 150,000,000,000 km
Answer: A

20) One light-year is the distance light travels in one year. The speed of light is about 300,000 km/s (3×10^5 km/s). How far is 1 light-year?
A) 3×10^5 km
B) 1.8×10^7 km
C) 1.08×10^9 km
D) 9.46×10^{12} km
Answer: D

21) Light travels at a speed of 300,000 km/s. About how far is a light-year?
A) 10 million meters
B) 10 billion km
C) 300,000 km
D) 10 million km
E) 10 trillion km
Answer: E

22) Consider how the Moon moves through the Solar System and complete the following sentence. The Moon orbits *the Sun* ________.
A) once a month
B) once a year
C) once a day
Answer: B

23) Suppose you know the speed of a spacecraft in kilometers per second. How would you calculate its speed in kilometers per hour?
A) Multiply by 60 and then multiply by 60 again.
B) Divide by 60 and then divide by 60 again.
C) Multiply by 24.
D) Divide by 24.
Answer: B

24) How many seconds are in one year? (Calculate this, do not look it up.)
A) About 380 million (380,000,000, or 3.8×10^8)
B) About 30 million (30,000,000, or 3×10^7)
C) About 86 thousand (86,000, or 8.6×10^5)
D) About 3600 (3.6×10^3)
Answer: B

25) One light-hour is the distance light travels in one hour. The speed of light is about 300,000 km/s (3×10^5 km/s). If Jupiter is 0.72 light hours from the Sun, how far is this?
A) 216 thousand km (2.16×10^5 km)
B) 13 million km (1.3×10^7 km)
C) 778 million km (7.78×10^8 km)
D) 1.5 billion km (1.5×10^9 km)
Answer: C

26) The planet Mars is, on average, about 228 million km from the Sun. How long does it take light from the Sun to reach Mars? (Recall that the speed of light is about 300,000 km/s.)
A) About 8.4 minutes
B) About 12.7 minutes
C) About 1.52 light seconds
D) About 1.52 hours
Answer: B

27) The Earth has a radius of about 6000 km. How long would it take for an object traveling at the speed of light to circle the Earth? (Recall that the speed of light is 300,000 km/s.)
A) 1/300,000 of a second (0.0000033 s)
B) 1/6000 of a second (0.000017 s)
C) 1/8 of a second (0.0125 s)
D) 1/2 of a second (0.5 s)
Answer: C

Section 1.2

1) Suppose we look at two distant galaxies: Galaxy 1 is twice as far away as Galaxy 2. In that case ________.
A) we are seeing Galaxy 1 as it looked at an earlier time in the history of the universe than Galaxy 2
B) we can't say anything about these galaxies except for their distances
C) we are seeing Galaxy 1 as it looked at a later time in the history of the universe than Galaxy 2
Answer: A

2) Shortly after the Big Bang, the chemical composition of the universe was ________.
A) almost entirely hydrogen and helium
B) hydrogen only
C) about equal amounts of all the elements
D) about the same as it is today
Answer: A

3) About what percentage of the original hydrogen and helium of the universe had been converted into heavier elements by the time our solar system was born?
A) 20%
B) 10%
C) 50%
D) 2%
Answer: D

4) What is *nuclear fusion*?
A) An explosion caused by putting together two volatile chemicals
B) The process of splitting nuclei to produce energy
C) The process of turning matter into pure energy
D) The process of combining lightweight nuclei to make heavier nuclei
E) A process that only occurs in bombs
Answer: D

5) Earth is made mostly of metals and rocks. Where did most of the elements that make up these materials (carbon, silicon, iron, etc.) form?
A) They were produced by the Big Bang.
B) They were produced by chemical reactions in interstellar gas clouds.
C) They were produced by stars.
D) They were produced in our Sun.
E) They were produced by nuclear fission of uranium and other radioactive materials in space.
Answer: C

6) Why did Carl Sagan say that we are *star stuff*?
A) The composition of most stars (mostly hydrogen and helium) is about the same as the composition of our bodies.
B) Cosmic rays reaching Earth from distant astronomical sources may be one source of mutations that help evolution along.
C) Nearly every atom from which we are made once (before the solar system formed) was inside of a star.
D) Nearly every atom from which we are made was once inside our star, the Sun.
E) Sagan thought that all of us have the potential to be movie (or TV) stars like he was.
Answer: C

7) The Sun is made primarily of ________.
A) hydrogen and oxygen
B) hydrogen and helium
C) carbon and nitrogen
D) oxygen and carbon
E) nearly equal portions of all the elements
Answer: B

8) Our Sun formed ________ our galaxy formed.
A) before
B) at the same time that
C) billions of years after
D) within about 10 million years after
Answer: C

9) In what sense are galaxies cosmic recycling plants?
A) Every time one star dies, a new one of exactly the same size and mass is born.
B) As a galaxy rotates, its stars cycle around the galaxy center again and again, each time returning to exactly where they started.
C) New stars in galaxies form from gas that has been ejected by previous generations of stars.
D) New galaxies are continuously being formed from the remains of older galaxies.
Answer: C

10) On the scale of the cosmic calendar, in which the history of the universe is compressed to 1 year, when did the Sun and Earth form?
A) January
B) December
C) September
D) February
Answer: C

11) On the scale of the cosmic calendar, in which the history of the universe is compressed to 1 year, how long has human civilization (i.e., since ancient Egypt) existed?
A) About half the year
B) About a month
C) A few hours
D) A few seconds
E) Less than a millionth of a second
Answer: D

12) On the scale of the cosmic calendar, in which the history of the universe is compressed into 1 year, when did the dinosaurs become extinct?
A) In late December
B) In late November
C) In late October
D) In late September
E) In late August
Answer: A

13) On the scale of the cosmic calendar, in which the history of the universe is compressed into 1 year, when did Kepler and Galileo first discover that we live on a planet in a solar system?
A) 1 second ago
B) 1 day ago
C) 1 week ago
D) December 25
E) December 30
Answer: A

14) On the scale of the cosmic calendar, in which the history of the universe is compressed into 1 year, how long is the average human life span?
A) 0.2 millisecond
B) 0.2 second
C) 2 seconds
D) 2 minutes
E) 2 hours
Answer: B

15) Your textbook discusses the cosmic calendar, a model of the history of the universe scaled to a single year. The length of time represented by one month on this cosmic calendar is therefore closest to ________.
A) 1 billion years.
B) 1 1000 years.
C) 10 million years.
D) 10 billion years.
E) 1 million years.
Answer: A

16) What made most of the oxygen nuclei in the solar system?
A) Stars
B) Nothing makes elements—oxygen has always been present in the universe.
C) The Big Bang
D) Our Sun
E) High energy collisions of dust and cosmic rays
Answer: A

17) Astronomer Alan says the universe is expanding at one rate and Astronomer Wendy says it is expanding at a faster rate. All other things being equal, which astronomer would say that the universe is *older*?
A) Wendy
B) Alan
C) Neither
Answer: B

18) Astronomers have used observations from the Hubble Space Telescope to measure the rate at which the universe is expanding, and have estimated the age of the universe from that measured rate. Suppose the expansion turns out to be *faster* than current measurements indicate. In that case, our new estimate for the age of the universe would be ________.
A) Unaffected
B) Younger (less time between now and the Big Bang)
C) Older (more time between now and the Big Bang)
Answer: B

19) About how long does it take our solar system to complete one orbit around the center of the Milky Way Galaxy?
A) 10,000 years
B) 1 million years
C) 230 million years
D) 4-1/2 billion years
E) 14 billion years
Answer: C

20) What do astronomers mean when they say the universe is expanding?
A) Everything in the universe is gradually growing in size.
B) Average distances are increasing between most galaxies.
C) Average distances are increasing between most stars.
D) The universe is expanding from a single point.
Answer: B

21) How do scientists estimate the age of the universe?
A) They look up the answer in a book or they Google it.
B) They measure the abundances of radioactive elements in meteorites, and use their half-lives to calculate the age of the meteorites, which are the oldest solids in the solar system.
C) They measure the speeds and distances of galaxies, and calculate the time it took for them to travel that distance (away from us).
D) They make a guess: no one really knows how old the universe is.
E) They measure how fast the Sun is losing energy, and how much energy it has left to lose.
Answer: C

22) According to astronomers, approximately how old is the universe?
A) 14 billion years
B) 14 trillion years
C) Infinite
D) 14 million years
Answer: A

23) According to current scientific estimates, when did the Big Bang occur?
A) About 4.5 billion years ago
B) About 20 billion years ago
C) About 65 million years ago
D) About 14 billion years ago
E) About 10 billion years ago
Answer: D

Section 1.3

1) Approximately how fast is a person located at the Earth's equator moving around Earth's axis due to the rotation of the Earth?
A) 17,000 km/hr
B) 1700 km/hr
C) 170 km/hr
D) 17 km/hr
E) Not moving at all
Answer: B

2) Earth's rotation causes a person at the North Pole to ________ relative to the center of the Earth.
A) move at a speed of about 1670 km/hr
B) spin in place once each year
C) remain completely stationary
D) spin in place once each day
Answer: D

3) The *ecliptic plane* is ________.
A) the plane of Earth's orbit around the Sun
B) the plane of the Moon's orbit around Earth
C) the plane of our solar system's orbit around the Milky Way Galaxy
D) a flat disk of material that lies between the Sun and Earth
E) the plane defined by Earth's equator
Answer: B

4) We say that Earth has an axis tilt of 23-1/2° because this is the angle between Earth's ________.
A) rotation axis and a line perpendicular (vertical) to the ecliptic plane
B) rotation axis and the star Polaris
C) equator and rotation axis
D) rotation axis and north pole
E) rotation axis and magnetic axis
Answer: A

5) Patterns of stars in constellations hardly change in appearance over times of even a few thousand years. Why?
A) Stars are fixed and never move.
B) Stars move, but they move very slowly—only a few kilometers in a thousand years.
C) Although most stars move through the sky, the brightest stars do not, and these are the ones that trace the patterns we see in the constellations.
D) The stars in our sky actually move rapidly relative to us—thousands of kilometers per hour—but are so far away that it takes a long time for this motion to make a noticeable change in the patterns in the sky.
E) Stars within a constellation move together as a group, which tends to hide their actual motion and prevent the pattern from changing.
Answer: D

6) Which of the following correctly lists the described speeds from slowest to fastest?
A) Earth's orbital speed about the Sun
Earth's speed of rotation on its axis
Earth's orbital speed about the Sun
typical speeds of stars in the local solar neighborhood relative to us
the speed of our solar system orbiting the center of the Milky Way Galaxy
the speeds of very distant galaxies relative to us
B) typical speeds of stars in the local solar neighborhood relative to us
Earth's speed of rotation on its axis
Earth's orbital speed about the Sun
the speed of our solar system orbiting the center of the Milky Way Galaxy
the speeds of very distant galaxies relative to us
C) Earth's speed of rotation on its axis
Earth's orbital speed about the Sun
the speed of our solar system orbiting the center of the Milky Way Galaxy
the speeds of very distant galaxies relative to us
typical speeds of stars in the local solar neighborhood relative to us
D) Earth's orbital speed about the Sun
the speeds of very distant galaxies relative to us
Earth's speed of rotation on its axis
typical speeds of stars in the local solar neighborhood relative to us
the speed of our solar system orbiting the center of the Milky Way Galaxy
E) typical speeds of stars in the local solar neighborhood relative to us
the speed of our solar system orbiting the center of the Milky Way Galaxy
Earth's orbital speed about the Sun
the speeds of very distant galaxies relative to us
Earth's speed of rotation on its axis
Answer: A

7) What evidence leads astronomers to conclude that most of the Milky Way's mass consists of a mysterious *dark matter*?
A) We observe many dark clouds of gas that block the light of stars behind them.
B) The galaxy's rotation indicates that it must contain much more matter than we can observe with our telescopes.
C) Observations indicate that most stars are dimmer than the Sun, so we say they are "dark."
D) Stars are separated from one another by vast distances, and therefore most places in the galaxy would be dark to our eyes.
Answer: B

8) Most of the mass in the Milky Way Galaxy is located ________.
A) in the halo (above/below the disk)
B) within the disk
C) in the stars in the spiral arms
D) in the gas and dust
E) in the central bulge of the galaxy
Answer: A

9) The amount and distribution of matter in the Milky Way Galaxy is determined by ________.
A) counting the number of stars in the galaxy
B) determining the amount of gas and dust in the galaxy
C) studying where stars are located in the Milky Way
D) studying the rotation of the galaxy
E) adding together the mass of the galaxy's stars and gas
Answer: D

10) What evidence leads astronomers to conclude that the universe contains a mysterious *dark energy?*
A) The expansion of the universe is accelerating with time.
B) The gravity of distant galaxies is stronger than that of galaxies nearby.
C) Studies of galactic motion indicate that there is more matter in the universe than we can account for with stars and gas.
D) Stars shine much more brightly than we would expect from nuclear fusion.
E) The existence of such dark energy is the only way to account for evil in the universe.
Answer: A

11) From the fact that virtually every galaxy is moving away from us and more distant galaxies are moving away from us at a faster rate than closer ones, we conclude that ________.
A) the Milky Way Galaxy is expanding
B) we are located at the center of the universe
C) even nearby galaxies will eventually be moving faster than the speed of light
D) the universe is expanding
E) the universe is shrinking
Answer: D

12) By studying distant galaxies in the 1920s, Hubble made the following important discovery that led us to conclude that the universe is expanding.
A) All galaxies contain billions of stars, and all galaxies have spiral shapes.
B) All galaxies were born at the same time, and all will die at the same time.
C) All galaxies outside the Local Group are moving away from us, and the farther away they are, the faster they're going.
D) All galaxies outside the Local Group are orbiting the Local Group.
E) Galaxies are in motion throughout the universe, with about equal numbers moving toward us and away from us.
Answer: C

13) Imagine that we put a raisin cake into the oven, with each raisin separated from the others by 1 cm. An hour later, we take it out and the distances between raisins are 3 cm. If you lived in one of the raisins and watched the other raisins as the cake expanded, which of the following would you observe?
A) All raisins would be moving away from you at the same speed.
B) More distant raisins would be moving away from you faster.
C) More distant raisins would be moving away from you more slowly.
D) It depends: If you lived in a raisin near the edge of the cake, you'd see other raisins moving away from you, but they'd be coming toward you if you lived in a raisin near the center of the cake.
E) The raisins would be expanding too, so you'd never notice any changes in the cake.
Answer: B

14) Recall the raisin cake model of the universe and its analogy to our expanding universe. Suppose you measure the recession velocity (the speed at which any object is moving away from us) of Galaxy A to be 2000 km/s and the recession velocity of Galaxy B to be 6000 km/s. What can you conclude about the relative distances of these two galaxies?
A) Galaxy A is 3 times as far from us as Galaxy B.
B) Galaxy B is 3 times as far from us as Galaxy A.
C) Galaxy A is 6 times as far from us as Galaxy B.
D) Galaxy B is 6 times as far from us as Galaxy A.
E) The relative distances cannot be determined from the information in this problem.
Answer: B

15) The reason that we observe more distant galaxies to be moving away from us at higher speeds than nearby galaxies is that ________.
A) the more distant galaxies were flung outward faster by the Big Bang
B) the more distant galaxies are smaller and less massive, so they can move faster
C) the nearby galaxies are slowed by our own galaxy's gravitational pull
D) there is more space to expand between us and the distant galaxies
Answer: D

16) We observe that most galaxies are moving away from us. If we could (somehow) communicate with an observer in a distant galaxy, what would that observer say about what it sees?
A) Most galaxies are moving away from me, except for yours.
B) Most galaxies are moving away from me, including yours.
C) Most galaxies are moving away from you, and about half are moving towards me.
Answer: B

17) The farthest galaxies visible in Hubble Space Telescope photos are about ________ light-years away.
A) 1 million
B) 12 million
C) 1 billion
D) 12 billion
E) 12 trillion
Answer: D

18) Our solar system is located about 27,000 light-years from the galactic center. About how far does our solar system travel in one orbit?
A) 54,000 light-years
B) 85,000 light-years
C) 100,000 light-years
D) 170,000 light-years
Answer: D

19) You observe two distant galaxies (well outside our Local Group of galaxies). You find that Galaxy W is moving away from us at a speed of 35,000 km/s and Galaxy X is moving away from us at a speed of 70,000 km/s. What can you say about the distances to those galaxies?
A) Galaxy W is four times as far as Galaxy X.
B) Galaxy W is twice as far as Galaxy X.
C) She can't say anything about the distances to Galaxy W or X.
D) Galaxy X is four times as far as Galaxy W.
E) Galaxy X is twice as far as Galaxy W.
Answer: B

Short Answer Questions

1) The speed of light is 300,000 km/s. How far is a light-year? Be sure to show all work clearly on your calculations.
Answer: 1 light-year
= (speed of light) × (1 yr)

$$= \left(300{,}000 \times \frac{\text{km}}{\text{s}}\right) \times \left(1\text{ yr} \times \frac{365}{1\text{ yr}} \times \frac{24}{1\text{ day}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{60\text{ s}}{1\text{ min}}\right)$$

= 9,460,000,000,000 km

2) Earth's actual diameter is about 12,800 kilometers. What is Earth's diameter in a 1-to-10 billion scale model solar system? Show your work clearly.
Answer: Scaled radius of Earth = actual radius/10^{10}
= 6,378 km/10^{10}
= 6,378 × 10^5 cm/10^{10}
= 6.378 × 10^8 cm/10^{10}
= 6.378 × 10^{-2} cm
= 0.6 mm - This is about the size of the tip of a (fine tip) ballpoint pen.

Reading Quiz Questions

1) Which of the following is a general difference between a planet and a star?
A) Stars shine with energy released by nuclear fusion while planets shine primarily with light reflected from stars.
B) Stars are found in galaxies but planets are not part of galaxies.
C) Stars are made of gas and planets are made of rock.
D) Stars are stationary while planets orbit stars.
Answer: A

2) Our solar system consists of ________.
A) the Sun and all the objects that orbit it
B) the Sun and the planets, and nothing else
C) a few hundred billion stars, bound together by gravity
D) the Sun and several nearby stars, as well as the planets and other objects that orbit these stars
Answer: A

3) A typical galaxy is a ________.
A) collection of millions or billions of stars, bound together by gravity and orbiting a common center
B) large, glowing ball of gas powered by nuclear energy
C) nearby object orbiting a planet
D) relatively small, icy object orbiting a star
E) system consisting of one or a few stars orbited by planets, moons, and smaller objects
Answer: A

4) Which of the following best describes what we mean by the term universe?
A) The sum total of all matter and energy
B) A vast collection of stars that number as many as the grains of sand on all the beaches on Earth
C) All the galaxies in all the superclusters
D) Our Milky Way Galaxy
Answer: A

5) An astronomical unit (AU) is ________.
A) any very large unit, such as a light-year
B) the *average* distance between Earth and the Sun
C) the *current* distance between Earth and the Sun
D) the average distance between any planet and the Sun
Answer: B

6) A *light-year* is ________.
A) about 10 trillion kilometers
B) the time it takes light to reach the nearest star
C) the time it takes light to travel around the Sun
D) about 300,000 kilometers per second
Answer: A

7) A television advertisement claiming that a product is light-years ahead of its time does not make sense because ________.
A) it doesn't specify the number of light-years
B) it uses "light-years" to talk about time, but a light-year is a unit of distance
C) a light-year is an astronomically large unit, so a product could not possibly be so advanced
D) light-years can only be used to talk about light
Answer: B

8) The term *observable universe* refers to ________.
A) the portion of the universe that we have so far photographed through telescopes
B) the portion of the universe that can be seen by the naked eye
C) the portion of the universe that is not hidden from view by, for example, being below the horizon
D) the portion of the universe that we can see *in principle*, given the current age of the universe
Answer: D

9) On a scale where the distance from Earth to the Sun is about 15 meters, the distance from Earth to the Moon is ________.
A) small enough to fit within your hand
B) about 1 meter
C) about 5 meters
D) about 30 meters
Answer: A

10) On a scale where the Sun is about the size of a grapefruit and the Earth is about 15 meters away, how far away are the nearest stars besides the Sun?
A) 100 meters
B) About the distance across 50 football fields
C) About the distance across the state of Delaware
D) About the distance across the United States
Answer: D

11) The number of stars in the Milky Way Galaxy is approximately ________.
A) a few hundred
B) a few hundred thousand
C) a few hundred billion
D) a few hundred million
Answer: C

12) What do astronomers mean by the *Big Bang*?
A) The event that marked the beginning of the expansion of the universe
B) A gigantic explosion that blew all the galaxies in the universe to smithereens
C) The explosion of a massive star at the end of its life
D) The event that marked the birth of our solar system
Answer: A

13) What do we mean when we say that the universe is *expanding*?
A) Everything in the universe is gradually growing in size.
B) Within galaxies, average distances between star systems are increasing with time.
C) The statement is not meant to be literal; rather, it means that our knowledge of the universe is growing.
D) Average distances between galaxies are increasing with time.
Answer: D

14) Based on observations of the universal expansion, the age of the universe is about ________.
A) 14,000 years
B) 14 million years
C) 14 billion years
D) The universe is younger than this.
Answer: C

15) If the 14 billion year history of the universe were compressed to one year, and "now" is exactly midnight December 31, approximately how long ago were your grandparents born?
A) 0.15 second ago
B) 1 second ago
C) 1 minute ago
D) 1 hour ago
Answer: C

16) What is the *ecliptic plane*?
A) The plane of Earth's orbit around the Sun
B) The plane of Earth's equator
C) The plane of the Sun's equator
D) The plane of the Milky Way Galaxy
Answer: A

17) How long does it take the Earth to complete one orbit around the Sun?
A) One year
B) One day
C) One month
D) One week
E) The time it takes Earth to orbit the Sun changes significantly from one orbit to the next.
Answer: A

18) What is the "raisin cake analogy" to the expanding universe intended to explain?
A) That as a raisin cake expands, every raisin moves away from every other raisin, just as galaxies move away from each other in an expanding universe
B) That raisins, like galaxies, expand in size as the cake or universe expands
C) That from within the raisin cake, you would see other raisins moving away from you only if you were on the central raisin, just as you see galaxies moving away only if you are in the center of the universe
D) That the universe heats up as it expands, just as the raisin cake heats up as it bakes
Answer: A

Concept Quiz Questions

1) Which of the following has your "cosmic address" in the correct order?
A) You, Earth, solar system, Local Group, Local Supercluster, Milky Way Galaxy, universe
B) You, Earth, solar system, Milky Way Galaxy, Local Group, Local Supercluster, universe
C) You, Earth, Local Group, Local Supercluster, solar system, Milky Way Galaxy, universe
D) You, Earth, solar system, Local Group, Milky Way Galaxy, Local Supercluster, universe
E) You, Earth, Milky Way Galaxy, solar system, Local Group, Local Supercluster, universe
Answer: B

2) When we look at an object that is 1,000 light-years away we see it ________.
A) as it was 1,000 years ago
B) as it was 1,000 light-years ago
C) as it is right now, but it appears 1,000 times dimmer
D) looking just the same as our ancestors would have seen it 1,000 years ago
Answer: A

3) Suppose we look at two distant galaxies: Galaxy 1 is twice as far away as Galaxy 2. In that case ________.
A) Galaxy 1 must be twice as big as Galaxy 2
B) we are seeing Galaxy 1 as it looked at an *earlier* time in the history of the universe than Galaxy 2
C) we are seeing Galaxy 1 as it looked at a *later* time in the history of the universe than Galaxy 2
D) Galaxy 2 must be twice as old as Galaxy 1
Answer: B

4) Could we see a galaxy that is 20 billion light-years away? (Assume that we mean a "lookback time" of 20 billion years.)
A) No, because it would be beyond the bounds of our observable universe.
B) Yes, if we had a big enough telescope.
C) No, because a galaxy could not possibly be that far away.
D) Yes, we have already detected galaxies at that distance.
Answer: A

5) Suppose we make a scale model of our solar system, with the Sun the size of a grapefruit. Which of the following best describes what the planets would look like?
A) The planets are all much smaller than the Sun. Four planets are within about 20 meters of the Sun, while the rest planets are spread much farther apart.
B) The planets are all much smaller than the Sun and are spread out evenly over a distance about the length of a large classroom.
C) The planets are all much smaller than the Sun. Four planets are located within a few centimeters of the Sun, and four planets are located at distances ranging up to about a meter.
D) The planets range in size from about the size of a marble to the size of a baseball. They are spread out over a region about the size of a football field.
Answer: A

6) If you could count stars at a rate of about one per second, how long would it take to count all the stars in the Milky Way Galaxy?
A) Several days
B) Several weeks
C) Several years
D) Several thousand years
Answer: D

7) The total number of stars in the observable universe is about ________.
A) 100 billion
B) the same as the number of grains of sand in a school sandbox
C) the same as the number of grains of sand on all the beaches on Earth
D) the same as the number of atoms that make up the Earth
Answer: C

8) Using the ideas discussed in your text, in what sense are we "star stuff"?
A) The overall chemical composition of our bodies is about the same as that of stars.
B) Movie stars and other people are all made of the same stuff, so we all have the potential to be famous.
C) Nearly every atom from which we are made was once inside of a star.
D) We could not survive without light from our star, the Sun.
Answer: C

9) How are galaxies important to our existence?
A) Without galaxies, there could not have been a Big Bang.
B) Without galaxies, the universe could not be expanding.
C) Deep in their centers, galaxies created the elements from which we are made.
D) Galaxies recycle material from one generation of stars to the next, and without this recycling we could not exist.
Answer: D

10) If we imagine the history of the universe compressed into one year, with the present as the stroke of midnight at the very end of that year, dinosaurs became extinct ________.
A) about 6 months ago
B) about 3 weeks ago
C) yesterday morning
D) about an hour ago
Answer: C

11) Relative to the age of the universe, how old is our solar system?
A) It is about 1% as old as the universe.
B) It is between about 5% and 10% as old as the universe.
C) It is about one-third the age of the universe.
D) It is nearly the same age as the universe.
Answer: C

12) How do the speeds at which we are moving with Earth's rotation and orbit compare to the speeds of more familiar objects?
A) Earth's rotation carries most people around the axis faster than a commercial jet travels, and Earth's orbit carries us around the Sun faster than the Space Station orbits Earth.
B) Earth's rotation carries most people around the axis at about the speed of a commercial jet, and Earth's orbit carries us around the Sun at about the speed of a military jet.
C) Earth's rotation carries most people around the axis at about the speed of a car on the freeway, and Earth's orbit carries us around the Sun at about the speed of a commercial jet.
D) Earth's rotation carries most people around the axis at about the speed at which the Space Station orbits Earth, and Earth's orbit carries us around the Sun at nearly the speed of light.
Answer: A

13) Why do the patterns of the stars in our sky look the same from year to year?
A) Because the stars in the constellations are so far away.
B) Because the stars in the constellations are not moving.
C) Because the stars in the constellations all move at the same speeds and in the same directions, so they don't change their relative positions.
D) Because the stars in the constellations move so slowly — typically about the speed of a snail — that their motions are not noticeable.
Answer: A

14) Where is our solar system located within the Milky Way Galaxy?
A) Very near the center of the galaxy
B) At the far edge of the galaxy's visible disk
C) Roughly halfway between the center and the edge of the visible disk of the galaxy
D) In the halo of the galaxy
Answer: C

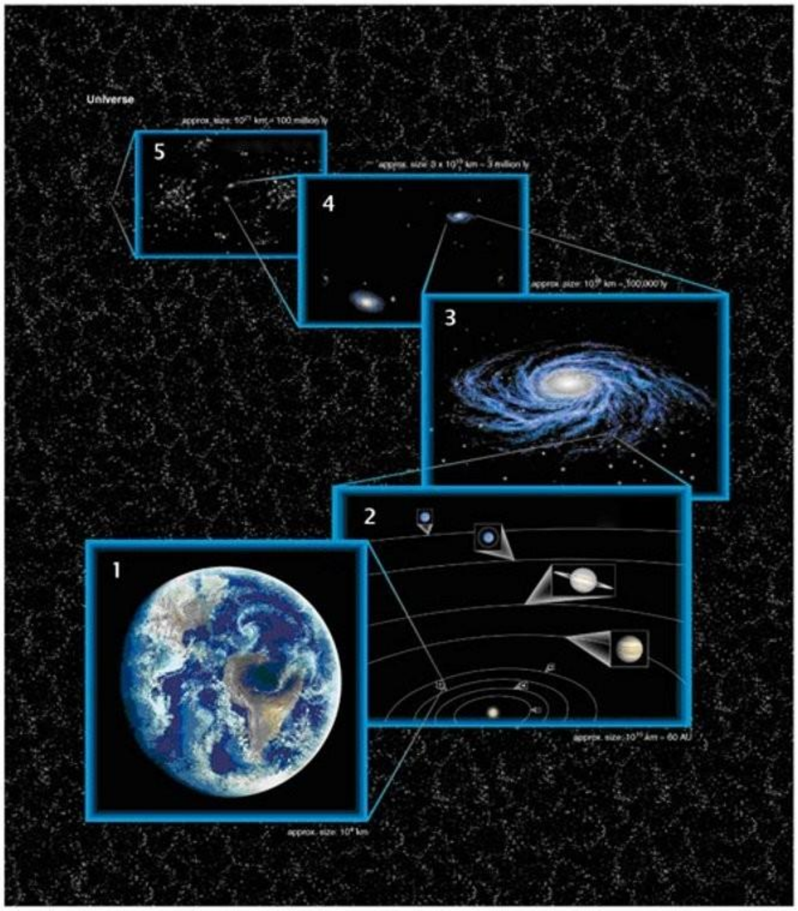
15) Consider a raisin cake expanding uniformly in an oven. Viewed from one of the raisins, you would see ________.
A) all other raisins moving away from you, with more distant raisins moving faster
B) all other raisins moving away from you, with more distant raisins moving slower
C) all other raisins moving away from you at the same speed
D) all raisins, including your own, growing in size as the cake expands
Answer: A

16) Astronomers infer that the universe is expanding because distant galaxies all appear to ________.
A) be growing in size
B) be moving away from us, with more distant ones moving faster
C) be made mostly of dark matter
D) rotate rapidly
Answer: B

17) Which statement about motion in the universe is *not* true?
A) The mysterious *dark matter* is the fastest-moving material in the universe.
B) Some stars in the Milky Way Galaxy are moving toward us and others are moving away from us.
C) Except for a few nearby galaxies, all other galaxies are moving away from us.
D) Your speed of rotation around Earth's axis is faster if you live near the equator than if you live near the North Pole.
Answer: A

Visual Quiz Questions

1) Each box in this figure represents a different level of structure in our universe. Each box is labeled with one of the numbers 1–5. Which box represents the Milky Way Galaxy?

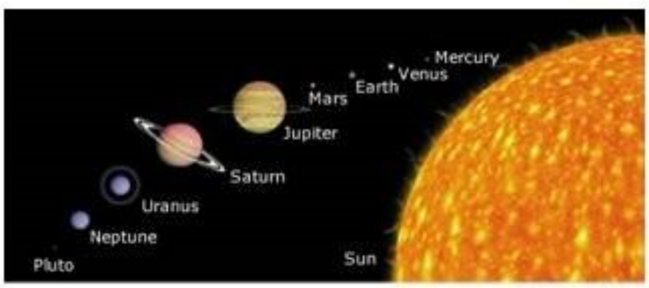


A) 1
B) 2
C) 3
D) 4
E) 5
Answer: C

2) What does this photograph show?

A) It is a picture of our own Milky Way Galaxy.
B) It is a picture of the Andromeda galaxy, located about 2.5 million light-years away.
C) It is a picture of a cloud of gas known as the Orion Nebula.
D) It is a picture of our own solar system.
E) It is a picture of a young star in the process of being born.
Answer: B

3) This painting represents the Sun and planets (and two dwarf planets) of our solar system. What is *not* to scale in this painting?

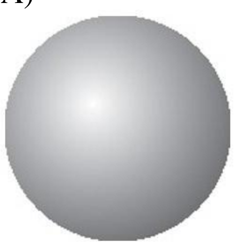


A) The sizes of the planets are not correctly scaled compared to each other or the Sun.
B) The distances between the planets are not shown to scale.
C) The Sun is too big compare to the planets.
D) Everything is correctly scaled, but the planets are shown in the wrong order from the Sun.
E) Neither distances nor sizes are correctly scaled.
Answer: B

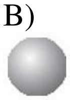
4) What is the significance of this photograph?

A) It shows the first person ever to land on Mars.
B) It shows a person standing on the most distant world ever visited by a human being.
C) It shows the first person ever to go into space.
D) It was taken Jan. 1, 2000, to commemorate the turn of the millennium.
Answer: B

5) Suppose we made a scale model of our Milky Way Galaxy in which the disk of the galaxy is the size of a football field. Which (if any) diagram represents the Sun on the same scale?
A)



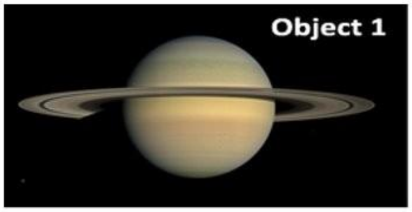
B)



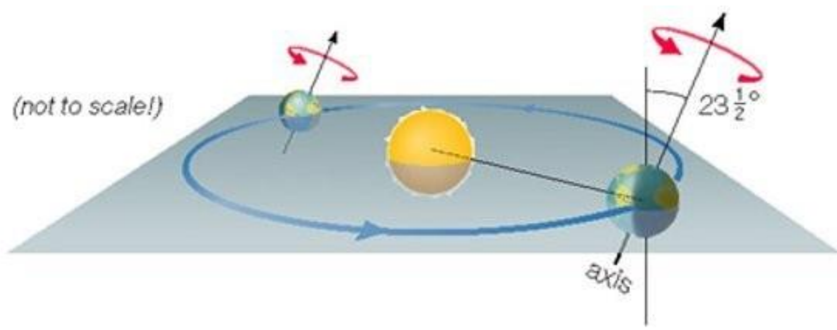
C)

D) The Sun on this scale would be about two feet in diameter and too big to show on the screen.
E) The Sun on this scale would be microscopic and too small to see on the screen.
Answer: E

6) These photos show two different astronomical objects. Which object is bigger, and by about how much?



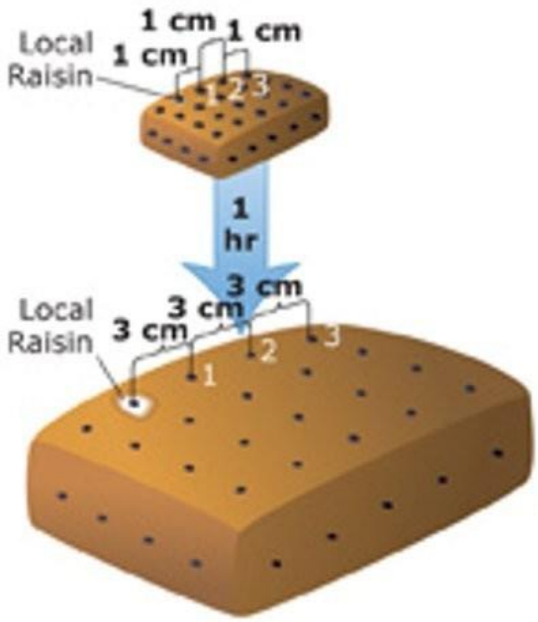
A) Object 2 is more than a trillion times as large as Object 1.
B) Object 2 is approximately 1,000 times as large as Object 1.
C) Object 2 is about 10 times as large as Object 1.
D) Object 1 is about 10 times as large as Object 2.
E) Both objects are about the same size.
Answer: A



7) This diagram represents Earth's rotation and orbit. What do we call the flat blue plane shown in this diagram?
A) The solar plane
B) The ecliptic plane
C) Earth's axis
D) The galactic plane
E) An astronomical unit
Answer: B

8) Notice that Earth's axis is shown with an arrowhead in this diagram. What does the arrow point to?
A) The Sun
B) The ecliptic plane
C) The center of the Milky Way Galaxy
D) Polaris, the North Star
E) The Northern lights
Answer: D

9) These diagrams show a raisin cake before it is put in the oven and again one hour later after it has expanded during baking. Suppose you lived in Raisin 3 (the raisin labeled "3"). What would you have noticed about Raisin 2 during baking?



A) Raisin 2 is moving away from you at a speed of 4 cm/hr.
B) Raisin 2 always stays in the same place but gets bigger in size.
C) Raisin 2 is moving away from you at a speed of 2 cm/hr.
D) Raisin 2 is moving away from you at a speed of 6 cm/hr.
E) Raisin 2 is moving toward you at a speed of 2 cm/hr.
Answer: C

10) Nearly all of the objects that you can see in this photograph are ________.

A) planets
B) stars
C) galaxies
D) astronomical units
Answer: C

End-of-Chapter Questions

Visual Skills Check
Use the following questions to check your understanding of some of the many types of visual information used in astronomy.

The figure above shows the sizes of Earth and the Moon to scale; the scale used is 1 cm = 4000 km. Using what you've learned about astronomical scale in this chapter, answer the following questions. (Hint: If you are unsure of the answers, you can calculate them using the given data.)

Earth—Sun distance = 150,000,000 km
Diameter of Sun = 1,400,000 km
Earth—Moon distance = 384,000 km
Diameter of Earth = 12,800 km

1) If you wanted to show the *distance* between Earth and the Moon on the same scale, about how far apart would you need to place the two photos?
A) 10 centimeters (about the width of your hand)
B) 1 meter (about the length of your arm)
C) 100 meters (about the length of a football field)
D) 1 kilometer (a little more than a half mile)
Answer: B

2) Suppose you wanted to show the Sun on the same scale. About how big would it need to be?
A) 3.5 centimeters in diameter (the size of a golf ball)
B) 35 centimeters in diameter (a little bigger than a basketball)
C) 3.5 meters in diameter (about 11-1/2 feet across)
D) 3.5 kilometers in diameter (the size of a small town)
Answer: C

3) About how far away from Earth would the Sun be located on this scale?
A) 3.75 meters (about 12 feet)
B) 37.5 meters (about the height of a 12-story building)
C) 375 meters (about the length of four football fields)
D) 37.5 kilometers (the size of a large city)
Answer: C

4) Could you use the same scale to represent the distances to nearby stars? Why or why not?
Answer: No. The nearest stars would not fit on Earth using this scale. The total distance to the nearest star would wrap around the Earth about 2.5 times!

Chapter Review Questions

1) Briefly describe the major levels of structure (such as planet, star, galaxy) in the universe.

2) Define *astronomical unit* and *light-year*.

3) Explain the statement *The farther away we look in distance, the further back we look in time.*

4) What do we mean by the *observable universe*? Is it the same thing as the entire universe?

5) Using techniques described in the chapter, put the following into perspective: the size of our solar system; the distance to nearby stars; the size and number of stars in the Milky Way Galaxy; the number of stars in the observable universe.

6) What do we mean when we say that the universe is *expanding*, and how does expansion lead to the idea of the *Big Bang* and our current estimate of the age of the universe?

7) In what sense are we "star stuff"?

8) Use the cosmic calendar to describe how the human race fits into the scale of time.

9) Briefly explain Earth's daily rotation and annual orbit, defining the terms *ecliptic plane* and *axis tilt.*

10) Briefly describe our solar system's location and motion within the Milky Way Galaxy.

11) Why do scientists suspect that most of our galaxy's mass consists of *dark matter*? Briefly describe the mystery of dark matter and *dark energy*.

12) What key observations lead us to conclude that the universe is expanding? Use the raisin cake model to explain how these observations imply expansion.

Does It Make Sense?
Decide whether or not each of the following statements makes sense (or is clearly true or 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.

13) Our solar system is bigger than some galaxies.

14) The universe is billions of light-years in age.

15) It will take me light-years to complete this homework assignment!

16) Someday we may build spaceships capable of traveling a light-year in only a decade.

17) Astronomers discovered a moon that does not orbit a planet.

18) NASA will soon launch a spaceship that will photograph our Milky Way Galaxy from beyond its halo.

19) The observable universe is larger today than it was a few billion years ago.

20) Photographs of distant galaxies show them as they were when they were much younger than they are today.

21) At a nearby park, I built a scale model of our solar system in which I used a basketball to represent Earth.

22) Because nearly all galaxies are moving away from us, we must be located near the center of the universe.

Quick Quiz

Choose the best answer to each of the following. For additional practice, try the Chapter 1 Reading and Concept Quizzes in the Study Area at www.MasteringAstronomy.com.

23) 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
Answer: No Correct Answer Was Provided.

24) 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
Answer: No Correct Answer Was Provided.

25) The star Betelgeuse is about 600 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 about 600 years from now
Answer: No Correct Answer Was Provided.

26) 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 are the size of basketballs and the nearest stars are a few miles away
B) the planets are marble-size or smaller and the nearest stars are thousands of miles away
C) the planets are microscopic and the stars are light-years away
Answer: No Correct Answer Was Provided.

27) 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
Answer: No Correct Answer Was Provided.

28) 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
Answer: No Correct Answer Was Provided.

29) 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 of galaxies
C) we would not exist because we are made of material that was recycled in galaxies
Answer: No Correct Answer Was Provided.

30) Could we see a galaxy that is 50 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
Answer: No Correct Answer Was Provided.

31) 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) 2 billion years younger than the age of the universe
Answer: No Correct Answer Was Provided.

32) 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
Answer: No Correct Answer Was Provided.

Inclusive Astronomy
Use these questions to reflect on participation in science.

33) *Group Discussion: What does a scientist look like?* The purpose of this exercise is to help you identify preconceptions that you or others may have about science and scientists.
a. Working independently, make a simple sketch of a professional scientist and write down five words that describe the scientist in your sketch. Then join with a group of two or three other students to share your sketches and word lists.
b. Make a list of all the words the group wrote down, then rank them in order of how often they were used.
c. Discuss any similarities, differences, or patterns you notice among the scientists described by the group members.
d. Discuss whether the group members feel they have much in common with professional scientists.
e. Discuss how feelings about what you have (or do not have) in common with scientists might affect your approach to scientific thinking.

The Process of Science

These questions may be answered individually in short-essay form or discussed in groups, except where identified as group-only.

34) *Earth as a Planet.* For most of human history, scholars assumed Earth was the center of the universe. Today, we know that Earth is just one planet orbiting the Sun, and the Sun is just one star in a vast universe. How did science make it possible for us to learn these facts about Earth?

35) *Thinking About Scale.* One key to success in science is finding a simple way 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.

36) *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 want to see before accepting the idea. (*Hint*: It's okay to look ahead in the book to see the evidence presented in later chapters.)

37) *A Human Adventure.* Astronomical discoveries clearly are important to science, but are they also important to our personal lives? Defend your opinion.

38) *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 through 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.

39) *Group Activity: Counting the Milky Way's Stars.* Work as a group to answer each part. *Note*: This activity works particularly well in groups of four students, with each student taking on one of the following roles: *scribe:* takes notes on the group's activities; *proposer:* suggests tentative explanations to the group; *skeptic:* points out weaknesses in proposed explanations; *moderator:* leads group discussion and makes sure everyone contributes.

a. Work together to estimate the number of stars in the Milky Way from just these two facts: (1) the number of stars within 12 light-years of the Sun, which you can count in Appendix F, and (2) the total volume of the Milky Way's disk (100,000 light-years in diameter and 1000 light-years thick), which is about 1 billion times the volume of the region of your star count.

b. Discuss how your value from part a compares to the value given in this chapter. Make a list of possible reasons why your technique may have underestimated or overestimated the actual number.

Investigate Further

40) *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 aliens' technology 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 with the distances we currently are capable of traveling.)

41) *Raisin Cake Universe.* Suppose that all the raisins in a cake are 1 centimeter apart before baking and 4 centimeters apart after baking.
a. Draw diagrams to represent the cake before and after baking.
b. 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.
c. Briefly explain how your expanding cake is similar to the expansion of the universe.

42) *The Hubble Extreme Deep Field.* The photo that opens this chapter is called the Hubble Extreme Deep Field. Find this photo on the Hubble Space Telescope website. Learn how it was taken, what it shows, and what we've learned from it. Write a short summary of your findings.
Answer: No Correct Answer Was Provided.

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.
Answer: No Correct Answer Was Provided.

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:
a. 1 light-second
b. 1 light-minute
c. 1 light-hour
d. 1 light-day

45) *Moonlight and Sunlight.* How long does it take light to travel from
a. the Moon to Earth?
b. the Sun to Earth?

46) *Saturn versus the Milky Way.* Photos of Saturn and photos of galaxies can look so similar that children often think the photos show similar objects. 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.)

47) *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. How long would it take to drive

a. around Earth's equator? (Earth's circumference ≈ 40,000 km)
b. from the Sun to Earth?
c. from the Sun to Pluto? (Pluto distance ≈ 5.9×10^9 km)
d. to Alpha Centauri (4.4 light-years away)?

48) *Faster Trip.* Suppose you wanted to reach Alpha Centauri in 100 years.

a. How fast would you have to go, in km/hr?
b. How many times faster is the speed you found in part a than the speeds of our fastest current spacecraft (around 50,000 km/hr)?

49) *Galaxy Scale.* Consider the 1-to-1019 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) *Age of the Universe*. Suppose we did not yet know the expansion rate of the universe, and two astronomers came up with two different measurements: Wendy measured an expansion rate for the universe that was 50% faster than the expansion rate Allan measured. Was the age of the universe that Allan inferred older or younger than the age that Wendy inferred? By how much? Explain. (*Hint*: Read the discussion of the raisin cake analogy carefully, and the answer should become clear.)

Chapter-by-Chapter Guide

Part I: Developing Perspective

The remainder of this *Instructor Guide* goes through the book chapter by chapter. Each chapter is organized as follows:

- A brief introduction with general comments about the chapter.
- Teaching Notes. Organized section by section for the chapter, these are essentially miscellaneous notes that may be of use to you when teaching your course.
- Answers/Discussion Points for Think About It and See It for Yourself questions.
- Solutions to end-of-chapter problems.

Chapter 1. A Modern View of the Universe

The purpose of this first chapter is to provide students with the contextual framework they need to learn the rest of the course material effectively: a general overview of the scale of the universe (Section 1.1), the history of the universe and the scale of time (Section 1.2), and an overview of motion in the universe (Section 1.3). We often tell students that, after completing this first chapter, they have essentially learned all the major ideas of astronomy, and the rest of the course will build the detailed scientific case for these general ideas.

As always, when you prepare to teach this chapter, be sure that you are familiar with the online quizzes, interactive figures, media, tutorials, assignable homework, and other resources available on the Mastering Astronomy website.

Key Changes for the Ninth Edition: For those who have used earlier editions of our textbook, please note the following significant changes in this chapter:

- Clarifications on number of galaxies in the universe to reflect recent discoveries.
- Updated Special Topic on Pluto and planet definition.
- New Figure 1.8 to help students understand the scale of the galaxy.
- Revised and simplified discussion of motion within the Milky Way Galaxy.

Note on Mathematics: The MasteringAstronomy website has a set of Math Review videos and brief, assignable tutorials that we created to cover basic topics like fractions, scientific notation, and unit analysis. Those instructors who include some mathematical work (such as covering the Cosmic Calculations boxes or assigning end-of-chapter quantitative exercises) may wish to assign these videos and tutorials along with the first couple of chapters of the text.

Teaching Notes (by Section)

Section 1.1 The Scale of the Universe

This section provides a brief overview of our place in the universe, including the hierarchical structure of the universe (our cosmic address) and the scale of the universe.

- Our emphasis on scale may seem unusual to those who have not taught from our book previously. However, we believe it is an extraordinarily important topic that generally is underappreciated by students. Most students enter our course without any realistic view of the true scale of the universe, and without the context of scale, they are likely to misinterpret much of the rest of the content and detail in an astronomy course. That is why, in addition to the discussion of scale in this section and throughout the book, we have also included the foldout "You Are Here in Space" in the front of the book, so students can refer to ideas of scale at any time.
- Note that the section begins with a brief discussion of the Hubble eXtreme Deep Field, which helps set the context for an overview of our place in the universe.
- Note the box titled "Basic Astronomical Definitions": Although some of the terms in this box are not discussed immediately, having them here in the beginning of the book should be helpful to students. All these terms also appear in the Glossary, but they are so basic and important that we want to emphasize them in Chapter 1.
- This section introduces astronomical distance measurements in AU and light-years. A couple of notes on our choices and definitions:
    - There are several different ways to define an average distance between Earth and the Sun (e.g., averaged over phase, or over time). In defining an astronomical unit (AU) as the *average* distance between Earth and the Sun, we are using the term *average* to mean (perihelion + aphelion)/2, which is equivalent to the semimajor axis. This has advantages when it comes to discussing Kepler's third law, as it is much easier for students to think of a in the equation $p^2 = a^3$ as *average* than as *semimajor axis*.
    - Note that we've chosen to use *light-years* rather than *parsecs* as our primary unit for stellar and galactic distances for three reasons: (1) We have found that light-years are more intuitively understandable than parsecs to most students, because light-years require only an understanding of light travel times, and not of the more complex trigonometry of parallax. (2) Lookback time is one of the most important concepts in astronomy, and use of light-years makes it far easier to think about lookback times (e.g., when a student hears that a star is 100 light-years away, he or she can immediately recognize that we're seeing light that left the star 100 years ago). (3) Fortuitously, 1 light-year happens to be very close to 10^{13} kilometers (9.46×10^{12} kilometers), making unit conversions very easy—this helps students remember that light-years are a unit of distance, not of time.

- Note that in discussing distances to very distant galaxies, we give distances in terms of lookback times; for example, when we say "7 billion light-years," we mean a lookback time of 7 billion years. With this definition, the radius of the observable universe is about 14 billion light-years, corresponding to the age of the universe. Unfortunately, some media reports instead quote distances as they would be today with the ongoing expansion, hence saying that the universe is 40+ billion light-years in radius. As a result, some students may be confused about which is the "real" radius of the observable universe. To alleviate this confusion, we point out that:
  - "Distance" is ambiguous in an expanding universe; for example, do you mean an object's distance at the time the light left, or now, or some time in between? The choice is arbitrary, with no particular choice (such as "now") being any better than any other (such as "at the time the light left").
  - In contrast, "lookback time" is unambiguous—it is the actual amount of time that the light has been traveling to reach us. For this reason, we feel that lookback time is a much better way to describe distances.
- For our discussion of scale, we begin by making use of the 1-to-10-billion scale of the Voyage scale model solar system in Washington, D.C., a project that was proposed by *The Essential Cosmic Perspective* lead author Jeff Bennett. Voyage replicas are being developed for other science centers and universities; if you are interested in learning more about how to get a Voyage replica in your town, please contact Jeff by email (jeff@bigkidscience.com).
- With regard to the count to 100 billion, it can be fun in lecture to describe what happens when you ask children how long it would take. Young children inevitably say they can count much faster than one per second. But what happens when they get to, say, "twenty-four billion, six hundred ninety-seven million, five hundred sixty-two thousand, nine hundred seventy-seven . . ."? How fast can they count now? And can they remember what comes next?
- Regarding our statement that there are "more than 100 billion large galaxies in the observable universe." You have probably heard news reports suggesting that the number of galaxies is more than 1 trillion. However, these reports are including galaxy counts in different epochs (based on distant observations), and there were more galaxies in the past than there are today, due to mergers. In addition, the number of galaxies depends on the cutoff size used. That is why we qualify our statement as "large" galaxies, meaning comparable in size to the Milky Way, for which 100 to 200 billion remains a reasonable estimate.
- Regarding our claim that the number of stars in the observable universe is roughly the same as the number of grains of sand on all the beaches on Earth, here are the assumptions we've made:
  - We are using 10^{22} as the number of stars in the universe. Assuming that grains of sand typically have a volume of 1 mm^3 (correct within a factor

of 2 or 3), 10^{22} grains of sand would occupy a volume of 10^{22} mm^3, or 10^{13} m^3.

- We estimate the depth of sand on a typical beach to be about 2–5 meters (based on beaches we've seen eroded by storms) and estimate the width of a typical beach at 20–50 meters; thus, the cross-sectional area of a typical beach is roughly 100 m^2.
- With this 100 m^2 cross-sectional area, it would take a length of 10^{11} meters, or 10^8 kilometers, to make a volume of 10^{13} m^3. This is almost certainly greater than the linear extent of sandy beaches on Earth. In fact, according to the "CIA Factbook," the total length of sandy beach on Earth is only about 360,000 kilometers.

Section 1.2 The History of the Universe

This section provides a brief overview of our place in time, including an overview of the history of the universe (our cosmic origins) and the scale of time.

- As in the first section, we include a major emphasis on scale—in this case, the scale of time. Be sure to point out the back side of the foldout in the front of the book, which is called "You Are Here in Time" and is in some sense a summary of this section.
- We give the age of the universe as "about 14 billion years"; we believe this rounding to two significant digits makes it easier for students to understand, given that the current best estimate of age (from the *Planck* mission) is 13.82 billion years, with a 1-sigma error bar of about 0.1 billion years.
- The idea of a "cosmic calendar" was popularized by Carl Sagan. Now that we've calibrated the cosmic calendar to a cosmic age of 14 billion years, note that 1 average month = 1.17 billion years.

Section 1.3 Spaceship Earth

This section completes our overview of the "big picture" of the universe by focusing on motion in the context of the motions of Earth in space, using R. Buckminster Fuller's idea of *Spaceship Earth*.

- Note that the summary figure for this section, Figure 1.17, comes at the section's end.
- We use the term *tilt*, rather than *obliquity*, as part of our continuing effort to limit the use of jargon.
- We note that universal expansion generally is not discussed until very late in other books. However, it's not difficult to understand through the raisin cake analogy; most students have heard about it before (although few know what it means); and it's one of the most important aspects of the universe as we know it today. Given all that, why wait to introduce it?
- Similarly, we briefly introduce the ideas of dark matter and dark energy, since students have almost undoubtedly heard of them in the media.

- With regard to our solar system's distance from the center of the galaxy, the literature offers values over a fairly wide range, for example:
  - 27,200 +/− 1100 lt-yr (Gilessen et al., 2009—from stellar orbits around central BH)
  - 25,400 +/− 2000 lt-yr (Majaess et al., 2009—from Cepheids)
  - 25,700 +/− 2600 lt-yr (Reid et al., 2009—VLBI of water masers near GC)

  Based on these values, we have chosen to go with 27,000 light-years, which is the result above with the smallest error bars and which is consistent with all three ranges.

Answers/Discussion Points for Think About It/See It for Yourself Questions

The Think About It and See It for Yourself questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 1.1

- (p. 4) This question is, of course, very subjective, but it can make for a lively in-class debate.
- (p. 6, SIFY) The main goal of this activity is for students to go out and look for the Andromeda Galaxy and contemplate seeing light that has been traveling through space for 2.5 million years. If people in the Andromeda Galaxy were looking at the Milky Way, they would see a spiral galaxy looking much like their galaxy looks to us. They would see our galaxy as it was about 2.5 million years ago (due to light travel time) and thus could not know that our civilization exists here today.
- (p. 10) This question can be a great topic of debate. We've found that most students tend to think it is inconceivable that we could be the only intelligent beings. However, some religious students will assume we are alone on grounds of their faith. In both cases, the question can generate discussion about how science goes only on evidence. For example, we don't assume there are others because we have no evidence that there are, and we don't assume we are alone for the same reason.

Section 1.2

- (p. 15) This is another very subjective question, similar to the one at the end of Section 1.1 but focused on our place in time rather than in space.

Section 1.3

- (p. 16) As we authors understand it, the only real reason that globes are oriented with north on top is that most of the early globe makers lived in the Northern Hemisphere. In any case, it is certainly equally correct to have the globe oriented in any other way.

- (p. 16) This question is easy to discuss if you refer to the 1-to-10-billion scale model developed earlier. On this scale, entire star systems (including all their planets) are typically only a few hundred meters in diameter, and they are separated from other systems by thousands of kilometers (at least in our vicinity of the galaxy).

Solutions to End-of-Chapter Problems (Chapter 1)

(*Note*: Solutions provided in the *Instructor Guide* are intended as samples only; individual answers may vary.)

Visual Skills Check

1. b 2. c 3. c 4. No. The nearest stars would not fit on Earth using this scale.

Review Questions

1. The largest scale is the universe itself, which is the sum total of all matter and energy. The largest known organized structures are superclusters of galaxies, then clusters and groups of galaxies, and then the roughly 100 billion individual galaxies, most of which are many thousands of light-years across. Each galaxy contains billions of stars, and many or most stars may be orbited by planets.
2. Astronomical unit: the average distance between Earth and Sun, which is about 1.496×10^8 kilometers. Light-year: the distance that light travels in 1 year, which is about 9.46 trillion kilometers.
3. Because light travels at a fixed speed, it takes time for it to go between two points in space. Although light travels very quickly, the distances in the universe are so large that the time for light to travel between stars is years or longer. The farther away we look, the longer it takes light to have traveled to us from the objects. So the light we see from more distant objects started its journey longer ago, which means we see more distant objects as they looked longer ago in time. Therefore, looking farther away means looking further back in time.
4. The observable universe is the portion of the entire universe that we can in principle see; it is about 14 billion light-years in radius, because light from more than 14 billion light-years away could not yet have reached us during the 14 billion years since the Big Bang. Scientists currently think that the entire universe is larger than the observable universe.
5. Solar system: On the 1-to-10-billion scale, the Sun is about the size of a grapefruit, and the planets are the sizes of marbles or smaller. The distances between the planets are a few meters for the inner solar system to many tens of meters in the outer solar system.

   Distances to nearby stars: On the same scale, the nearest stars are thousands of kilometers away.

   The Milky Way Galaxy: One way to understand the size of our galaxy is to note that if the Milky Way were the size of a football field, then the distance to the nearest star would be about 4 millimeters. The number of stars in the galaxy is more than 100 billion, so many that it would take thousands of years to count them out loud.

The observable universe: One way to get a sense of the size of the observable universe is to note that the number of stars in it is comparable to the number of grains of sand on all of the beaches on the entire planet Earth.

6. When we say that the universe is expanding, we mean that the average distance between galaxies is increasing with time. If the universe is expanding, then if we imagine running time backward, we'd see the universe shrinking. Eventually, if we went far enough back in time, the universe would be compressed until everything was on top of everything else. This suggests that the universe may have been very tiny and dense at some point in the distant past and has been expanding ever since. This beginning is what we call the Big Bang. Based on observations of the expansion rate, the Big Bang must have occurred about 14 billion years ago.
7. We are "star stuff" because most of the atoms in our bodies (all the elements except for hydrogen, since our bodies generally do not contain helium) were made by stars that died long ago. These elements were released into space when the stars died, expelling their materials. The material was then incorporated into new generations of stars. This is how our solar system obtained those elements, some of which then formed the Earth, and ultimately, us.
8. There are numerous ways to describe how humanity fits into cosmic time, but here is one straight from the cosmic calendar: If the entire history of the universe were compressed into a single year, modern humans would have evolved only 2 minutes ago and the pyramids would have been built only 11 seconds ago.
9. Earth rotates once each day on its axis and orbits the Sun once each year. The ecliptic plane is the plane defined by Earth's orbit around the Sun. Most of the other planets orbit nearly in this same plane. Axis tilt is the amount that a planet's rotation axis is tipped relative to a line *perpendicular* to the ecliptic plane.
10. The Milky Way Galaxy is a spiral galaxy, which means that it is disk-shaped with a large bulge in the center. The galactic disk includes a few large spiral arms. Our solar system is located about 27,000 light-years from the center of the galaxy, or about halfway out to the edge of the galaxy. Our solar system orbits about the galactic center in a nearly circular orbit, making one trip around every 230 million years.
11. Dark matter is matter that does not emit light, and is therefore invisible to our telescopes, but that we can detect because it has gravity that affects other objects we *can* see. Most dark matter resides in the halo of the galaxy, which is the large, spherical region that surrounds the galaxy's flat disk. Dark energy is the name given to whatever is causing the expansion of the universe to accelerate with time. Dark matter and dark energy are mysterious

because we don't know exactly what they are, and they are important because the make up the majority of the total energy content of the universe.

12. Edwin Hubble discovered that most galaxies are moving away from our galaxy, and more distant galaxies are moving away at higher speeds. While at first this might seem to suggest that we are at the center of the universe, a little more reflection indicates that this is not the case. If we imagine a raisin cake rising, we can see that every raisin will move away from every other raisin. So each raisin will see all of the others moving away from it, with more distant ones moving away faster—just as Hubble observed galaxies to be moving. Thus, just as the raisin observations can be explained by the fact that the raisin cake is expanding, Hubble's galaxy observations tell us that our universe is expanding.

Does It Make Sense?

13. *Our solar system is bigger than some galaxies*. This statement does not make sense, because all galaxies are defined as collections of many (millions or more) star systems, so a single star system cannot be larger than a galaxy.
14. *The universe is billions of light-years in age*. This statement does not make sense, because it uses the term "light-years" as a time, rather than as a distance.
15. *It will take me light-years to complete this homework assignment!* This statement does not make sense, because it uses the term "light-years" as a time, rather than as a distance.
16. *Someday we may build spaceships capable of traveling a light-year in only a decade*. This statement is fine. A light-year is the distance that light can travel in 1 year, so traveling this distance in a decade would require a speed of 10% of the speed of light.
17. *Astronomers discovered a moon that does not orbit a planet*. This statement does not make sense, because a moon is defined to be an object that orbits a planet.
18. *NASA will soon launch a spaceship that will photograph our Milky Way Galaxy from beyond its halo*. This statement does not make sense, because of the size scales involved: Even if we could build a spaceship that traveled close to the speed of light, it would take tens of thousands of years to get high enough into the halo to photograph the disk, and then tens of thousands of years more for the picture to be transmitted back to Earth.
19. *The observable universe is larger today than it was a few billion years ago*. This statement makes sense, because the size of the observable universe depends on the age of the universe, which means it must grow larger with time.
20. *Photographs of distant galaxies show them as they were when they were much younger than they are today*. This statement makes sense, because when we look far into space we also see far back in time. Thus, we see

distant galaxies as they were in the distant past, when they were younger than they are today.

21. *At a nearby park, I built a scale model of our solar system in which I used a basketball to represent Earth*. This statement does not make sense. On a scale where Earth is the size of a basketball, we could not fit the rest of the solar system in a local park. (A basketball is roughly 200 times the diameter of Earth in the Voyage model described in the book. Since the Earth–Sun distance is 15 meters in the Voyage model, a basketball-size Earth would require an Earth–Sun distance of about 3 kilometers and a Sun–Pluto distance of about 120 kilometers.)
22. *Because nearly all galaxies are moving away from us, we must be located near the center of the universe.* This statement does not make sense, as we can tell when we think about the raisin cake model. Every raisin sees every other raisin moving away from it, so in this sense no raisin is any more central than any other. (Equivalently, we could say that every raisin—or galaxy—is the center of its own observable universe, which is true but very different from the idea of an absolute center to the universe.)

Quick Quiz

23. a 24. b 25. c 26. b 27. a 28. b 29. c 30. b 31. a 32. a

Inclusive Astronomy/Process of Science

These are discussion-oriented questions, so we list only a few suggested things to look for in the student work.

33. Use this question to help direct your students to understanding and overcoming preconceptions they may have about scientists. It should be especially useful for students from backgrounds that are underrepresented in astronomy, as it should help them realize that people like them can be professional astronomers.
34. Major changes in scientific views are possible because science relies on physical evidence. Science must be backed by evidence from observations or experiments, and when the evidence contradicts the scientific story, the story is changed. That is what happened, for example, when belief in an Earth-centered universe gave way to the idea that Earth orbits the Sun. (In contrast, religious or cultural beliefs generally are less subject to change, because they are based on faith or scriptures rather than on a search for physical evidence.)
35. Using the Voyage model scale (1 to 10 billion), Earth is barely 1 millimeter across but is located 15 meters from the Sun. In other words, Earth's distance from the Sun is some 15,000 times as great as Earth's diameter. Given that fact, the difference in distance of the day and night sides of Earth is negligible, so it would be difficult to see how it could explain day and night temperature differences. If we had no other explanation for the temperature difference, then we might still be forced to

consider whether there is some missing piece to our understanding. In this case, however, we have a much simpler alternative explanation: The day side is warm because it faces the Sun, and the night side is cooler because it faces away from the Sun.

36. Answers will vary based on the topic students choose. This question is designed to get students thinking about the nature of evidence and what it might take to get them to accept some scientific idea.
37. This is an opinion-based question, but look for students to show that they understand the chapter material when answering it.
38. This is an opinion-based question, but look for students to show that they understand the cosmic calendar when answering it.
39. This is group activity.

Short Answer/Essay Questions

40. This is a short essay question. Key points should include discussion of the difference in scale between interstellar travel and travel about our own world, so that students recognize that alien technology would have to be far more advanced than our own to allow them to visit us with ease.
41. a. The diagrams should be much like Figure 1.17, except that the distances between raisins in the expanded figure will be 4 centimeters instead of 3 centimeters.

    b.

Distances and Speeds of Other Raisins as Seen from the Local Raisin			
Raisin Number	**Distance before Baking**	**Distance after Baking (1 hour later)**	**Speed**
1	1 cm	4 cm	3 cm/hr
2	2 cm	8 cm	6 cm/hr
3	3 cm	12 cm	9 cm/hr
4	4 cm	16 cm	12 cm/hr
⋮	⋮	⋮	⋮
10	10 cm	40 cm	30 cm/hr
⋮	⋮	⋮	⋮

    c. As viewed from any location inside the cake, more distant raisins appear to move away at faster speeds. This is much like what we see in our universe, where more distant galaxies appear to be moving away from us at higher speeds. Thus, we conclude that our universe, like the raisin cake, is expanding.

42. This question asks students to learn more about the Hubble eXtreme Deep Field, writing about how it was taken, what it shows, and what we've learned from it.
43. This is a subjective essay question. Grade should be based on clarity of the essay.

Quantitative Problems

44. a. A light-second is the distance that light travels in 1 second. We know that light travels at a speed of 300,000 km/s, so a light-second is a distance of 300,000 kilometers.

b. A light-minute is the speed of light multiplied by 1 minute:

$$\begin{aligned} 1 \text{ light-minute} &= (\text{speed of light}) \times (1 \text{ min}) \\ &= 300{,}000 \frac{\text{km}}{\cancel{\text{s}}} \times 1 \ \cancel{\text{min}} \times \frac{60 \ \cancel{\text{s}}}{1 \ \cancel{\text{min}}} \\ &= 18{,}000{,}000 \text{ km} \end{aligned}$$

That is, "1 light-minute" is just another way of saying "18 million kilometers."

c. Following a similar procedure, we find that 1 light-hour is 1.08 billion kilometers; and

d. 1 light-day is 2.59×10^{10} km, or about 26 billion kilometers.

45. Recall that

$$\text{speed} = \frac{\text{distance traveled}}{\text{time of travel}}$$

We can solve for time by multiplying both sides by "time of travel" and dividing both sides by distance:

$$\text{time of travel} = \frac{\text{distance traveled}}{\text{speed}}$$

The speed of light is 3×10^5 km/s. (We choose the value in kilometers per second rather than meters per second because we are given distances in kilometers.)

a. According to Appendix E, the Earth–Moon distance is 3.844×10^5 km. Using this distance and the equation above for travel time, we get

$$\text{time of travel} = \frac{3.844 \times 10^5 \ \cancel{\text{km}}}{3.00 \times 10^5 \ \cancel{\text{km}}/\text{s}} = 1.28 \text{ s}$$

Light takes 1.28 seconds to travel from the Moon to Earth.

b. Appendix E also tells us that the distance between Earth and the Sun is 1.496×10^8 km. So we calculate:

$$\text{time of travel} = \frac{1.496 \times 10^8 \ \cancel{\text{km}}}{3.00 \times 10^5 \ \cancel{\text{km}}/\text{s}} = 499 \text{ s}$$

But most people don't really know how long 499 seconds is. It would be more useful if this number were in a more appropriate time unit. So we start by converting this to minutes:

$$499 \ \cancel{\text{sec}} \times \frac{1 \text{ min}}{60 \ \cancel{\text{sec}}} = 8.32 \text{ min}$$

Because 8 minutes is 480 seconds $\left(8 \text{ min} \times \frac{60 \text{ s}}{1 \text{ min}} = 480 \text{ s}\right)$, 499 seconds is also equivalent to 8 minutes and 19 seconds. Thus, light takes 8 minutes and 19 seconds to travel from the Sun to Earth.

46. We are asked to find how many times larger in diameter the Milky Way Galaxy is than the rings of Saturn. We are told that Saturn's rings are about 270,000 kilometers across and that the Milky Way is 100,000 light-years in diameter. Clearly, we'll have to convert one set of units or the other. Let's change light-years to kilometers. In Appendix A, we find that 1 light-year = 9.46×10^{12} km, so we can convert:

$$100{,}000 \ \cancel{\text{light-years}} \times \frac{9.46\times10^{12} \text{ km}}{1 \ \cancel{\text{light-year}}} = 9.46\times10^{17} \text{ km}$$

We can now find the ratio of the two diameters:

$$\begin{aligned}\text{ratio} &= \frac{\text{diameter of Milky Way}}{\text{diameter of Saturn's rings}}\\ &= \frac{9.46\times10^{17} \ \cancel{\text{km}}}{2.7\times10^{5} \ \cancel{\text{km}}} = 3.5\times10^{12}\end{aligned}$$

The diameter of the Milky Way Galaxy is about 3.5 trillion times as large as the diameter of Saturn's rings!

47. a. The circumference of Earth is $2\pi \times 6380$ km = 40,087 km. At a speed of 100 km/hr, it would take:

$$40{,}087 \text{ km} \div 100 \text{ km/hr} = 40{,}087 \ \cancel{\text{km}} \times \frac{1 \ \cancel{\text{hr}}}{100 \ \cancel{\text{km}}} \times \frac{1 \text{ day}}{24 \ \cancel{\text{hr}}} = 16.7 \text{ days}$$

to drive around Earth. That is, a trip around the equator at 100 km/hr would take a little under 17 days.

b. We find the time by dividing the distance to Earth from the Sun by the speed of 100 km/hr. It would take about 170 years to drive from the Sun to Earth.

c. Similarly, it would take 6700 years to drive from the Sun to Pluto at 100 km/hr. *Note*: The following table shows the driving times from the Sun to each of the planets at a speed of 100 km/hr.

Planet	Driving Time
Mercury	66 years
Venus	123 years
Earth	170 years
Mars	259 years
Jupiter	888 years
Saturn	1630 years
Uranus	3300 years
Neptune	5100 years
Pluto	6700 years

d. We are given the distance to Alpha Centauri in light-years; converting to kilometers, we get:

$$4.4\ \cancel{\text{light-years}} \times \frac{9.46\times10^{12}\ \text{km}}{1\ \cancel{\text{light-year}}} = 41.6\times10^{12}\ \text{km}$$

At a speed of 100 km/hr, the travel time to Alpha Centauri would be about

$$4.16\times10^{13}\ \text{km} \div 100\frac{\text{km}}{\text{hr}} = 4.16\times10^{13}\ \cancel{\text{km}} \times \frac{1\ \cancel{\text{hr}}}{100\ \cancel{\text{km}}} \times \frac{1\ \cancel{\text{day}}}{24\ \cancel{\text{hr}}} \times \frac{1\ \text{yr}}{365\ \cancel{\text{day}}}$$

$$= 4.7\times10^{7}\ \text{yr}$$

It would take about 47 million years to reach Alpha Centauri at a speed of 100 km/hr.

48. a. To reach Alpha Centauri in 100 years, you would have to travel at

$$\frac{4.4\ \cancel{\text{lt-yr}} \times 9.46\times10^{12}\dfrac{\text{km}}{\cancel{\text{lt-yr}}}}{100\ \cancel{\text{yr}} \times 365\dfrac{\cancel{\text{day}}}{\cancel{\text{yr}}} \times 24\dfrac{\cancel{\text{hr}}}{\cancel{\text{day}}} \times 60\dfrac{\cancel{\text{min}}}{\cancel{\text{hr}}} \times 60\dfrac{\text{s}}{\cancel{\text{min}}}} \approx 13220\frac{\text{km}}{\text{s}}$$

or nearly 50 million kilometers per hour. Note: An alternate (and perhaps easier) way to get this answer is to recognize that traveling 4.4 light-years in 100 years means traveling at 4.4% of the speed of light, or 0.44c. A unit conversion then gives the same answer of nearly 50 million kilometers per hour.

b. This is about 1000 times the speed of our fastest current spacecraft.

49. We are given the distance to Alpha Centauri as 4.4 light-years, but those units aren't very useful to us. So let's convert to kilometers. From Appendix A, we see that 1 light-year $= 9.46\times10^{12}$ kilometers. So the distance to Alpha Centauri is

$$4.4\ \cancel{\text{light-years}} \times \frac{9.46\times10^{12}\ \text{km}}{1\ \cancel{\text{light-year}}} = 4.2\times10^{13}\ \text{km}$$

At a scale of 1 to 10^{19}, the distance to Alpha Centauri is

$$\frac{4.2\times10^{13}\text{ km}}{10^{19}}=4.2\times10^{-6}\text{ km}$$

As numbers go, that one's not very easy to picture. So let's convert it to some smaller units. Since there are a thousand (10^3) meters to a kilometer and a thousand (10^3) millimeters to a meter, there are (10^6) millimeters to a kilometer. Those units seem about right for this distance, so let's convert:

$$4.2\times10^{-6}\ \cancel{\text{km}}\times\frac{10^6\text{ mm}}{1\ \cancel{\text{km}}}=4.2\text{ mm}$$

From Appendix E, the Sun is 7.0×10^5 kilometers in radius, so the diameter is twice this, or 1.4×10^6 kilometers. On the 1-to-10^{19} scale, this is

$$\frac{1.4\times10^{6}\text{ km}}{10^{19}}=1.4\times10^{-13}\text{ km}$$

We're asked to compare this to the size of an atom, 10^{-10} meter, so we had better convert one of the numbers. We'll convert from kilometers to meters:

$$1.4\times10^{-13}\ \cancel{\text{km}}\times\frac{1000\text{ m}}{1\ \cancel{\text{km}}}=1.4\times10^{-10}\text{ m}$$

Note that this is about the same size as a typical atom. In summary, we've found that on a scale on which the Milky Way Galaxy would fit on a football field, the distance from the Sun to Alpha Centauri is only about 4.2 millimeters—smaller than the width of a finger—and the Sun itself becomes as small as an atom.

50. A faster expansion rate means the universe reached its current size in less time, so the fact that Wendy measured a faster expansion rate means she will calculate a younger age for the universe than Allan will. Wendy found the expansion rate to be 50% faster, which means a rate that is 150% of, or 1.5 times, the expansion rate that Allan measured. Therefore, she will calculate an age for the universe that is 1/1.5, or 2/3, of the age that Allan calculates.

Chapter 2. Discovering the Universe for Yourself

This chapter introduces major phenomena of the sky, with emphasis on these topics:

- The concept of the celestial sphere.
- The basic daily motion of the sky, and how it varies with latitude.
- The cause of seasons.
- Phases of the Moon and eclipses.
- The apparent retrograde motion of the planets and how it posed a problem for ancient observers.

As always, when you prepare to teach this chapter, be sure that you are familiar with the online quizzes, interactive figures, media, tutorials, assignable homework, and other resources available on the Mastering Astronomy website.

Key Changes for the Ninth Edition: For those who have used earlier editions of our textbook, please note the following significant changes in this chapter:

- Revised to make discussions more friendly to Southern Hemisphere users as well as to those in the Northern Hemisphere; also clarified text relating to seasons around the world.
- Almost completely reworked the section on eclipses with a new set of art pieces and revised pedagogy to clarify the topic and to reflect the fact that many students will have witnessed the 2017 eclipse.
- Updated eclipse table/map.

Teaching Notes (by Section)

Section 2.1 Patterns in the Night Sky

This section introduces the concepts of constellations and the celestial sphere, as well as horizon-based coordinates and daily and annual sky motions.

- Stars in the daytime: You may be surprised at how many of your students actually believe that stars disappear in the daytime. If you have a campus observatory or can set up a small telescope, it's well worth offering a daytime opportunity to point the telescope at some bright stars, showing the students that they are still there.
- In class, you may wish to go further in explaining the correspondence between the Milky Way Galaxy and the Milky Way in our night sky. Tell your students to imagine being a tiny grain of flour inside and a little more than halfway toward the outer edge of a very thin pancake (or crepe!) that bulges in the middle. Ask, "What will you see if you look toward the middle?" The answer should be "dough." Then ask what they will see if they look toward the far edge, and they'll give the same answer. Proceeding similarly, they should soon realize that they'll see a band of

dough encircling their location, but that if they look away from the plane, the pancake is thin enough that they can see to the distant universe.

- Sky variation with latitude: The intention of this discussion is only to give students an overview of the idea and the most basic rules (such as latitude equals altitude of north celestial pole).
- Note that in our jargon-reduction efforts, we do not introduce the term *asterism*, but instead speak of patterns of stars in the constellations. We also avoid the term *azimuth* when discussing horizon-based coordinates. Instead, we simply refer to *direction* along the horizon (e.g., south, northwest). The distinction of "along the horizon" should remove potential ambiguity with direction on the celestial sphere (where "north" would mean toward the north celestial pole rather than toward the horizon).

Section 2.2 The Reason for Seasons

This section focuses on seasons and why they occur.

- In combating misconceptions about the cause of the seasons, we recommend that you follow the logic in the Common Misconceptions box. That is, begin by asking your students what they think causes the seasons. When many of them suggest that the seasons are linked to distance from the Sun, ask how seasons differ between the two hemispheres. They should then see for themselves that the reason can't be distance from the Sun, or the seasons would be the same globally rather than opposite in the two hemispheres.
- As a follow-up on the above note: Some students get confused by the fact that season diagrams (such as our Figure 2.15) cannot show the Sun–Earth distance and size of Earth to scale. The common confusion is that, by tilting, the northern hemisphere comes closer to the Sun during its summer and the southern hemisphere comes closer to the Sun during its summer. Thus, unless you emphasize this point (as we do in the figure), it might actually look like the two hemispheres are at significantly different distances from the Sun. This is another reason why we believe it is critical to emphasize ideas of scale throughout your course. In this case, use the scale model solar system as introduced in Section 1.2, and students will quickly see that the two hemispheres are effectively at the same distance from the Sun at all times.
- Note that we do not go deeply into the physics that causes precession, as even a basic treatment of this topic requires discussing the vector nature of angular momentum. Instead, we include a brief motivation for the cause of precession using the analogy to a spinning top. In the classroom, it may be helpful to open planetarium software (such as Sky Gazer or Stellarium) and show how the north celestial pole changes locations over long periods of time. Students may initially think that it is a bug in the software, but that idea is soon dismissed.
- Fyi, regarding Sun signs: Most astrologers have "delinked" the constellations from the Sun signs. Thus, most astrologers would say that

the vernal equinox still is in Aries—it's just that Aries is no longer associated with the same pattern of stars as it was in A.D. 150.

Section 2.3 The Moon, Our Constant Companion

This section discusses the Moon's motion and its observational consequences, including the lunar phases and eclipses.

- Though it may appear to be an easy concept, many students find it remarkably difficult to understand the phases of the Moon. You may want to do an in-class demonstration of phases by darkening the room, using a lamp to represent the Sun, and giving each student a Styrofoam ball to represent the Moon. If your lamp is bright enough, the students can remain in their seats and watch the phases as they move the ball around their heads.
- Going along with the above note, it is virtually impossible for students to understand phases from a flat figure on a flat page in a book. We have therefore opted to eliminate the "standard" Moon phases figure that you'll find in almost every other text—which shows the Moon in eight different positions around Earth—because students just don't get it, and the multiple moons confuse them. Instead, our Figure 2.21 shows how students can conduct a demonstration that will help them understand the phases. The Phases of the Moon tutorial and videos on the MasteringAstronomy website has also proved very successful at helping students understand phases.
    - *Note about the appearance of lunar phases*: We have often heard instructors describe the appearance of the lunar phases in terms of the illuminated portion of the Moon progressing from "right to left" during the cycle of phases. However, please remember that this is true only in the Northern Hemisphere (where the Moon transits to the south of zenith); the progression appears reversed in the Southern Hemisphere (where the Moon transits to the north of zenith). In equatorial regions, phases look more like movement from bottom to top. For that reason, we recommend not focusing on left/right and instead focusing on the time of visibility: waxing moons in the afternoon/evening, where the Moon appears to "chase after" the Sun, and waning moons in the morning, where the Sun appears to "chase after" the Moon.
- When covering the causes of eclipses, it helps to demonstrate the Moon's orbit. Keep a model Sun on a table in the center of the lecture area; have your left fist (or an Earth ball) represent Earth, and hold a ball (such as a Moon ball) in the other hand to represent the Moon. Then you can show how the Moon orbits your fist at an inclination to the ecliptic plane, explaining the meaning of the nodes. You can also show eclipse seasons by demonstrating the Moon's orbit (with fixed nodes) as you walk around your model Sun. The students will see that eclipses are possible only during two periods each year. If you then add in precession of the nodes, students can see why eclipse seasons occur slightly more often than every 6 months.

- The painting *Moon Pond* in Figure 2.28 should also be an effective way to explain what we mean by *nodes* of the Moon's orbit.
- FYI: We've found that even many astronomers are unfamiliar with the saros cycle of eclipses. Hopefully, our discussion is clear, but some additional information may help you as an instructor:
    - The Saros cycle is 6585.3211 days, and is usually referred to as a period of 18 years and 11.32 days. However, if 5 leap years occur within this period, then the Saros cycle would be a period of 18 years and 10.32 days.
    - Nodal precession is where the nodes of the Moon's orbit precess with an 18.6-year period. However, this has no special connection to the period of the Saros cycle (it essentially is a mathematical coincidence).
    - Apsidal precession is where the Moon's line of apsides (the line connecting perigee and apogee points in the Moon's orbit) also precesses, but with a period of 8.85 years.
    - Apsidal precession, and to a lesser degree nodal precession, impacts eclipses in that the same type of eclipse (partial, annular, or total) does not always recur in each Saros cycle.

Section 2.4 The Ancient Mystery of the Planets

This section covers the ancient mystery of planetary motion, explaining the motion, how we now understand it, and how the mystery helped lead to the development of modern science.

- We have chosen to refer to the westward movement of planets in our sky as *apparent* retrograde motion, in order to emphasize that planets only appear to go backward, but never really reverse their direction of travel in their orbits. This makes it easy to use analogies—for example, when students try the demonstration in Figure 2.30, they never say that their friend really moves backward as they pass by, only that the friend appears to move backward against the background.
- You should emphasize that apparent retrograde motion of planets is noticeable only by comparing planetary positions over many nights. In the past, we've found a tendency for students to misinterpret diagrams of retrograde motion and thereby expect to see planets moving about during the course of a single night.
- It is somewhat rare among astronomy texts to introduce stellar parallax so early. However, it played such an important role in the historical debate over a geocentric universe that we feel it must be included at this point. Note that we do *not* give the formula for finding stellar distances at this point; that comes in Chapter 11.

Answers/Discussion Points for Think About It/See It for Yourself Questions

The Think About It and See It for Yourself questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 2.1

- (p. 28) No. We can only describe angular sizes and distances in the sky, so physical measurements do not make sense. This is a difficult idea for many children to understand, but hopefully comes more easily for college students.
- (p. 29) Yes, because it is Earth's rotation that causes the rising and setting of all the objects in the sky. *Note:* Many instructors are surprised that this question often gives students trouble, but the trouble arises from at least a couple of misconceptions harbored by many students. First, even though students can recite the fact that the motion of the stars is caused by the rotation of Earth, they haven't always absorbed the idea and therefore don't automatically apply it to less familiar objects like galaxies. Second, many students have trouble visualizing galaxies as fixed objects on the celestial sphere like stars, perhaps because they perceive them as being "big" and therefore have trouble fitting them onto the sphere in their minds. Thus, this simple question can help you address these misconceptions and thereby make it easier for students to continue their progress in the course.
- (p. 30, SIFY) This activity is designed to help students become familiar with their local sky by learning their latitude and then checking to see that the north or south celestial pole is indeed at the altitude it should be.
- (p. 31, SIFY) This activity checks that students can properly interpret Figure 2.14 and then asks that they go outside to check their answers in the sky. Sample answer for September 21: The Sun appears to be in Virgo, which means you'll see the opposite zodiac constellation—Pisces—on your horizon at midnight. After sunset, you'll see Libra setting in the western sky, since it is east of Virgo and therefore follows it around the sky.

Section 2.2

- (p. 33) Jupiter does not have seasons because of its lack of appreciable axis tilt. Saturn has an axis tilt that is similar to Earth's, so it does have seasons.
- (p. 38) No. As shown in Figure 2.19, the location of the north celestial pole moves with precession on a 26,000 year cycle. The north celestial pole stays near Polaris for only a short time (less than a thousand years or so), so Polaris was not a good north star in ancient times (i.e., for ancient Greeks approximately 2,000 years ago).

Section 2.3

- (p. 41) A "half light and half dark" moon visible in the morning must be third-quarter, since the third-quarter moon rises around midnight and sets around noon.
- (p. 41) About 2 weeks each. Because the Moon takes about a month to rotate, your "day" would last about a month. Thus, you'd have about 2 weeks of daylight followed by about 2 weeks of darkness as you watched Earth hanging in your sky and going through its cycle of phases.
- (p. 44) A solar eclipse can only occur during a new moon phase, and a lunar eclipse can only occur during a full moon phase. The change from new moon to full moon takes approximately two weeks, so no one could see a lunar eclipse on the evening that follows the day of a solar eclipse. You might see lunar eclipse two weeks after the solar eclipse, but only if the Moon is still near the node. After two months, you will not see a lunar eclipse because the Moon would no longer be near the node.

Section 2.4

- (p. 48) Opposite ends of Earth's orbit are about 300 million kilometers apart, or about 30 meters on the 1-to-10-billion scale used in Chapter 1. The nearest stars are tens of trillions of kilometers away, or on the 1-to-10-billion scale, thousands of kilometers away but typically only about the size of grapefruits or smaller The challenge of detecting stellar parallax should now be clear.

Solutions to End-of-Chapter Problems (Chapter 2)

Visual Skills Check

1. B 2. D 3. C 4. d 5. b 6. d 7. c 8. c

Review Questions

1. A constellation is a section of the sky, like a state within the United States. The boundaries have been determined by the International Astronomical Union. They were originally based on groups of stars that form patterns that suggested shapes to the cultures of the people who first named them. The official names of most of the constellations in the Northern Hemisphere are based on the names given by the ancient cultures of the Middle East and the Mediterranean, while the constellations of the Southern Hemisphere have official names that are based on the names given by 17th-century Europeans.

2. If we were making a model of the celestial sphere on a ball, we would definitely need to mark the north and south celestial poles, which are the points directly above Earth's poles. Halfway between the two poles we would mark the great circle of the celestial equator, which is the projection of Earth's equator out into space. And we definitely would need to mark the

circle of the ecliptic, which is the path that the Sun appears to make across the sky. Then we could add stars and borders of constellations.

3. No, space is not really full of stars. Because the distance to the stars is very large and because stars lie at different distances from Earth, stars are not really crowded together.

4. The local sky looks like a dome because we see half of the full celestial sphere at any one time.

   Horizon—The boundary line dividing the ground and the sky.

   Zenith—The highest point in the sky, directly overhead.

   Meridian—The semicircle extending from the horizon due north to the zenith to the horizon due south.

   We can locate an object in the sky by specifying its altitude and its direction along the horizon.

5. We can measure only angular size or angular distance on the sky because we lack a simple way to measure distance to objects just by looking at them. It is therefore usually impossible to tell if we are looking at a smaller object that's near us or a more distant object that's much larger.

   Arcminutes and arcseconds are subdivisions of degrees. There are 60 arcminutes in 1 degree, and there are 60 arcseconds in 1 arcminute.

6. Circumpolar stars are stars that never appear to rise or set from a given location, but are always visible on any clear night. From the North Pole, every visible star is circumpolar, as all circle the horizon at constant altitudes. In contrast, a much smaller portion of the sky is circumpolar from the United States, as most stars follow paths that make them rise and set.

7. Latitude measures angular distance north or south of Earth's equator. Longitude measures angular distance east or west of the Prime Meridian. The night sky changes with latitude, because it changes the portion of the celestial sphere that can be above your horizon at any time. The sky does not change with changing longitude, however, because as Earth rotates, all points on the same latitude line will come under the same set of stars, regardless of their longitude.

8. The zodiac is the set of constellations through which the Sun passes at some time during each year. We see different parts of the zodiac at different times of the year because of the Sun's apparent motion around the celestial sphere. When the Sun is in a particular zodiac constellation, that constellation is above our horizon only in the daytime, so we cannot see it at night. As the Sun moves through the zodiac, we therefore see different constellations at different times of night over the course of the year.

9. If Earth's axis had no tilt, Earth would not have significant seasons because the intensity of sunlight at any particular latitude would not vary with the time of year.

10. On the solstice, the Sun has reached its furthest north or furthest south position on the celestial sphere. The June solstice is the day when the Northern Hemisphere receives its most direct sunlight and has the greatest number of daylight hours, while the Southern Hemisphere receives its least direct sunlight and has the least number of daylight hours. The situation is reversed on the December Solstice, when it is summer for the Southern Hemisphere and winter for the Northern Hemisphere. (Incidentally, solstice means "standing Sun," referring to the fact that the Sun's northward or southward progression in the sky appears to stop on the solstices.)

    On the March and September equinoxes, the two hemispheres receive the same amount of sunlight, and the day and night are the same length (12 hours) in both hemispheres (hence the name equinox, which means "equal night"). The Sun rises due east and sets due west on these days, and it passes directly overhead at the equator.

11. The direction in which Earth's rotation axis points in space changes slowly over the centuries, and we call this change *precession.* Because of this movement, the celestial poles change position relative to the stars slowly in time. So while Polaris is the best choice for a pole star now, in 13,000 years the star Vega will be the best choice for a pole star instead.

12. The Moon's phases start with the new phase when the Moon is nearest the Sun in our sky; we cannot see the new moon, both because the Moon's night side is facing us and because the dim light we might otherwise see from the night side (reflected light from Earth) is overwhelmed by the bright daytime sky.

    The waxing phases—in which we see a gradually increasing amount of the Moon's visible face illuminated—then progress with one side of the Moon's visible face slowly becoming sunlit, moving to crescent, then to first quarter (when we see the Moon with the side to the west lit up and the side to the east still dark), to gibbous, and then to full. Full moon is when the entire visible face of the Moon is sunlit and the Moon is visible all night long.

    The waning phases—in which we see a gradually decreasing amount of the Moon's visible face illuminated—then occur in reverse of the waxing phases. The Moon progresses through gibbous, then third quarter (when we see the Moon with the side to the east lit up and the side to the west now dark), then crescent, and back to new again.

    We can never see a full moon at noon because for the Moon to be full, it and the Sun must be on opposite sides of Earth. So as the full moon rises, the Sun must be setting, and when the Moon is setting, the Sun is rising. (*Exception:* At very high latitudes, there may be times when the full moon is circumpolar, in which case it could be seen at noon—but it would still be 180° away from the Sun's position.)

13. We always see the same face of the Moon because the Moon displays synchronous rotation, meaning that the Moon's rotation period and its

orbital period around Earth are the same and in the same direction (both counterclockwise as seen from above Earth's North Pole.

14. While the Moon must be in its new phase for a solar eclipse or in its full phase for a lunar eclipse, we do not see eclipses every month. This is because the Moon usually passes to the north or south of the Sun during these phases because its orbit is tilted relative to the ecliptic plane. The Moon must be near the nodes, where the lunar orbit crosses the ecliptic, as well as being at the appropriate phase (new phase for a solar eclipse and full phase for a lunar eclipse) in order for an eclipse to be occur.
15. Apparent retrograde motion is when a planet appears to stop moving eastward relative to the stars and, instead, moves westward for a few weeks or months. Ancient astronomers had to resort to complex models in order for them to explain this behavior with their Earth-centered model of the universe. In contrast, apparent retrograde motion is easily explained by our Sun-centered model, in which it is a natural consequence of the fact that the different planets move at different speeds as they orbit the Sun. For planets that orbit further from the Sun than Earth (specifically: Mars, Jupiter, Saturn, Uranus and Neptune), we see that the planets appear to move backward because we (Earth) are passing by them in our orbit. For planets that orbit closer to the Sun than Earth (specifically: Venus and Mercury), the opposite is true, that these planets are passing by Earth because they are moving faster than Earth moves.
16. Stellar parallax is the apparent movement of relatively nearby stars against the background of more distant stars (or galaxies) as Earth orbits the Sun. It occurs for the same reason that alternately opening and closing your left and right eyes makes your finger appear to shift its position against the background even when you are holding your finger still. The shift due to stellar parallax is very small because Earth's orbit is much smaller than the distances to even the closest stars. Because the effect is so small, the ancients were unable to observe it. However, they correctly realized that if Earth is going around the Sun, they should see stellar parallax. Since they could not see the stars shift, they concluded that Earth does not move.

Does It Make Sense?

17. *The constellation of Orion didn't exist when my grandfather was a child.* This statement does not make sense because the constellations don't appear to change on the time scales of human lifetimes.
18. *When I looked into the dark lanes of the Milky Way with my binoculars, I saw a cluster of distant galaxies*. This statement does not make sense, because we cannot see through the band of light and dark that we call the Milky Way, in which the light comes from our own galaxy's stars and the dark lanes are made up of gas and dust that blocks light coming from behind it. Because a distant cluster of galaxies lies far beyond our own galaxy, the dust and gas prevents us from seeing it (at least with visible light) when we look directly into the Milky Way.

19. *Last night the Moon was so big that it stretched for a mile across the sky.* This statement does not make sense because a mile is a physical distance, and we can measure only angular sizes or distances when we observe objects in the sky.
20. *I live in the United States, and during a trip to Argentina I saw many constellations that I'd never seen before.* This statement makes sense because the constellations visible in the sky depend on latitude. Because Argentina is in the Southern Hemisphere, the constellations visible there include many that are not visible from the United States.
21. *Last night I saw Jupiter in the middle of the Big Dipper. (Hint: Is the Big Dipper part of the zodiac?)* This statement does not make sense because Jupiter, like all the planets, is always found very close to the ecliptic in the sky. The ecliptic passes through the constellations of the zodiac, so Jupiter can appear to be only in one of the zodiac constellations—and the Big Dipper (part of the constellation Ursa Major) is not part of the zodiac.
22. *Last night I saw Mars move westward through the sky in its apparent retrograde motion*. This statement does not make sense, because apparent retrograde motion is noticeable only over many nights, not during a single night. (Earth's rotation means that all celestial objects, including Mars, move from east to west over the course of each single night.)
23. *Although all the known stars rise in the east and set in the west, we might someday discover a star that will rise in the west and set in the east*. This statement does not make sense. The stars aren't really moving around us; they only appear to rise in the east and set in the west because Earth rotates.
24. *If Earth's orbit were a perfect circle, we would not have seasons*. This statement does not make sense. Seasons on Earth are caused by Earth's axis tilt, not by a varying distance to the Sun. As long as Earth still has its axis tilted, we'll still have seasons.
25. *Because of precession, someday it will be summer everywhere on Earth at the same time*. This statement does not make sense. Precession does not change the amount of the axis tilt, it only changes its orientation (the direction the axis points) in space. As long as there is an axis tilt, we will continue to have opposite seasons in the two hemispheres.
26. *This morning I saw the full moon setting at about the same time the Sun was rising.* This statement makes sense because a full moon is opposite the Sun in the sky.

Quick Quiz

27. c 28. a 29. a 30. a 31. a 32. b 33. b 34. b 35. a 36. b

Inclusive Astronomy/Process of Science

These are discussion-oriented questions, so we list only a few suggested things to look for in the student work.

37. Answers will vary based on the culture students choose to learn. The key point should be showing that they understand that constellation figures and which stars comprise each constellation are culturally chosen, even though we all see the same sky.
38. Use this question to help direct your students to understanding the concept that "we all share the same sky," even while there are differences with latitude. The questions about ancient skies should prompt students to realize that while the stars have not noticeably changed, we may view them differently because of the changes in the way we think about what the sky means to us.
39. (a) Consistent with Earth-centered view, simply by having the stars rotate around Earth as if they were attached to a celestial sphere.
    (b) Consistent with Earth-centered view by having the Sun actually move through the constellations, on the path of the ecliptic, along the celestial sphere. The Sun's position north or south of the celestial equator would be due to the Sun physically moving northward or southward, rather than as a consequence of the tilt of Earth's axis.
    (c) Consistent with Earth-centered view, since phases are caused by relative positions of the Sun, Earth, and the Moon—which are about the same with either viewpoint, since the Moon really does orbit Earth.
    (d) Consistent with Earth-centered view; as with (c), eclipses depend only on the Sun-Earth-Moon geometry.
    (e) In terms of just having the "heavens" revolve around Earth, apparent retrograde motion is inconsistent with the Earth-centered view. However, this view was not immediately rejected because the absence of parallax (and other beliefs) which caused ancient astronomers to go to great lengths to find a way to preserve the Earth-centered system. As we'll see in the next chapter, Ptolemy succeeded well enough for the system to remain in use for another 1500 years. Ultimately, however, the inconsistencies in predictions of planetary motion led to the downfall of the Earth-centered model.
40. The shapes of the phases do not agree with what we would see if they were due to shadows from Earth. For example, during the gibbous phase the dark portion of the Moon has the shape of a crescent, and a round object could not cast a shadow in that shape. You could also show that the crescent moon can be seen in the same sky and nearly the same direction as the Sun, whereas your shadow would be cast in the opposite direction. Earth's shadow would also be cast away from the Sun, so it can't possibly cast a shadow toward the crescent moon (nearly the direction of the Sun).
41. This is an opinion-based question, but look for students to identify examples of Earth-centered language in the way we talk about motions of the sky.
42. It's a sad fact that "flat Earth" believers are back in vogue, so use this question to help your students recognize how easily this belief can be debunked. You can find many great ways of doing so with a quick Web search, but here are a few examples: the fact that your horizon varies with

altitude is inconsistent with a flat Earth, as is the fact that we see objects like ships rise up as they come into view on the horizon; a flat Earth could not reproduce the shape of Earth's shadow during a lunar eclipse (a proof given by Aristotle); an airplane could not circumnavigate the world by flying in one direction if the world were flat; we could not explain the photos of Earth from space if it were flat. Note: For more insight into how flat Earth beliefs have come into vogue, we recommend the documentary "Behind the Curve" (2018).

43. This is group activity.

Short Answer/Essay Questions

44. The planet will have seasons because of its axis tilt, even though its orbit is circular. Because its 35° axis tilt is greater than Earth's 23.5° axis tilt, we'd expect this planet to have more extreme seasonal variations than Earth.

45. Answers will vary with location; the following is a sample answer for Boulder, CO.
    a. The latitude in Boulder is 40°N and the longitude is about 105°E.
    b. The north celestial pole appears in Boulder's sky at an altitude of 40°, in the direction due north.
    c. Polaris is circumpolar because it never rises or sets in Boulder's sky. It makes a daily circle, less than 1° in radius, around the north celestial pole.

46. a. When you see a full earth, people on Earth must have a new moon.
    b. At full moon, you would see new earth from your home on the Moon. It would be daylight at your home, with the Sun on your meridian and about a week until sunset.
    c. When people on Earth see a waxing gibbous moon, you would see a waning crescent earth.
    d. If you were on the Moon during a total lunar eclipse (as seen from Earth), you would see a total eclipse of the Sun.

47. You would not see the Moon go through phases if you were viewing it from the Sun. You would always see the sunlit side of the Moon, so it would always be "full." In fact, the same would be true of Earth and all the other planets as well.

48. If the Moon were twice as far from Earth, its angular size would be too small to create a total solar eclipse. It would still be possible to have annular eclipses, although the Moon would cover only a small portion of the solar disk.

49. If Earth were smaller, solar eclipses would still occur since the geometry of the positions of the Sun, Moon, and Earth have not changed. However, a smaller Earth is a smaller target area, which would mean fewer solar eclipses in general. Additionally, a smaller Earth means that Earth's surface

would be slightly more distant from the Moon, so there would be a small number of total eclipses that would become annular eclipses instead.

50. This is an observing project that will stretch over several weeks.
51. For students in the United States, this project gives students a great opportunity to prepare for the 2024 eclipse.

Quantitative Problems

52. a. There are 360 × 60 = 21,600 arcminutes in a full circle.
    b. There are 360 × 60 × 60 = 1,296,000 arcseconds in a full circle.
    c. The Moon's angular size of 0.5° is equivalent to 30 arcminutes or 30 × 60 = 1800 arcseconds.
53. To solve this problem, we turn to Cosmic Calculations 2.1, where we learn that the physical size of an object, its distance, and its angular size are related by this equation:

$$\text{physical size} = \frac{2\pi \times (\text{distance}) \times (\text{angular size})}{360°}$$

We are told that the Sun is 0.5° in angular diameter and is about 150,000,000 kilometers away. So we put those values in:

$$\begin{aligned}\text{physical size} &= \frac{2\pi \times (150{,}000{,}000\text{ km}) \times (0.5°)}{360°} \\ &= 1{,}310{,}000\text{ km}\end{aligned}$$

For the values given, we estimate the size to be about 1,310,000 kilometers. We are told that the actual value is about 1,390,000 kilometers. The two values are pretty close, and the difference can probably be explained by the Sun's actual diameter not being exactly 0.5° and the distance to the Sun not being exactly 150,000,000 kilometers.

54. To solve this problem, we use the equation relating distance, physical size, and angular size given in Cosmic Calculations 2.1:

$$\text{physical size} = \frac{2\pi(\text{distance}) \times (\text{angular size})}{360°}$$

In this case, we are given the distance to Betelgeuse as 600 light-years and the angular size as 0.05 arcsecond. We have to convert the angular size to degrees (so that the units in the numerator and denominator cancel):

$$0.05\ \cancel{\text{arcsecond}} \times \frac{1\ \cancel{\text{arcminute}}}{60\ \cancel{\text{arcseconds}}} \times \frac{1°}{60\ \cancel{\text{arcminutes}}} = (1.39 \times 10^{-5})°$$

We can leave the distance in light-years for now and calculate the size of Betelgeuse:

$$\begin{aligned}\text{physical size} &= \frac{2\pi \times (600\text{ light-years}) \times (1.39 \times 10^{-5})\cancel{°}}{360\cancel{°}} \\ &= 1.5 \times 10^{-4}\ \text{light-years}\end{aligned}$$

Clearly, we've chosen to express this in the wrong units: light-years are too large to be convenient for expressing the size of stars. So we convert to kilometers using the conversion factor found in Appendix A:

$$1.5\times10^{-4}\ \cancel{\text{light-years}}\times\frac{9.46\times10^{12}\ \text{km}}{1\ \cancel{\text{light-year}}}=1.4\times10^{9}\ \text{km}$$

(Note that we could have converted the distance to Betelgeuse to kilometers before we calculated Betelgeuse's size and gotten the diameter in kilometers out of our formula for physical size.)

The diameter of Betelgeuse is about 1.4 billion kilometers, which is more than 1000 times the Sun's diameter of 1.39×10^{6} kilometers. It is also almost ten times the distance between Earth and Sun $(1.5\times10^{8}$ kilometers).

Note: There is a wide range of uncertainty in the precise distance to Betelgeuse, so its actual size may be somewhat different than that calculated here.

55. a. Rearranging the formula from Cosmic Calculations 2.1 gives us:

$$\text{angular size}=\text{physical size}\times\frac{360°}{2\pi\times\text{distance}}$$

We are given the physical size of the Moon (3476 kilometers) and the minimum orbital distance (356,400 kilometers), so we can compute the angular size:

$$\text{angular size}=(3476\ \cancel{\text{km}})\times\frac{360°}{2\pi\times(356{,}400\ \cancel{\text{km}})}=0.559°$$

When the Moon is at its most distant, it is at 406,700 kilometers, so we can repeat the calculation for this distance:

$$\text{angular size}=(3476\ \cancel{\text{km}})\times\frac{360°}{2\pi\times(406{,}700\ \cancel{\text{km}})}=0.426°$$

The Moon's angular diameter varies from 0.426° to 0.559° (at its farthest distance from Earth and at its closest, respectively).

b. We can do the same thing as in part (a), except we use the Sun's diameter (1,390,000 kilometers) and minimum and maximum distances (147,500,000 kilometers and 152,600,000 kilometers) from Earth. At its closest, the Sun's angular diameter is

$$\text{angular size}=(1{,}390{,}000\ \cancel{\text{km}})\times\frac{360°}{2\pi\times(147{,}500{,}000\ \cancel{\text{km}})}=0.540°$$

At its farthest from Earth, the Sun's angular diameter is

$$\text{angular size}=(1{,}390{,}000\ \cancel{\text{km}})\times\frac{360°}{2\pi\times(152{,}600{,}000\ \cancel{\text{km}})}=0.522°$$

The Sun's angular diameter varies from 0.522° to 0.540°.

c. When both objects are at their maximum distances from Earth, both objects appear with their smallest angular diameters. At this time, the Sun's angular diameter is 0.522°, and the Moon's angular diameter is 0.426°. The Moon's angular diameter under these conditions is significantly smaller than the Sun's, so it could *not* fully cover the Sun's disk. Because it cannot completely cover the Sun, there can be no total eclipse under these conditions. There can be only an annular or partial eclipse under these conditions.

Chapter 3. The Science of Astronomy

Most students do not really understand how science works, and our aim in this chapter is to edify them in an interesting and multicultural way. If you are used to teaching from other textbooks, you may be surprised that we have chosen to wait until Chapter 3 to introduce this material. However, we have found that students are better able to appreciate the development of science and how science works after they first have some idea of what science has accomplished. Thus, we find that covering the development of science at this point is more effective than introducing it earlier.

As always, when you prepare to teach this chapter, be sure that you are familiar with the online quizzes, interactive figures, media, tutorials, assignable homework, and other resources available on the Mastering Astronomy website.

Key Changes for the Ninth Edition: We have left the basic organization and content of this chapter unchanged from the prior edition. However, we have made numerous edits throughout the chapter to improve clarity for students.

Teaching Notes (by Section)

Section 3.1 The Ancient Roots of Science

This section introduces students to the development of astronomy by discussing how ancient observations were made and used by different cultures. We stress that these ancient observations helped lay the groundwork for modern science. The particular examples cited were chosen to give a multicultural perspective on ancient astronomy; instructors may wish to add their own favorite examples of ancient observations. In teaching from this section, you can take one of two basic approaches, depending on how much time you have available: (1) If you have little time to discuss the section in class, you can focus on the examples generally without delving into the observational details; or (2) if you have more time available, you may emphasize the details of how observations allowed determination of the time and date and how lunar cycles are used to make lunar calendars.

Section 3.2 Ancient Greek Science

This section focuses on the crucial role of the ancient Greeks in the development of science. We focus on the idea of creating scientific models through the example of the gradual development of the Ptolemaic model of the universe. The section includes a discussion of the role of Islamic scholars in preserving and expanding upon Greek knowledge, setting the stage for discussion of the Copernican revolution in the next section.

- The flat Earth: There's a good article about the common misconception that medieval Europeans thought Earth to be flat in *Mercury*, Sept/Oct 2002, page 34.
- Occasionally, a student may be under the impression that a model is not useful in science. While it may not be clear how or why a student may come to this conclusion, this section, and the next, may be a good place to

emphasize the benefits of modeling, whether it be by drawing, sculpting, mathematics, or computer simulation. The key factors to emphasize is that scientific models are judged by how well they fit observations.

Section 3.3 The Copernican Revolution

With the background from the previous two sections, students now are capable of understanding how and why the geocentric model of the universe was abandoned. We therefore use this section to discuss the unfolding of the Copernican revolution by emphasizing the roles of each of the key personalities involved.

- Note that Kepler's laws are introduced in this section in their historical context.
- Note that we present Galileo's role by focusing on how he overcame remaining objections to the Copernican model. This is a particularly good example of the process of science, since it shows that old ideas were *not* ridiculous while also showing how new ideas gained acceptance.
- It may also be helpful to point out in this section that even Copernicus was hesitant to publish his work. We can make connections between this fear and the fear that students often have of speaking aloud in class. We all have this fear, but great things can happen if we are able to overcome it.
- Similarly, while Tycho's model of the Solar System is only briefly mentioned, its existence can be a great discussion point: there may exist more options than just the two extreme cases that we see in a debate. Tycho's model was essentially a hybrid of both the heliocentric and geocentric models. Tycho's discussions with Kepler would have, almost certainly, helped Kepler to think outside the box (or the circle, you might say in this case).

Section 3.4 The Nature of Science

The historical background of the previous sections has gotten students ready to discuss just what science really is. Here are a few notes:

- We emphasize that the traditional idea of a "scientific method" is a useful idealization, but that science rarely proceeds so linearly.
- The most important part of this section is the concept of *hallmarks of science*. We have developed these three hallmarks through extensive discussions with both scientists and philosophers of science, and we believe they represent a concise summary of the distinguishing features of science.
- One of the key reasons that the hallmarks are useful is that they make it relatively easy for students to distinguish between science and nonscience.
- We include only a brief discussion of the idea of scientific paradigms; you may wish to supplement this discussion with your favorite examples of paradigm shifts.

- Table 3.2 should be especially useful, and can offer points of discussion, as it shows how words in science can have different meanings than the same words in everyday language.
- This section may also be a useful point to discuss the value of perspectives in science. A diverse set of experiences and perspectives often help to overcome unintentional biases that we all have, and the sharing of those perspectives has helped scientific advancement from ancient civilizations through today.
- Public confusion between astronomy and astrology is well known. To address this confusion, we include a short Special Topic box designed to help students distinguish between the two. We have tried to avoid direct criticism of astrology and astrologers, even while pointing out that it is clearly not a science. Nevertheless, we suggest that you treat this topic carefully. A fair number of students are hard-core believers in astrology, and an attempt to dissuade them may backfire by making them dislike you and/or your course. If you can at least get such students to ask a few questions of themselves and their beliefs, you will have achieved a great deal.

Answers/Discussion Points for Think About It/See It for Yourself Questions

The Think About It and See It for Yourself questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 3.1

- (p. 55) This question simply asks students to think about the process of learning by trial and error. If you use this question for in-class discussion, you should encourage students to think about how this process is similar to the process of thinking used in science.
- (p. 56) The answer is debatable, but based on the origins of our seven days of the week, it seems quite reasonable to imagine that we would have ended up with eight days in a week if Uranus had been recognized as a planet.

Section 3.2

- (p. 59) The intent of this question is to help students gain appreciation for the accomplishments of ancient Greece. In class, this question can lead to further discussion of how much was lost when the Library of Alexandria was destroyed and also to discussion of whether the knowledge of our own civilization might someday suffer a similar fate.

Section 3.3

- (p. 65) Kepler's third law tells us that an orbital period depends only on average distance, so the comet with an average distance of 1 AU would orbit the Sun in the same time that Earth orbits the Sun: 1 year. Kepler's second law tells us that the comet would move fast near its perihelion and slow near its aphelion, so it would spend most of its time far from the Sun, out near the orbit of Mars.

Section 3.4

- (p. 75) When someone says that something is "only a theory," he or she usually means that it doesn't have a lot of evidence in its favor. However, according to the scientific definitions, "only a theory" is an oxymoron, because a theory must be backed by extensive evidence. Nevertheless, even scientists often use the phrase in both senses, so you have to analyze the context to decide which sense is meant.

Solutions to End-of-Chapter Problems (Chapter 3)

Visual Skills Check

1. d 2. a 3. d 4. a 5. a 6. a 7. a

Review Questions

1. We all use the trial-and-error methods that are used in science frequently in our everyday lives. Science builds upon this type of thinking by being more systematic in its approach, thereby facilitating discovery and collaboration.
2. Ancient cultures studied astronomy to track the changes of the seasons. They needed this information to help them plant, grow, and harvest crops each year.

   Astronomically, the origin of the day is tied to Earth's rotation period (or, as ancient people thought of it, the time for the Sun to make a circuit of our sky), the month comes from the lunar cycle (new moon to new moon), and the year from Earth's orbital period (or, as ancient people thought of it, from an equinox or solstice one year to the same event the next year). The days of the week are named for the seven wandering objects in the sky that the ancients knew: the Sun and Moon and the planets Mercury, Venus, Mars, Jupiter, and Saturn.
3. A lunar calendar is a calendar in which the months are tied to the Moon's 29 1/2-day cycle. As a result, a lunar calendar has 11 fewer days per year than a calendar that is based on Earth's orbital period. Lunar calendars are still used for many religious and cultural purposes. A lunar calendar can be kept roughly synchronized with a solar calendar by taking advantage of the 19-year Metonic cycle in which lunar phases recur on the same solar dates. For example, the Jewish calendar stays roughly synchronized with our solar

calendar by compensating for the 11-day annual shortage with an added month in 7 of the 19 years in each Metonic cycle.

4. A scientific model is a representation of our understanding of some real, natural phenomena. Scientific models do not necessarily need to be physical models, but the representation is meant to be used to demonstrate, explain and predict natural phenomena without the use of magic, mythology or the supernatural. The Greek geocentric model is the ancient model that placed Earth at the center of a great celestial sphere.
5. The Ptolemaic model was the Greek geocentric model made specifically by Claudius Ptolemy in the 2nd century B.C. His model was able to explain retrograde motion by having the planets move on smaller circles attached to the larger circles on which they went around Earth.
6. The Copernican revolution was the overthrowing of the Ptolemaic model of the solar system, essentially changing the human view of the universe from one in which Earth was imagined to be central to one in which Earth is just one of many similar planets.
7. An ellipse is an oval-like figure. We can draw an ellipse by putting two tacks down into a piece of paper and then running a loop of string around both of them. If we hook a pencil inside the string, pull the loop tight, and then drag the pencil around, keeping the string taut, we get our ellipse.

   The foci of the ellipse are the locations of the tacks.

   The semimajor axis is *half* the length of the ellipse along its longest axis.

   The eccentricity is a measure of how noncircular the ellipse is, where zero eccentricity is a circle and higher values of the eccentricity make more stretched-out ellipses. (The maximum value of eccentricity for an ellipse is 1.)
8. *Kepler's first law: The orbit of each planet around the Sun is an ellipse with the Sun at one focus.* This describes the shape of the orbits (ellipses rather than the circles that were used by most previous models) and where the Sun is located relative to the orbits (at a focus rather than in the center).

   Kepler's second law: As a planet moves around its orbit, it sweeps out equal areas in equal times. This describes a mathematical relationship between the speed and the distance, such that a line from a planet to the Sun sweeps out equal areas in equal amounts of time. This law describes how fast the planets move in their orbits. When they are close to the Sun, they move faster, and when they are far away, they move slower.

   Kepler's third law: More distant planets orbit the Sun at slower average speeds, obeying the mathematical relationship $p^2 = a^3$, where p is the planet's orbital period (in years) and a is its semimajor axis (in AU). This law describes the mathematical relationship that the more distant planets orbit more slowly than the ones that are closer to the Sun. This correlation is not affected by mass or eccentricity of the orbit.

9. The hallmarks of science are that it:
   1.) Seeks explanations for phenomena using natural causes
   2.) Relies on the creation and testing of models (which should be as simple as possible)
   3.) Uses testable predictions to determine if a model should be kept or discarded.

   In the Copernican revolution, the first hallmark is evident in the way that Tycho's data led Kepler to look for a natural explanation for the observations.

   The second is presented in the way that the Copernican model, with Kepler's improvements, made more accurate predictions than any competing model, such as the Ptolemaic model.

   The third is presented in the way that the models were carefully tested by looking for observations that each model predicted. The Ptolemaic model was thereby abandoned in favor of the heliocentric model that is used today.

   Occam's razor is the idea that when faced with more than one model or idea that appears to adequately explain our observations, we should prefer the simplest model or idea.

   Personal testimony does not count as evidence in science because it is impossible for other people to verify the testimony independently.

10. A hypothesis in science is a tentative, evidence-based explanation or model about why or how some specific phenomenon happens that is yet to be fully tested.

    A theory offers a wide range of explanations and models that have been rigorously tested and confirmed.

    If a hypothesis (1) is consistently confirmed through rigorous testing and attempts to disprove it, and (2) explains a wide range of observations, it may be elevated to the status of scientific theory.

Science or Nonscience?

11. *The Yankees are the best baseball team of all time.* Nonscience, because the term "best" is subjective and cannot be disproven.
12. *Several kilometers below its surface, Jupiter's moon Europa has an ocean of liquid water.* This statement can be evaluated scientifically. The existence of a liquid water ocean under Europa is testable and relies on natural phenomenon.
13. *My house is haunted by ghosts who make the creaking noises I hear each night.* Nonscience. The noises may be real, but no evidence is offered for concluding that they are caused by ghosts, and therefore, it is not testable (there is no way for it to be disproven).
14. *There are no lakes or seas on the surface of Mars today.* This statement can be evaluated scientifically, and in fact has been tested by study of Mars.

15. *Dogs are smarter than cats.* Nonscience, because the term "smarter" is not well-defined and cannot be disproven.
16. *Children born when Jupiter is in the constellation Taurus are more likely to be musicians than other children.* The statement can be evaluated scientifically. The test could be carried out by, for example, finding out whether musicians are more or less common among people born under that astrological condition than among people born at any other time. In fact, this statement has been tested and it is untrue. Note that being false does not make the claim unscientific, since it was still a testable claim. This is a subtle difference between the scientific validity of the claim and the truth value of the claim.
17. *Aliens can manipulate time and memory so that they can abduct and perform experiments on people who never realize they were taken.* Nonscience, because it offers no way to test whether the abductions really occur.
18. *Newton's law of gravity works as well for explaining orbits of planets around other stars as it does for explaining orbits of the planets in our own solar system.* Can be evaluated scientifically by observing extrasolar planets.
19. *God created the laws of motion that were discovered by Newton.* Nonscience, since the claim requires the use of something supernatural (God) in order to occur. It does not meet all the hallmarks of science and is an idea that cannot be tested scientifically.
20. *A huge fleet of alien spacecraft will land on Earth and introduce an era of peace and prosperity on January 1, 2035.* Can be evaluated scientifically by seeing whether or not the aliens show up on the appointed date.

Quick Quiz

23. b 24. a 25. c 26. b 27. b 28. c 29. c 30. b 31. c 32. b

Inclusive Astronomy/Process of Science

These are discussion-oriented questions, so we list only a few suggested things to look for in the student work.

31. For this question, we suggest you encourage students to consider a branch of their ancestry that is non-European (if possible), and also to try to get groups to have a variety of ancestral backgrounds to compare.
32. Answers will vary depending on the idea chosen. The key in grading is for students to explain themselves clearly and to defend their opinions well.
33. Students should discuss the role of astronomy in ancient times before forming their opinion on how it led to modern astronomy.
34. This is an opinion-based question, but students should use it to explore the many ways in which science impacts our lives.

35. This is an opinion-based question, but look for students to show that they understand the difference between astronomy and astrology.
36. This is group activity.

Short Answer/Essay Questions

37. More than one answer is possible for each part of this question, but here are some samples: (a) Observing changes in the sky with latitude would show that Earth is not flat. (b) Showing that the Sun is in different positions (i.e., different times of day) for different longitudes would show that Earth is curved east-west in addition to north-south. (c) Showing that changes in the sky with latitude and longitude are independent of where you start would show that Earth has spherical symmetry rather than some other shape.
38. This question asks students to make a bulleted "executive summary" of the Copernican revolution. Answers will vary, so grades should be based on the clarity, conciseness, and completeness of the list.
39. This essay question can generate interesting responses. Of course, the impacts of the Copernican revolution involve opinion, so grade essays based on how well they are written and defended.
40. This question involves independent research. Answers will vary.
41. This question involves independent research. Answers will vary.

Quantitative Problems

42. We will follow Eratosthenes's method, as described in Cosmic Calculations 3.1. In the case of Nearth, we learn that the Sun is straight overhead at Nyene at the same time that it is 10° from the zenith at Alectown and that the two cities are 1000 kilometers apart. We can set up the same type of relationship as Eratosthenes did:

$$\frac{10\cancel{^\circ}}{360\cancel{^\circ}} \times (\text{circumference of Nearth}) = 1000 \text{ km}$$

We solve for the circumference of Nearth:

$$\begin{aligned}\text{circumference of Nearth} &= 1000 \text{ km} \times \frac{360\cancel{^\circ}}{10\cancel{^\circ}} \\ &= 36{,}000 \text{ km}\end{aligned}$$

The circumference of Nearth is 36,000 kilometers.

43. Kepler's third law states:

$$a^3 = p^2$$

where a is the semimajor axis in AU and p is the period in years. Solving for the average distance a, we find:

$$a = \sqrt[3]{p^2}$$

We now put in Eris's period of $p = 557$ years to find its average distance in AU:

$$a = \sqrt[3]{557^2} = 67.7 \text{ AU}$$

Eris has an average distance (semimajor axis) of 67.7 AU, which is about 70% larger than Pluto's average distance of 39.5 AU.

44. a. We can use Kepler's third law to find the semimajor axis of Halley's comet. Kepler's third law states that:

$$a^3 = p^2$$

where a is the semimajor axis in AU and p is the period in years. We are asked to find the semimajor axis, so we can solve for a by taking the cube root of both sides:

$$a = \sqrt[3]{p^2}$$

Because Halley has an orbital period of 76 years, we can calculate the semimajor axis:

$$\begin{aligned} a &= \sqrt[3]{76^2} \\ &= 17.9 \text{ AU} \end{aligned}$$

Comet Halley has a semimajor axis of 17.9 AU.

b. The average of Comet Halley's perihelion and aphelion distances must be its average distance of 17.9 AU. The given perihelion distance of 90 million km is equivalent to 0.6 AU (90/150 = 0.6) Therefore we find:

$$\frac{\text{perihelion} + \text{aphelion}}{2} = \text{avg. distance}$$
$$\Rightarrow \text{aphelion} = 2 \times (\text{avg. distance}) - \text{perihelion}$$

Putting in the values, we find:

$$\text{aphelion} = 2 \times (17.9 \text{ AU}) - 0.6 = 35.2 \text{ AU}$$

Halley's Comet comes as close as 0.537 AU to the Sun and travels as far away as 35.2 AU from the Sun.