Motions of Earth, Moon, and Sun

TOPIC 4

How Scientists Study Motions of Earth, Moon, and Sun

Does the man on the moon change his facial expressions?

There is a common misconception that Earth's moon does *not* rotate. Most people likely believe that the moon revolves around Earth as Earth revolves around the sun. The revolution period of the moon's orbit around Earth is about 27 ⅓ days. When you observe the moon over a period of a month or more, you may notice that even though you see varying amounts of the moon (due to the changing phases), you always see the same features of the full moon, which makes it seem as if the moon does not spin on its own axis.

Try the following: Use your desktop as a model of the moon's orbital plane about Earth. Use a Roosevelt dime as a model of the moon, and a half dollar a model of Earth. Point the top of Roosevelt's head (moon) towards the half-dollar (Earth) and revolve the moon around Earth. Now try it again but always keep Roosevelt's head pointed toward Earth. What action occurs? Right! The dime rotates, but just once as it travels around the half-dollar. Thus, the same side of the moon must point toward Earth all the time. In other words, the man on the moon has the same face all the time, because the moon rotates once per revolution in 27 ⅓ days.

TOPIC 4

Motions of Earth, Moon, and Sun

Vocabulary

axis (of rotation)	Foucault pendulum	phases (of the moon)
constellation	geocentric model	tides
Coriolis effect	heliocentric model	time zone
eclipse	local time	

Topic Overview

Throughout time, most cultures have attempted to understand the nature and the motions of celestial objects—the stars, sun, moon, and planets. Many of the explanations of the nature and cause of motions of celestial objects have become part of the belief systems of past and present cultures.

In this topic you will study the nature and motion of celestial objects in relationship to Earth and our satellite, the moon. Some scientists consider Earth and its moon to be a double planet, but for the purpose of this book, the moon will be considered a satellite of Earth, and Earth a satellite of the sun.

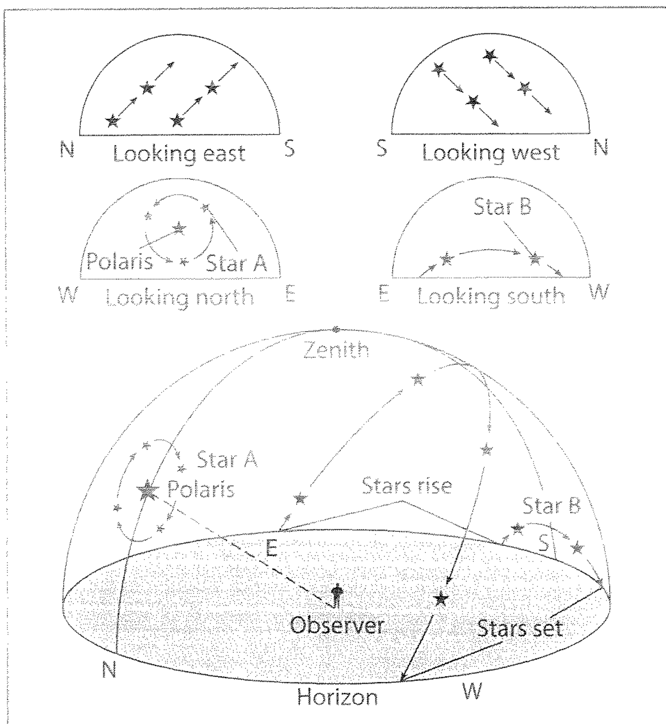


Figure 4-1. Apparent daily motion of stars in middle northern latitudes: To an observer in the mid-latitudes of the Northern Hemisphere—such as New York State—most stars appear to move from east to west in circular paths, or along arcs. The complete circular path can be seen for stars in the northern part of the sky around Polaris. Other stars rise over the eastern horizon and set at the western horizon in the middle latitudes.

Apparent Motions of Celestial Objects

An apparent motion is a motion that an object appears to make. Apparent motions can be real or illusions. When you observe a person spinning around, that motion is real. However, when the spinning person sees the room as spinning, that is an illusion and not a real motion. It has always been difficult for people looking into space to distinguish real motions of celestial objects from illusions. For example, the stars appear to move across the sky from east to west. However, this apparent motion is caused by Earth's rotation.

Daily Motion and Stars

Most celestial objects appear to move across the sky, rising in the eastern part of the sky and setting in the western part of the sky. The vast majority of the 6000 or so celestial objects visible with the unaided eye at any location are stars.

Some of the stars near the North Star, or Polaris, appear to move in a complete circle in 24 hours. The paths of all celestial objects moving in the sky are circular, or parts of a circle called an arc. All the motion occurs at a constant rate of approximately 15° per hour or 360° in 24 hours. These movements of celestial objects over a 24-hour period are called daily motion. (See Figure 4-1.)

Apparent Motions of the Planets

As seen from Earth, the planets exhibit daily motion similar to that of the stars. However, over extended periods of time (weeks to months), the planets appear to change position with respect to the background field of stars around them. As illustrated in Figure 4-2, this apparent movement of the planets relative to the stars is not uniform and often appears complicated. Each year, a similar motion would be observed, but in a different region of the sky. From a central sun perspective, the complicated motion of the planets is the result of Earth and other planets revolving around the sun in different orbits at different speeds. This causes other planets viewed from Earth to sometimes appear to make loops and move back and forth.

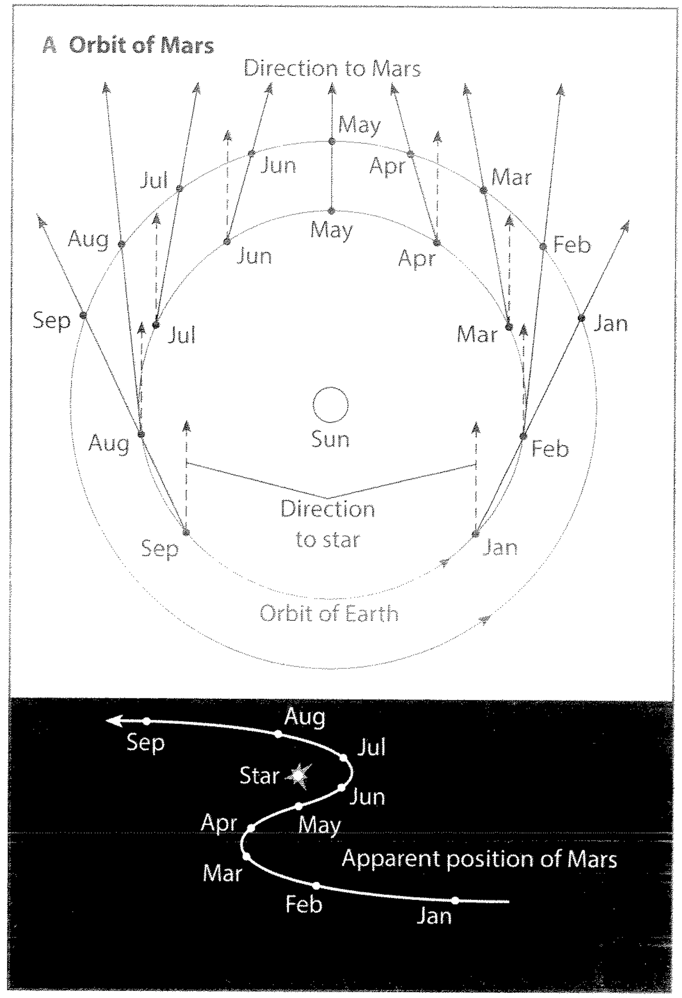


Figure 4-2. Apparent motions of a planet: Diagram A shows successive positions of Earth and Mars along their orbits at monthly intervals during part of a given year. The dashed arrows show the sight lines from Earth to a certain star. These sight lines are practically parallel because of the great distance of the star. The solid arrows are the sight lines toward Mars. As the diagram shows, the sight line changes in relation to the star each month. Diagram B shows how the apparent position of Mars changed with respect to the star.

Apparent Motions of Earth's Moon

The moon also follows the daily east-to-west motion of the stars. However, it appears to rise about 50 minutes later each day and shifts eastward each day compared to the background field of stars.

Apparent Sun Motions in Northern Mid-Latitudes

Like all other visible celestial objects, the sun also seems to move in the sky. The sun's apparent path, from sunrise to sunset, has the shape of an arc. As shown in Figure 4-3, the sun's path changes both its position and its length with the seasons. The greater the length of the sun's path over an area, the more hours of daylight the area has. In summer, daylight is longest, in winter shortest, and in spring and fall in-between—approximately 12 hours. Figure 4-3 also shows how the position of the sun at sunrise and sunset varies predictably with the seasons. In spring and fall, the sun rises due, or exactly, east and sets due west. In summer, the sun rises north of east and sets north of west. In the winter, the sun rises south of east and sets south of west.

Changes in the Altitude of the Sun at Noon Figure 4-3 indicates that the daily altitude of the sun is lowest at sunrise and increases in altitude until noon, when the sun then decreases to its sunset position. The sun always reaches its highest position in the sky at local solar noon. However, the altitude of

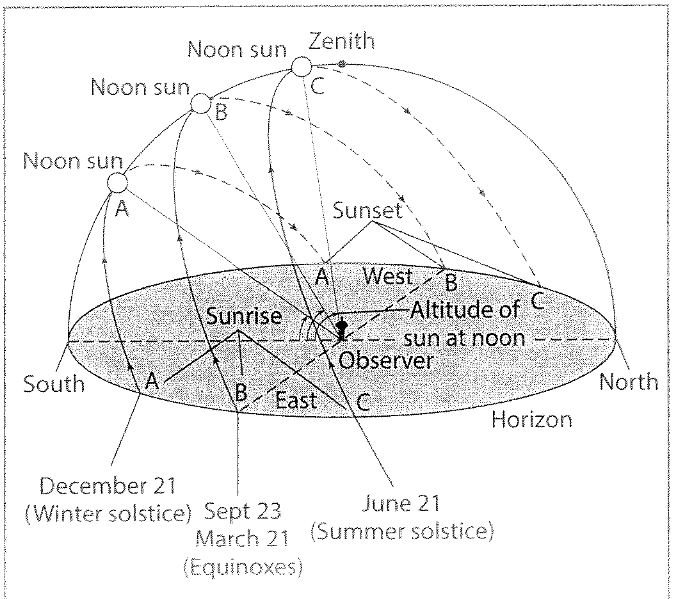


Figure 4-3. The changing apparent path of the sun in the northern mid-latitudes: Note that the length of the sun's apparent path is longest on June 21, shortest on December 21, and in-between on March 21 and September 23. Also, the altitude of the sun at noon is highest on June 21, shortest on December 21, and in-between on September 23 and March 21. (See Appendix 4.)

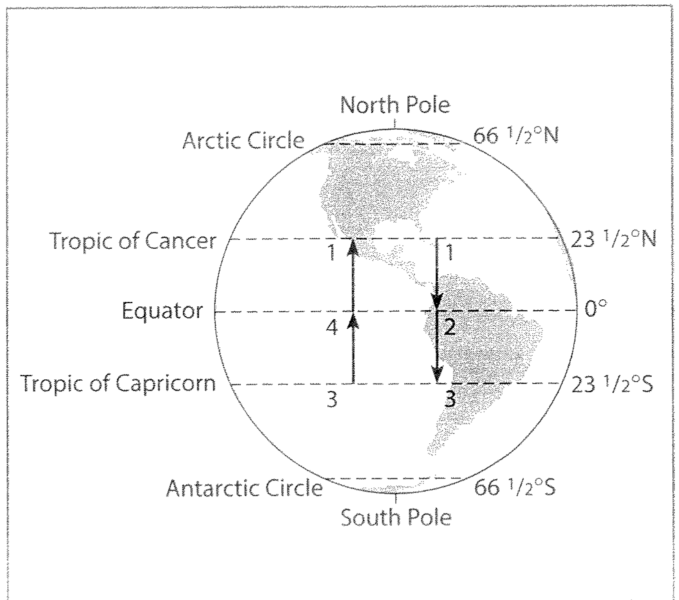


Figure 4-4. The yearly changes in latitude where the sun is directly overhead at noon—at an altitude of 90°: Point 1 is June 21, point 2 is September 23, point 3 is December 21, and point 4 is March 21.

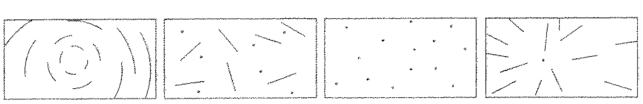
(A4) the sun at noon depends on the time of year and the latitude of the observer. Only between latitudes 23 ½° N and 23 ½° S can the noon sun be directly overhead at an altitude of 90°. Thus, the noon sun is never directly overhead anywhere in the continental United States. Figure 4-4 shows how the latitude at which the sun is overhead at noon changes during a year.

Review Questions

1. If Earth rotated from north to south, the North Star would appear to

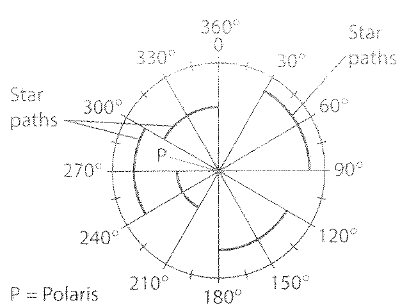
(1) set in the south
(2) set in the north
(3) move in a circle in the sky
(4) remain stationary

2. How would a three-hour time exposure photograph of stars in the northern sky appear if Earth did not rotate?



(1) (2) (3) (4)

3. An observer took a time-exposure photograph of Polaris and five nearby stars. How many hours were required to show these star paths?



(1) 6 (2) 2 (3) 8 (4) 4

4. When observed from a location in New York State for an entire night, the North Star (Polaris) appears to
   (1) rise in the east and set in the west
   (2) rise in the west and set in the east
   (3) move southward along an arc-shaped path
   (4) remain stationary in the sky

5. Explain why most stars seem to move from east to west across the sky in New York State.

6. The star Sirius is observed in the evening sky during the month of January. At the end of 3 hours, Sirius will appear to have moved
   (1) 60° (2) 45° (3) 3° (4) 0°

7. On December 21, at which latitude would an observer find the sun directly overhead?
   (1) 0° (3) 23 ½° South
   (2) 23 ½° North (4) 90° South

8. The sun's apparent daily movement across the sky is caused by
   (1) the sun's revolution around Earth
   (2) Earth's revolution around the sun
   (3) the sun's rotation on its axis
   (4) Earth's rotation on its axis

9. At which location below would the sun produce an angle of 23.5° relative to an observer's head, at noon on June 21?
   (1) 0° (3) 23.5°S
   (2) 23.5°N (4) 66.5°N

10. At 40° N latitude, for how many days a year is the sun directly overhead at noon?
    (1) 1 (2) 2 (3) 3 (4) 0

11. In New York State, to see the sun at noon, one would look towards the
    (1) north (3) east
    (2) south (4) west

12. A student in New York State obtained the data below by noting the altitude of the sun at noon for three consecutive months.

Month	Altitude of Sun at Noon
X	27.0°
Y	23.5°
Z	25.5°

The data for month Y were obtained during
    (1) March (3) September
    (2) June (4) December

13. To a person located at 43° North latitude, the sun appears to rise due east on
    (1) December 22 (3) March 21
    (2) March 1 (4) June 22

14. From September 21 to December 20 in the United States, the direction in which the sun sets
    (1) is always directly east
    (2) is always directly west
    (3) moves from the east towards the north
    (4) moves from the west towards the south

Models that Help Explain Apparent Celestial Motions

For thousands of years, people have developed theories to explain their observations of the movements of celestial objects. An explanation of two of these theories follows.

Geocentric Models

A majority of early cultures believed the most obvious way to explain the daily motion of celestial objects. They assumed that Earth is stationary, and that most celestial objects revolve around it. This Earth-centered model is called the **geocentric model.** In many geocentric models, the moon and sun were thought to travel at slightly different speeds in their orbits of Earth. The geocentric model explained most of the motions of the stars, sun, and moon, but it did not explain the apparent motions of the planets. One version of the geocentric model proposed that the planets moved around in circles as the planets revolved around Earth. The geocentric model also could not explain some Earth motions and the behavior of a freely

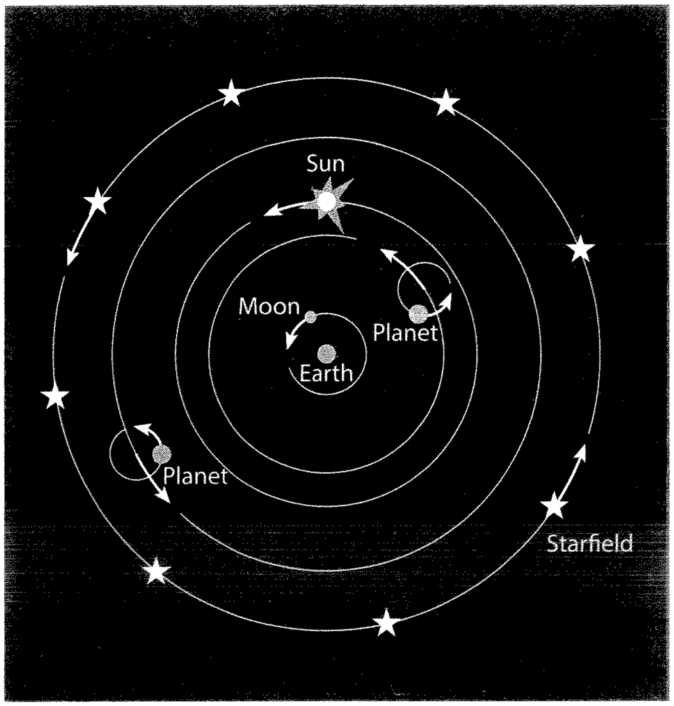


Figure 4-5. Geocentric model of celestial objects: In this model, Earth neither rotates nor revolves. The moon, sun, and other stars orbit Earth in circular paths at different speeds. All stars are the same distance from Earth. The planets revolve in small circles, while the centers of these circles revolve around Earth in circular orbits. These additional small circles for the planets are needed to explain the planet's irregular motions. The small circles are much more complicated than those shown here.

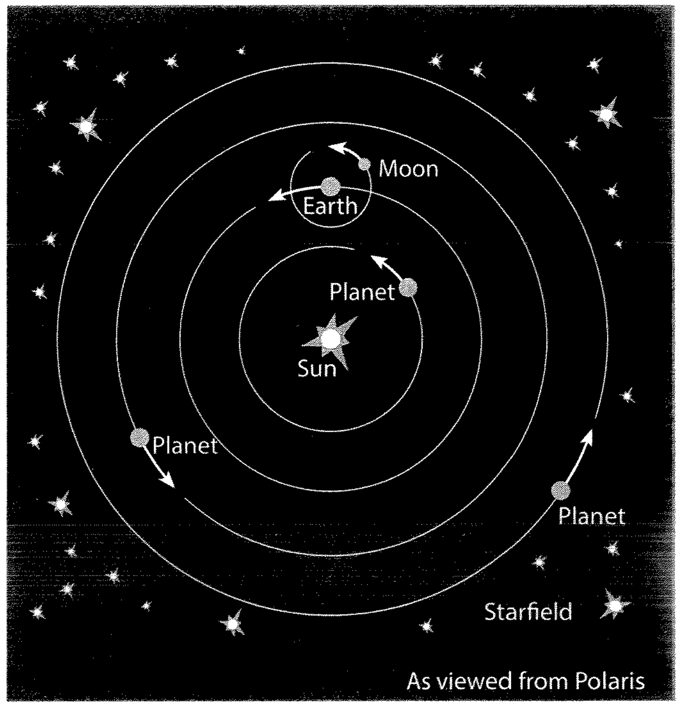


Figure 4-6: A modern heliocentric model: The sun is the center of motion. Earth and other planets rotate and revolve around the sun at different speeds in elliptical orbits with some eccentricity. Note the counterclockwise revolution of the planets as viewed from Polaris. The stars don't revolve around Earth and are at varying distances from the solar system.

Memory Jogger

Recall that eccentricity can be described as the amount of difference between an ellipse as compared to a circle. With the exception of Mercury, the slightly elliptical orbits of the planets, drawn to scale, look like circles to the human eye.

swinging pendulum. In European cultures, the geocentric model was largely accepted up to the 16th century.

Heliocentric Models

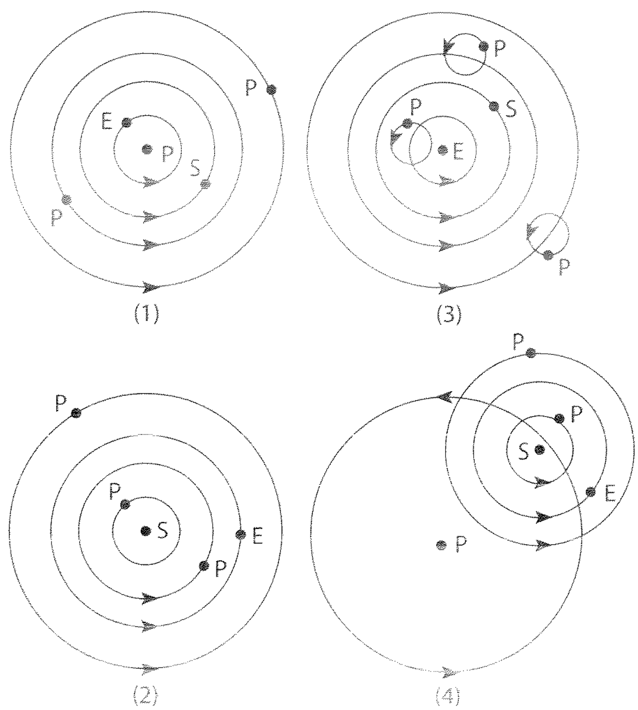
Some ancient cultures and most modern societies use a **heliocentric model**—sun-centered model—to explain the apparent motions of celestial objects in Earth's sky. In all heliocentric models, Earth both rotates on an imaginary axis and revolves around the sun in an orbit. The moon revolves around Earth as Earth revolves around the sun. The daily motion of stars is explained by the rotation of Earth. The motions of the moon are explained by the rotation of Earth, the revolution of Earth around the sun, and the revolution of the moon around Earth. The apparent motions of the sun are explained by the rotation of Earth on a tilted axis and the revolution of Earth around the sun.

Because they used circular orbits for the planets, most early heliocentric models did no better in predicting the motions of the planets than did the geocentric views. When elliptical orbits and varying orbital speeds were added to the heliocentric model, the motions of the planets could be predicted. The heliocentric model did explain the behavior of a freely swinging pendulum.

Review Questions

15. In the geocentric model, which motion would occur?
    (1) Earth would revolve around the sun.
    (2) Earth would rotate on its axis.
    (3) The moon would revolve around the sun.
    (4) The sun would revolve around Earth.

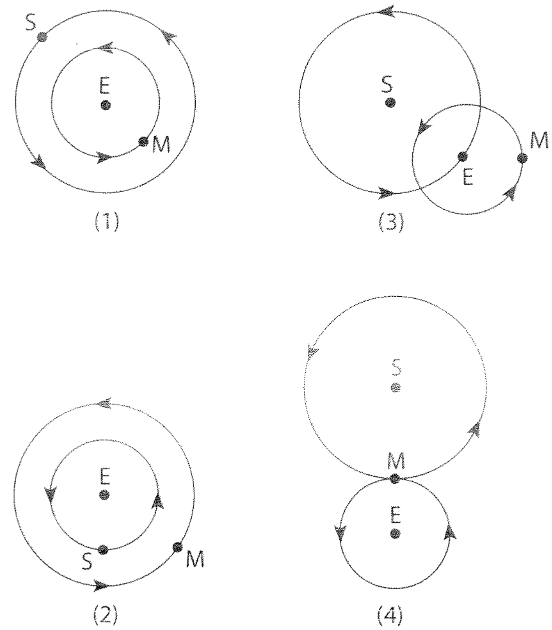
16. Which diagram represents a geocentric model?



Key: E = Earth, P = Planet, S = Sun

17. The apparent rising and setting of the sun as seen from Earth are caused by the
    (1) rotation of the sun
    (2) rotation of Earth
    (3) revolution of Earth
    (4) revolution of the sun

18. Which diagram best represents a portion of the heliocentric model of the solar system?



S = Sun, E = Earth, and M = Moon

19. Which planetary orbit model allows a scientist to predict the exact positions of the planets in the night sky for many years?
    (1) The planets' orbits are circles in a geocentric model.
    (2) The planets' orbits are ellipses in a geocentric model.
    (3) The planets' orbits are circles in a heliocentric model.
    (4) The planets' orbits are ellipses in a heliocentric model.

Actual Earth Motions

Earth moves constantly in a variety of motions. Earth moves with the Milky Way Galaxy as the universe expands. It moves around the center of the Milky Way Galaxy with our solar system in a 225-million-year period. Earth also rotates and revolves around the sun in an orbit.

Rotation of Earth

The spinning of Earth on its **axis**—the imaginary line through the planet from the North Pole to the South Pole—is its rotation. The axis of Earth is tilted $23\frac{1}{2}°$ from a line perpendicular to the plane of its orbit of the sun.

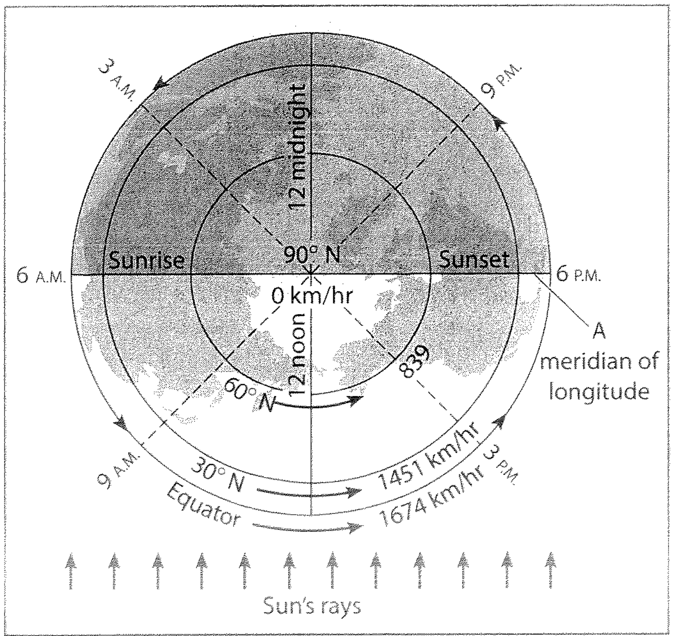


Figure 4-7. Circle of rotation—meridians of longitude—showing local solar times: Angular rotation rate is 15° per hour at any latitude. Local solar time changes 1 hour for each 15 degrees of longitude. When it is local solar noon on the side of Earth facing the sun, it is midnight on the opposite side.

As Earth orbits the sun, Earth's axis remains tilted at $23\frac{1}{2}°$. The north end of the axis points towards the North Star, or Polaris.

Earth rotates 360° from west to east in 24 hours, at an angular rate of 15° per hour. This angular rate is the same at all locations on Earth. Looking down over the North Pole, the direction of Earth's rotation is west to east—counterclockwise—as shown in Figure 4-7.

Evidence of Earth's Rotation

Throughout much of human history, scientists have searched for evidence that Earth rotates. Earth's movement is not apparent because people don't feel very smooth motions the same way that they are aware of abrupt motions. Also, there is nothing near Earth with which to compare its motion. Only in recent history have people and satellites been able to observe the rotation of Earth.

The Foucault Pendulum When a **Foucault pendulum** is allowed to swing freely (first observed in 1851), its path will appear to change in a predictable way, as shown in Figure 4-8. This is evidence of Earth's rotation because the pendulum—due to inertia—would continue to swing in the original path if Earth did not rotate. (See A-A′ in Figure 4-8.)

The path of the Foucault pendulum only appears to change. Actually, the pendulum swings in a fixed direction in space, while Earth, carrying the observer with it, rotates under the pendulum. If you could observe the pendulum moving through a powerful telescope in space, you would see no apparent change in its path. Foucault pendulums can be found in a number of museums to recreate the experiment.

The Coriolis Effect The tendency of all particles of matter moving at Earth's surface to be deflected, or curve away, from a straight-line path is the **Coriolis effect.** The deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This deflection occurs because Earth is rotating, and therefore Earth's surface is moving with respect to the path of the particles.

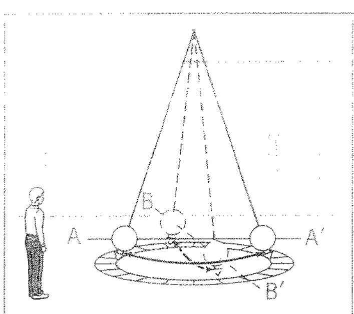


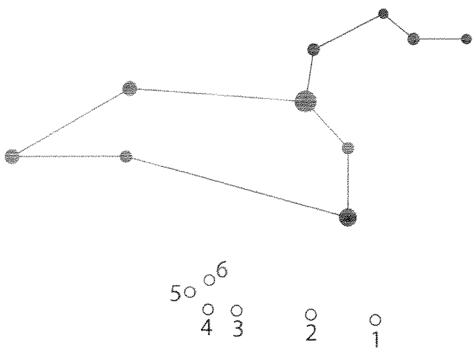
Figure 4-8: Apparent motion of a Foucault pendulum: An observer sees a pendulum swing in the direction A-A′. Several hours later, the pendulum has changed its direction of swing to the line B-B′.

The following example can help to explain the effect. Imagine that you are at the center of a merry-go-round that is rotating counterclockwise. Your friend is near the rim of the merry-go-round. You throw a ball directly at your friend. By the time the ball reaches the rim of the merry-go-round, your friend has been carried to the left. The ball reaches the rim at a point that is now to the right of your friend. With respect to the moving merry-go-round, the ball has been deflected to the right. In a similar manner, rockets, ocean currents, large storms, and winds are deflected with respect to Earth's surface. Since the only reasonable explanation of the Coriolis effect is that Earth rotates, the Coriolis effect is good evidence for Earth's rotation.

away from a given star. These movements toward or away from a star result in small yearly cyclic changes in blue and red shifting of starlight.

Review Questions

20. The following diagram represents part of the night sky, including the constellation Leo. The black circles represent stars. The unshaded circles represent the changing positions of one celestial object over a period of a few weeks.



The celestial object represented by the unshaded circles most likely is

(1) a galaxy
(2) a planet
(3) Earth's moon
(4) another star

21. Why are different constellations visible in the night sky at different seasons of the year?

22. An angle of $23\frac{1}{2}°$ is formed between the axis of Earth and a line

(1) from the center of Earth to Polaris
(2) from the center of Earth to the sun
(3) perpendicular to the plane of Earth's orbit
(4) perpendicular to the plane of the moon's orbit

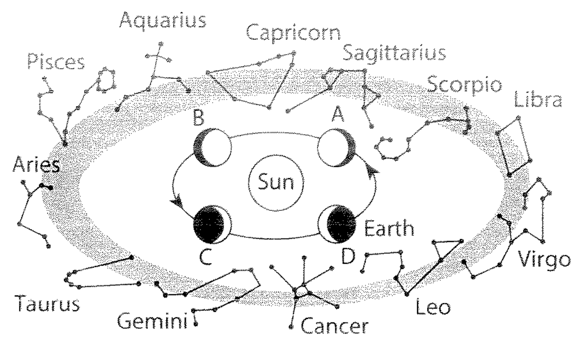
23. The Foucault pendulum provides evidence of Earth's

(1) rotation
(2) revolution
(3) insolation
(4) inclination

24. On Earth, surface ocean currents rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere because of the

(1) Coriolis effect
(2) Seasonal effect
(3) Tidal effect
(4) Doppler effect

Base your answers to questions 25 and 26 on the following diagram. The diagram shows, over the course of a year, twelve constellations that are visible in the night sky to an observer in New York State. Different positions of Earth are represented by letters A through D. The arrows represent the direction of Earth's motion around the sun.



(Not drawn to scale.)

25. Which constellations are both visible at midnight to an observer in New York State when Earth is located at position D?

(1) Aries and Taurus
(2) Pisces and Libra
(3) Leo and Virgo
(4) Aquarius and Scorpio

26. The constellations observed from New York State when Earth is at position A are different from the constellations observed from New York State when Earth is located at position C because

(1) Earth moves in its orbit
(2) Earth is tilted on its axis
(3) the lengths of day and night are different
(4) the stars move around Earth as shown by star trails

27. Which statement provides the best evidence that Earth revolves around the sun?

(1) The sun follows an apparent daily path, rising in the east and setting in the west.
(2) A Foucault pendulum appears to shift its direction of swing in a predictable manner.
(3) The stars appear to follow circular paths around the North Star (Polaris).
(4) The seasons of spring, summer, fall, and winter repeat in a pattern.

Evidence of Earth's Revolution Around the Sun

Earth revolves around the sun in a slightly eccentric elliptical orbit, or path, once a year. Earth revolves in a counterclockwise direction (as viewed from Polaris) at a rate of approximately 1 degree per day (360 degrees in 365 days). Just as scientists had trouble providing proof that Earth rotates, they also had difficulty finding solid evidence of Earth's revolution around the sun.

If you understand that Earth's limited change in distance from the sun during the year does not cause seasons, then the seasonal changes associated with changes of the sun's path is evidence of revolution. If Earth did not revolve around the sun, the same part of Earth would tilt toward the sun all the time. Therefore, the same part of Earth would receive the more direct rays of sunlight. The seasons would not change; each part of Earth would have the same season all the time.

Having different constellations associated with each of the four seasons is further evidence of Earth's revolution. A **constellation** is a group of stars that form a pattern and are used to help people locate celestial objects. At night you can see different constellations at different times of the year, as shown in Figure 4-9.

Earth's revolution around the sun produces other effects that can be used as evidence of revolution. During the year the apparent diameter of the sun changes in a cyclic fashion. Earth's changing distance from the sun as Earth revolves in its slightly elliptical orbit causes the size of the sun to appear to change. The sun appears the largest when Earth is closest to the sun around January 3. The sun appears the smallest when it is farthest away from Earth on about July 4.

Slight changes in the Doppler effect of stars can also be used as evidence of revolution. As Earth revolves around the sun, Earth is traveling toward a given star for about half the year, and the other half of the year it is moving

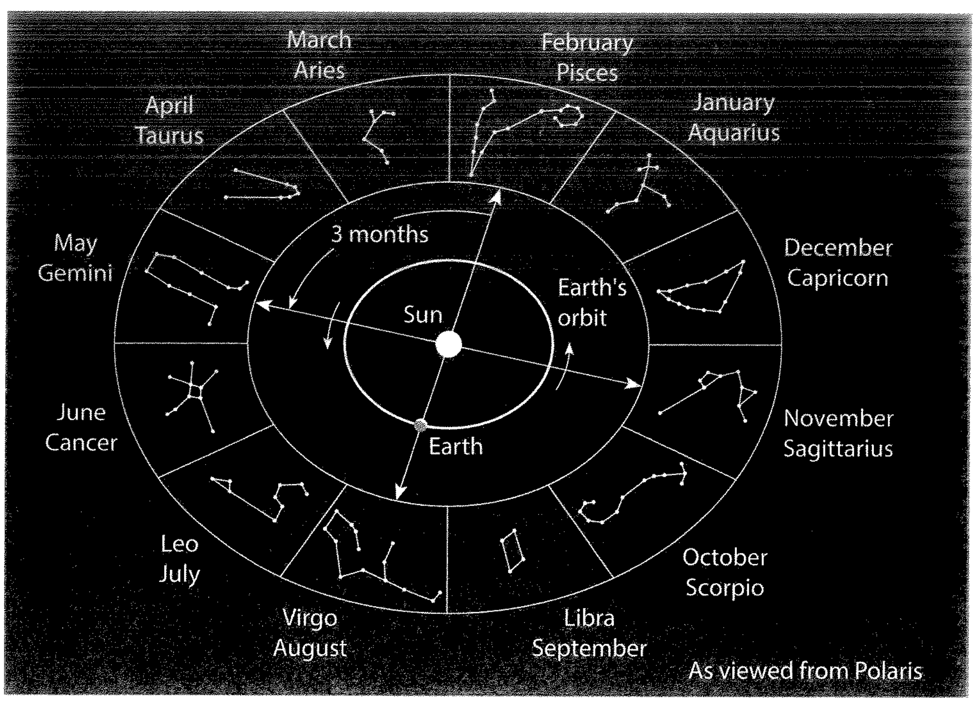
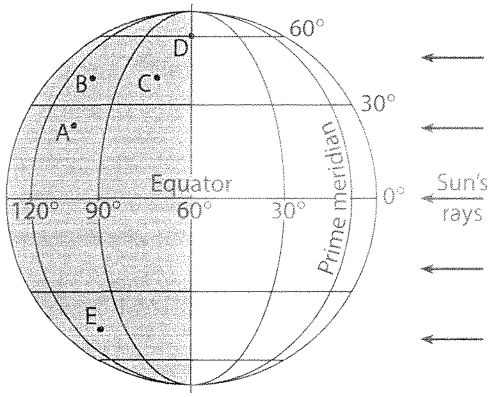


Figure 4-9. Changes in the constellations during the year: The fact that you observe different constellations in different seasons is evidence of Earth's revolution around the sun. Constellations are visible when the dark side of Earth (away from the sun) faces toward the constellation.

34. When does local solar noon always occur for an observer in New York State?

(1) when the clock reads 12 noon
(2) when the sun reaches its maximum altitude
(3) when the sun is directly overhead
(4) when the sun is on the prime meridian

Base your answers to questions 35 through 37 on the following diagram of Earth. Some of the latitude and longitude lines have been labeled. Points A through E represent locations on Earth's surface.



35. What do locations A, B, and E have in common?

(1) They are in the same season.
(2) They have the same local time.
(3) They have the same prevailing wind direction.
(4) They are at the same latitude.

36. The latitude and longitude of which location are closest to those of New York State?

(1) A (2) B (3) C (4) D

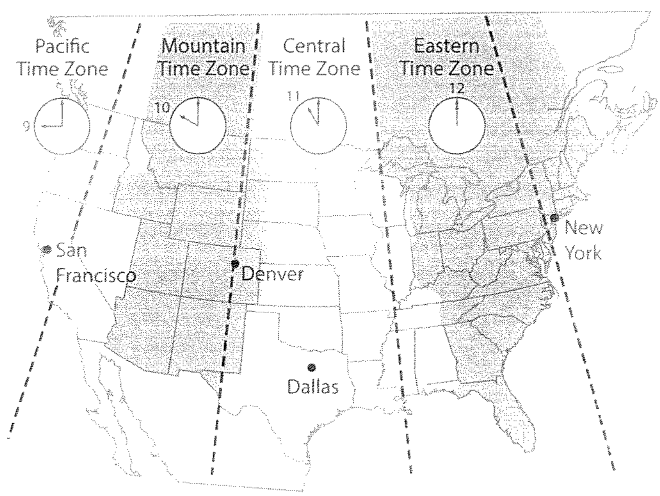
37. What is the approximate time at location D?

(1) 6 A.M. (3) 9 P.M.
(2) 12 noon (4) 12 midnight

38. Ship X and ship Y are sailing along the equator. The difference in local solar time between their locations is 2 hours. What is their difference in longitude?

(1) 0° (2) 15° (3) 30° (4) 45°

Base your answers to questions 39 and 40 on the following time zone map.



39. What is the time in San Francisco when it is 6 A.M. in Dallas?

(1) 5 A.M. (2) 7 A.M. (3) 3 A.M. (4) 4 A.M.

40. The dashed boundaries between time zones are how many degrees of longitude apart?

(1) 10° (2) 15° (3) $23\frac{1}{2}$° (4) 24°

Actual Motions of Earth's Moon

The revolution of the moon around Earth as Earth revolves around the sun results in many common observable events, including phases of the moon, tides, and eclipses. The moon revolves around Earth in an elliptical orbit that is tilted about 5° from Earth's orbit and that has a period of $27\frac{1}{3}$ days. Besides revolving around Earth in $27\frac{1}{3}$ days, the moon also rotates on its axis in $27\frac{1}{3}$ days. Thus as the moon revolves once, it rotates once. This is the reason why the same "face" or side of the moon always points towards Earth. Figure 4-12 provides some details of the orbital motions of Earth and its moon.

Moon Phases

Half of the moon is always receiving light from the sun at any given time—except during lunar eclipses. Since the moon revolves around Earth, an observer on Earth sees varying amounts of this lighted half as the moon moves through its orbit. The varying amounts of the lighted moon as seen from Earth are known as the moon's **phases.** (See Figure 4-13.)

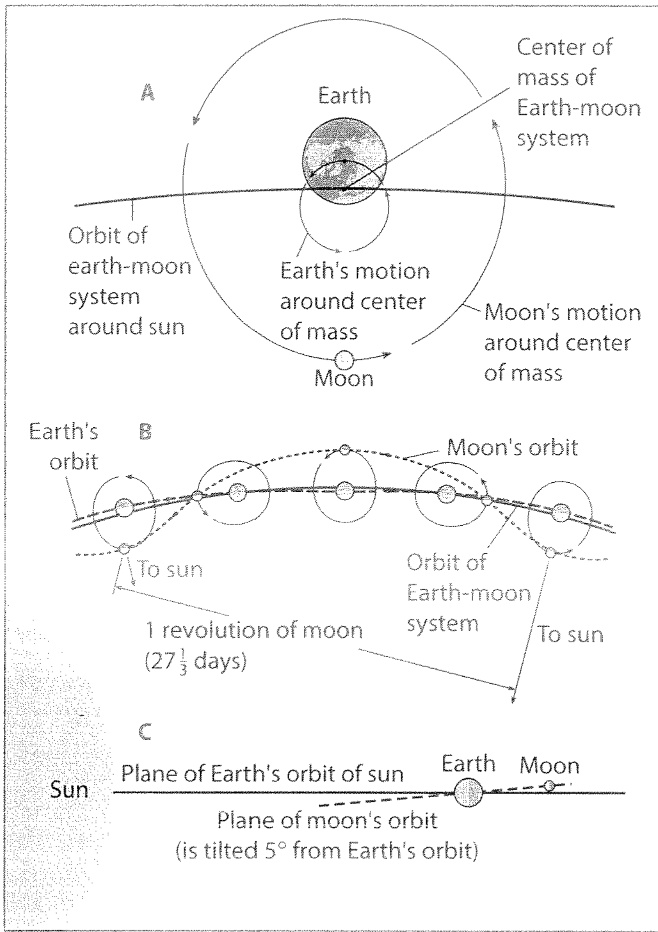


Figure 4-12. The moon's orbit: (A) The revolution of the moon around Earth is due to a balance between the inertia of the moon and the gravitational attraction of the moon to the center of the Earth-moon system. (B) The movements of the moon are exaggerated. (C) The moon's orbit of Earth is tilted 5° from Earth's orbital plane of the sun.

Because the revolution of the moon around the center of the Earth-moon system is cyclic, the phases of the moon are also cyclic. However, because of the revolution of the Earth-moon system around the sun, the cycle of phases is somewhat longer than the time of one revolution of the moon. The period from one full moon to the next is $29\frac{1}{2}$ days, whereas the moon's period of revolution and rotation is just $27\frac{1}{3}$ days. This difference in time is explained in Figure 4-14.

Tides

The gravitation between Earth, the moon, and the sun results in a cyclic rise and fall of ocean waters on Earth called **tides.** Figure 4-15 illustrates a typical tide pattern and how the varying positions of Earth, the moon, and the sun result in different levels of ocean water.

The tidal effect is caused primarily by the moon not the sun. Even though the moon is much smaller than the sun, it is about 400 times closer to Earth. Figure 4-15 illustrates that there is a bulge of water—a high tide—on Earth directly under the moon's position. There is also a high tide on the opposite side of Earth because the solid Earth is closer to the Earth-moon center of gravitation than the ocean water. This causes Earth to be pulled away from the water, leaving the high tide. At right angles to the positions of high tide, the gravitational pull of the moon is least, and the levels of ocean water are low, resulting in a low tide.

Because Earth is rotating, the low and high tides follow the straight-line alignment between Earth and the moon. The timing of high and low tides is not only affected by the rotating Earth, it is also influenced by the moon revolving around Earth. Thus, the ideal time between two high tides or two low tides would be about 12 hours and 25 minutes. A complete ideal cycle of two high tides and two low tides at a location would then take about 24 hours and 50 minutes. Few ocean shores experience an ideal cycle of tides, due to many factors.

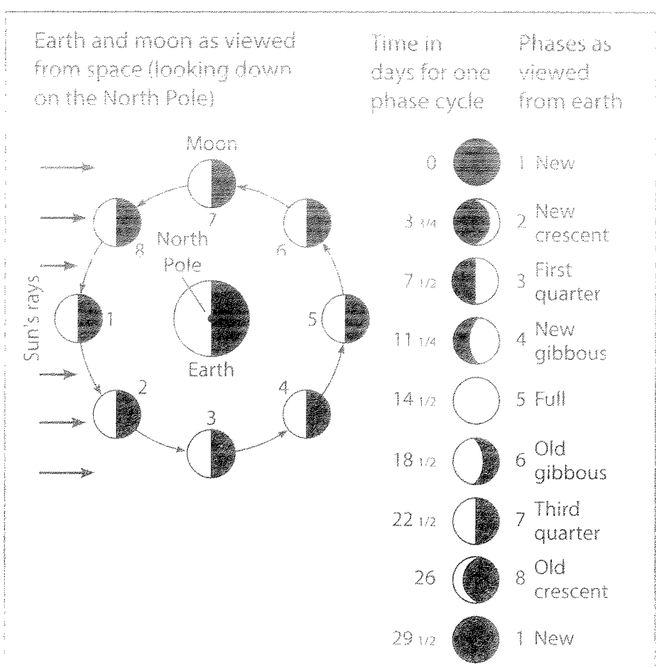


Figure 4-13. The phases of the moon: The half of the moon facing the sun is always illuminated by light from the sun. The right side of the diagram shows how the moon appears as viewed from Earth for each phase of the moon.

The effect of the sun on tides is largely that of reducing or enhancing their heights. When Earth, the moon, and the sun are in a straight line, the sun enhances the tidal effect, and high tides are higher and low tides are lower. This large tidal range happens during new and full moon phases. When the moon is in one of the quarter phases, the sun is pulling at right angles to the moon. As a result, high tides are then lower, and low tides are higher, producing a smaller tidal range.

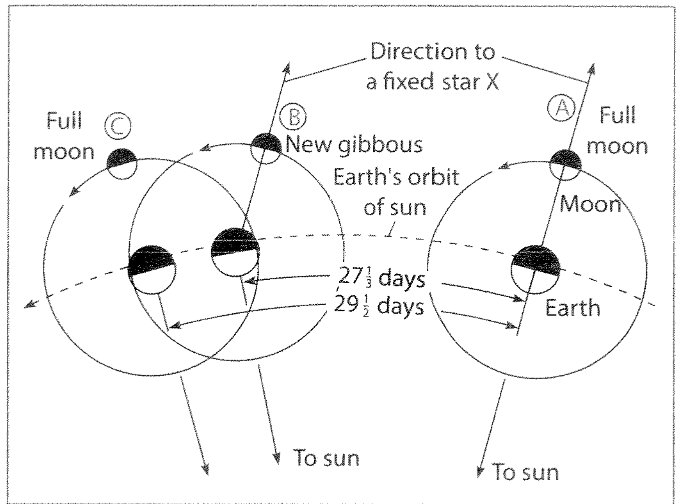


Figure 4-14. Different lengths of the moon's period of revolution and one phase cycle: The moon takes about 27 $\frac{1}{3}$ days to revolve around Earth, but one phase cycle, such as from full moon to full moon, takes 29 $\frac{1}{2}$ days.

Eclipses

Earth and the moon, like all other opaque objects that don't produce their own light, cast long shadows into space. When a celestial object partly or completely comes into the shadow of another celestial object, there is an event called an **eclipse.**

Lunar Eclipse When the moon revolves into the shadow of Earth at the full moon phase, a lunar eclipse, or eclipse of the moon, can occur. (See Figure 4-16.) A lunar eclipse doesn't happen during most full moons because the moon's orbit of Earth is tilted about 5 degrees compared to Earth's orbit. If Earth's shadow (umbra) covers only part of the moon, there is a partial eclipse. The curved shadow of Earth on the moon during a partial lunar eclipse is evidence for Earth's spherical shape.

When there is a total lunar eclipse, the moon is completely covered by Earth's shadow and all people on the dark half of Earth can view the eclipse for up to about 100 minutes. The complicated cycle of lunar eclipses results in an average of two total lunar eclipses a year.

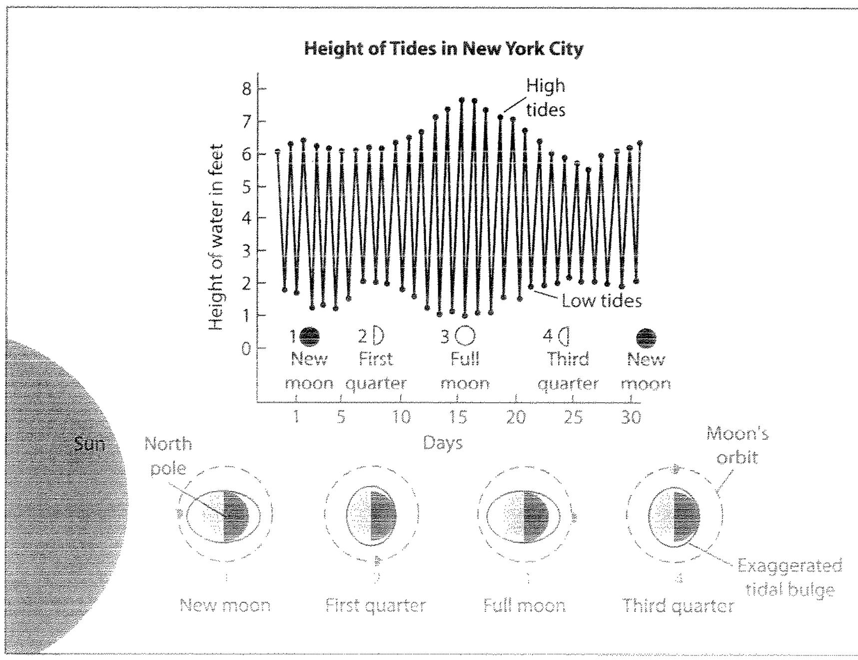


Figure 4-15. Ideal tide pattern in New York City: When the moon is in the new or full moon phase (positions 1 and 3), the gravity of the moon and sun are in a straight line. This causes higher high tides and lower low tides—a large tidal range. When the moon is in the quarter phase (positions 2 and 4), the gravitational force of the sun is at a 90° angle to the moon's force. This causes lower high tides and higher low tides—a smaller tidal range.

Solar Eclipse Under rare ideal conditions at the new moon phase, the moon can just barely block out the sun, casting a shadow on Earth that causes a solar eclipse. As seen in Figure 4-17, the moon's shadow can just barely reach Earth, making solar eclipses a rare event. A total eclipse of the sun can only be observed at any one location on Earth for up to 7 $\frac{1}{2}$ minutes once every 200 years or so.

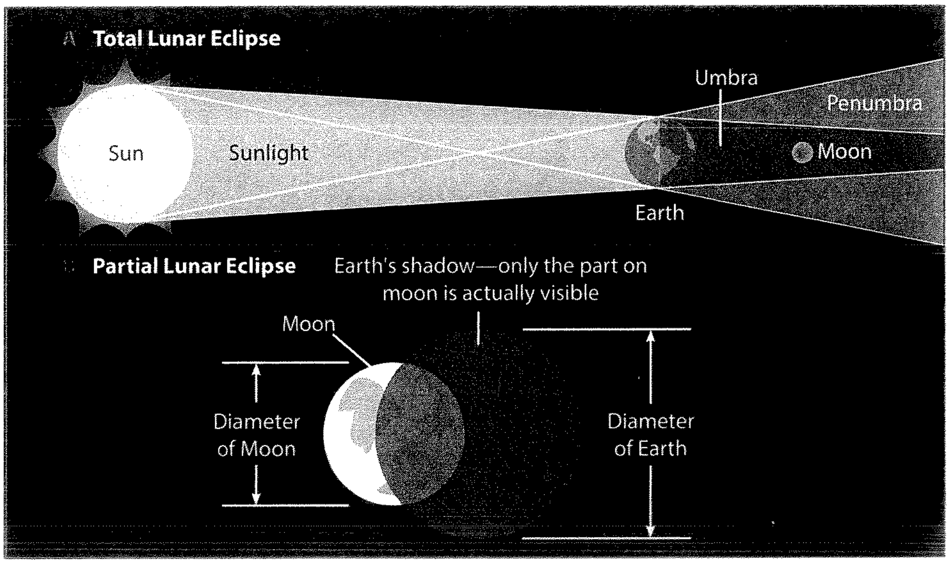


Figure 4-16. Lunar eclipse: Diagram A shows the condition of a total eclipse when the moon is completely covered by Earth's shadow (umbra). Diagram B shows a partial lunar eclipse as viewed from Earth when the moon is only partly in Earth's shadow. (Distance and size are not drawn to scale.)

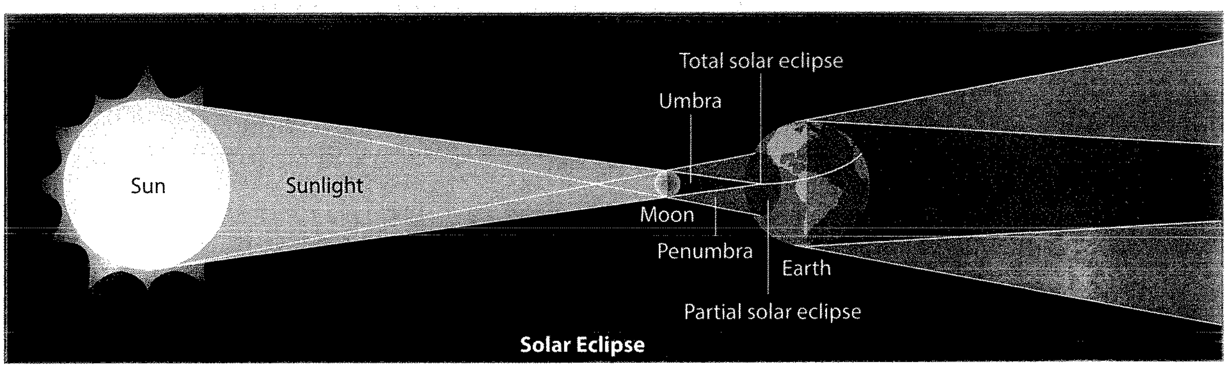
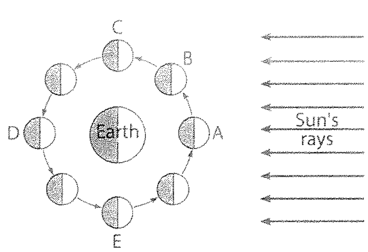


Figure 4-17. Solar eclipses: When the new moon revolves in front of the sun, the diagram shows that the moon's shadow (umbra) just barely reaches Earth and the path of the total eclipse is small. When only the lighter part of the moon's shadow (penumbra) hits Earth, people in this shadow see the sun only partly blocked out—a partial solar eclipse. (Distances and sizes are not to scale.)

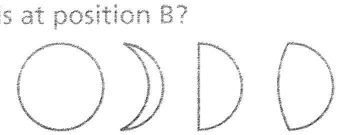
Review Questions

Base your answers to questions 41 through 47 on the following diagram. The diagram represents the moon in various positions in its orbit around Earth. Letters A through E represent five of the moon's positions.



(Not drawn to scale.)

41. Which diagram best represents the appearance of the moon to an observer on Earth when the moon is at position B?



(1) (2) (3) (4)

42. The moon would not be visible from Earth when the moon is at position

(1) A (2) E (3) C (4) D

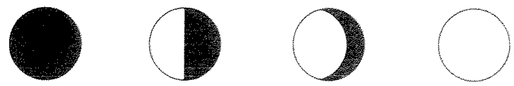
43. Why would an observer on Earth see a complete cycle of phases of the moon in approximately one month?

(1) The moon rotates on its axis.
(2) The moon revolves around Earth.
(3) Earth rotates on its axis.
(4) Earth revolves around the sun.

44. If the distance of the moon from Earth were to increase, the length of time the moon would take to complete one revolution around Earth would

(1) decrease (2) increase (3) remain the same

45. How does the moon appear to an observer in New York State when the moon is located at position E?



(1) (2) (3) (4)

46. The shadow of the moon may fall on Earth at position

(1) A (2) B (3) C (4) D

47. At which positions of the moon do the smallest high tides occur on Earth?

(1) C and E
(2) A and D
(3) B and C
(4) A and B

---

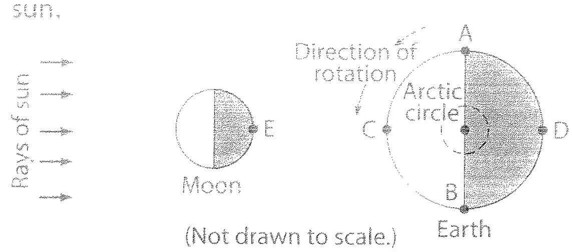
48. If a full moon occurs on November 1, the next full moon phase will occur about

(1) November 22
(2) November 30
(3) December 6
(4) December 13

49. In the open ocean, a bulge of water two to three feet high that follows the moon's movement around Earth is a

(1) tide
(2) tsunami
(3) wind wave
(4) surface ocean current

50. The following diagram represents a north polar view of Earth in relation to the moon and the sun.



(Not drawn to scale.)

The tides that occur when the sun, moon, and Earth are in the relative positions indicated by the diagram are best described as

(1) the highest high tides and the lowest low tides
(2) the highest high tides and the highest low tides
(3) the lowest high tides and the lowest low tides
(4) the lowest high tides and the highest low tides

51. A high tide occurs at Boston on a certain day at 3 P.M. The next high tide may be expected to occur at

(1) 9:26 P.M. the same day
(2) 3:26 A.M. the following day
(3) 9:52 A.M. the following day
(4) 3:52 P.M. the following day

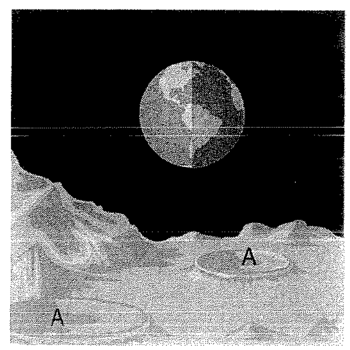
52. During which event does our moon receive the least amount of sunlight?

(1) a Jupiter eclipse
(2) an Earth eclipse
(3) a solar eclipse
(4) a lunar eclipse

53. During which phase of the moon do solar eclipses occur?

(1) new moon
(2) first quarter moon
(3) last quarter moon
(4) full moon

The following diagram represents the landscape on the moon with Earth shown in the background. Use this diagram to answer questions 54 through 57.



54. As viewed from Earth, what is the phase of the moon?

(1) new
(2) full
(3) quarter
(4) gibbous

55. With respect to the diagram, which statement is true?

(1) No eclipse could occur.
(2) A lunar eclipse might occur.
(3) A partial solar eclipse might occur.
(4) A total solar eclipse might occur.

56. In the week following the period shown in the diagram, the amount of the moon's surface that is illuminated by the sun will

(1) increase
(2) decrease
(3) remain the same
(4) increase, then decrease

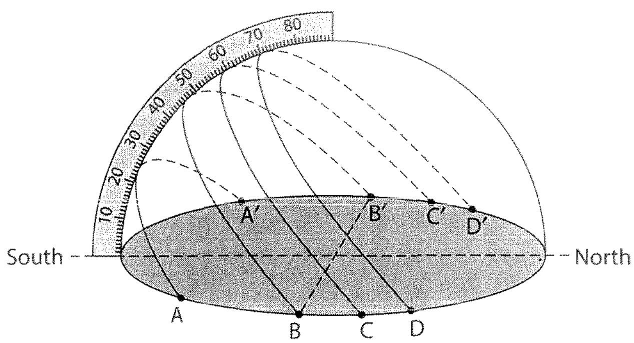
57. What is the most probable cause of the lunar features indicated by A?

Practice Questions
for the New York Regents Exam

Directions
Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

Base your answers to questions 1 through 4 on the following diagram. The diagram represents a plastic hemisphere upon which lines have been drawn to show the apparent paths of the sun on four days at a location in New York State. Two of the days are December 21 and June 21. The protractor is placed over the north-south line.



1 On which two dates could the sun have followed path C-C′?
(1) October 22 and March 28
(2) September 9 and January 7
(3) January 27 and August 21
(4) May 7 and August 1

2 Which path was recorded on a day that had 12 hours of daylight and 12 hours of darkness?
(1) A-A′ (2) B-B′ (3) C-C′ (4) D-D′

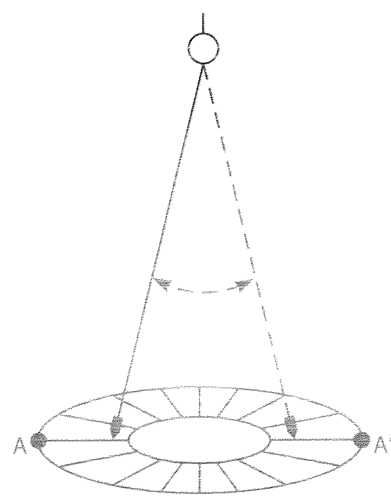
3 Which would be the approximate length of daylight for the observer, when the sun travels along the entire length of path A-A′?
(1) 9 hours (3) 15 hours
(2) 12 hours (4) 18 hours

4 Which observation about the sun's apparent path on June 21 is best supported by the diagram?
(1) The sun appears to move across the sky at a rate of 1° per hour.
(2) The sun's total daytime path is shortest on this date.
(3) Sunrise occurs north of east.
(4) Sunset occurs south of west.

5 Which motion causes the apparent rising and setting of the moon each day as seen from a location in New York State?
(1) Earth revolving around the sun
(2) the moon revolving around Earth
(3) Earth rotating on its axis
(4) the moon rotating on its axis

6 As Earth revolves in orbit from its January position to its July position, the angle between its axis and orbital plane will
(1) decrease
(2) increase
(3) remain the same

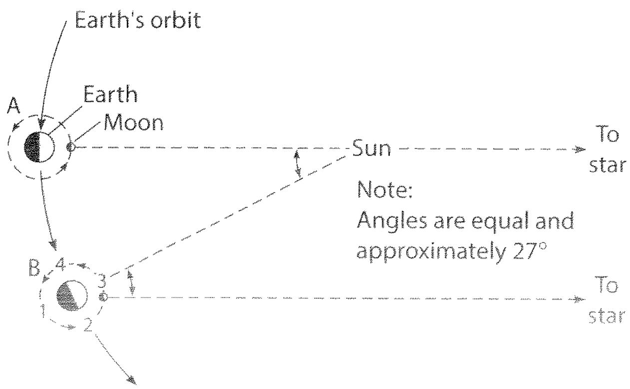
7 The following diagram represents a Foucault pendulum in a building in New York State. Points A and A′ are fixed points on the floor.



As the pendulum swings for six hours, it will
(1) appear to change position due to Earth's rotation
(2) appear to change position due to Earth's revolution
(3) continue to swing between A and A′ due to inertia
(4) continue to swing between A and A′ due to air pressure

4 Motions of Earth, Moon, and Sun

Base your answers to questions 8 through 12 on the following diagram.



8 Earth will travel from A to B in
(1) 1 day
(2) 2.5 days
(3) $27\frac{1}{3}$ days
(4) $29\frac{1}{2}$ days

9 In respect to Earth at position B, in which phase is the moon?
(1) full
(2) new
(3) gibbous
(4) crescent

10 When Earth is at position B, how long must the moon travel beyond where it is shown to be in the same phase as it was in position A?
(1) 1 day
(2) 2 days
(3) 6 hours
(4) 7 days

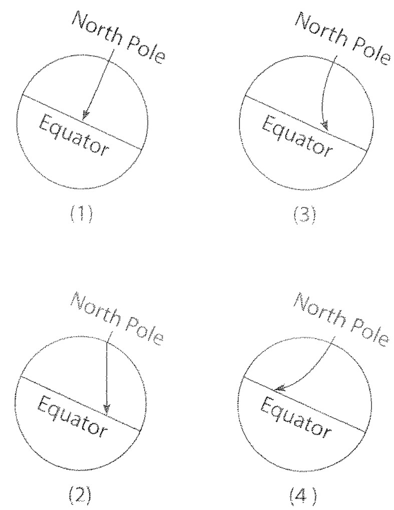
11 What is the main reason why the moon must travel a greater distance to be in the same phase at position B as it was at position A?
(1) The sun's rays are essentially parallel when they reach Earth.
(2) The moon's periods of revolution and rotation are the same.
(3) Earth is constantly revolving around the sun.
(4) Earth's axis is inclined to the plane of its orbit.

12 At position B, the highest tides on Earth will occur when the moon is at points
(1) 1 and 2
(2) 1 and 3
(3) 2 and 4
(4) 3 and 4

---

13 The Coriolis effect provides evidence that Earth
(1) has a magnetic field
(2) has an elliptical orbit
(3) revolves around the sun
(4) rotates on its axis

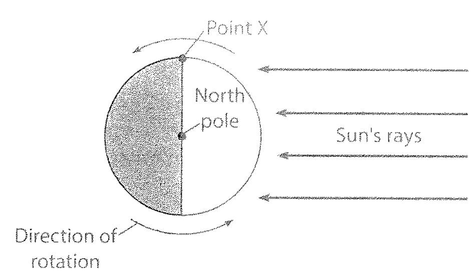
14 A projectile is launched from a point near the North Pole toward the equator. Which diagram best represents the apparent path of the projectile, if it were viewed from Earth?



15 Some stars that can be seen in New York State on a summer night cannot be seen on a winter night. This fact is a result of the
(1) rotation of Earth on its axis
(2) rotation of the stars around Polaris
(3) revolution of Polaris around Earth
(4) revolution of Earth around the sun

16 To an observer on Earth, the planet Venus does not appear at one fixed position among the stars because Venus
(1) rotates on its axis
(2) revolves around the sun
(3) shows an apparent motion around Earth
(4) shows a complete cycle of phases

17 The diagram below shows the rotation of Earth as it would appear from a satellite over the North Pole. The time at point X is closest to



(1) 6 A.M.
(2) 12 noon
(3) 6 P.M.
(4) 12 midnight

18 The new moon phase occurs when the moon is positioned between Earth and the sun. However, these positions do not always cause an eclipse of the sun because the
(1) moon's orbit is tilted relative to Earth's orbit
(2) new moon phase is visible only at night
(3) night side of the moon faces toward Earth
(4) apparent diameter of the moon is greatest during the new moon phase

Part B

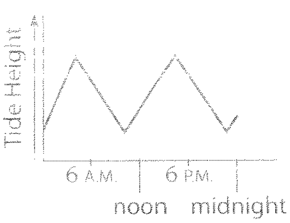
Base your answers to questions 19 through 23 on the following table and information.

Tidal Record for Reversing Falls, St. John River

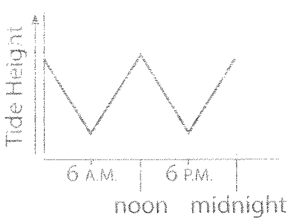
Date	Time of First High Tide	Time of First Low Tide	Time of Second High Tide	Time of Second Low Tide
June 26	2:25 A.M.	8:45 A.M.	2:55 P.M.	9:05 P.M.
June 27	3:15 A.M.	9:35 A.M.	3:45 P.M.	9:55 P.M.
June 28	4:05 A.M.	10:25 A.M.	4:35 P.M.	10:45 P.M.

The Bay of Fundy, located on the east coast of Canada, has the highest ocean tides in the world. The St. John River enters the Bay of Fundy at the city of St. John, where the river actually reverses direction twice a day at high tides. Data for the famous Reversing Falls of the St. John River are given for high and low tides on June 26–28, 1994.

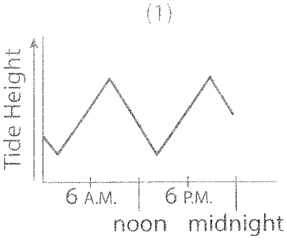
19 Which graph best represents the tides recorded on June 28?



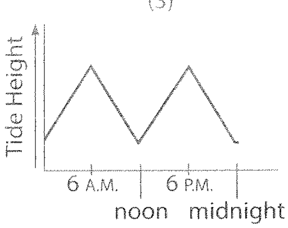
(1)



(3)



(2)



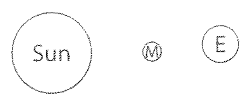
(4)

20 Compared to the first high tide on June 26, how much later in the day did the first high tide occur on June 27? [1]

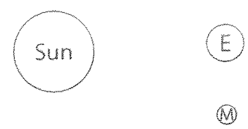
21 Tides in the Bay of Fundy are best described as
(1) predictable and noncyclic
(2) predictable and cyclic
(3) unpredictable and noncyclic
(4) unpredictable and cyclic

22 Complete the following sentence: The moon has a greater effect on Earth's ocean tides than the sun has because the

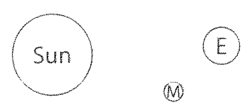
23 Which model of the sun, Earth (E), and moon (M) best represents a position that would cause the highest ocean tides in the Bay of Fundy?



(1)



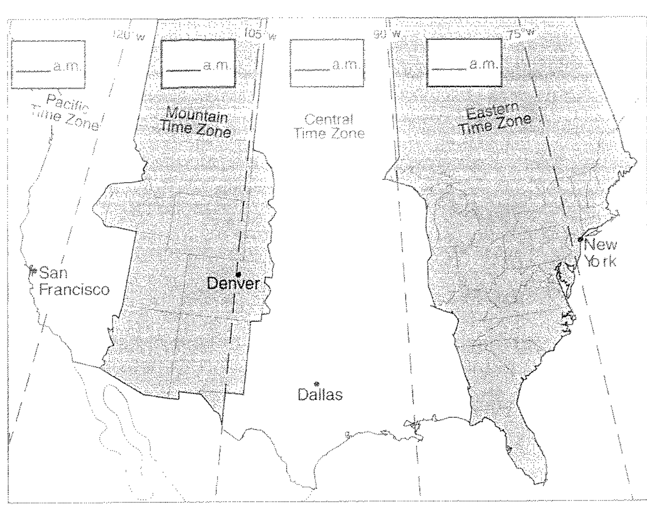
(3)



(2)

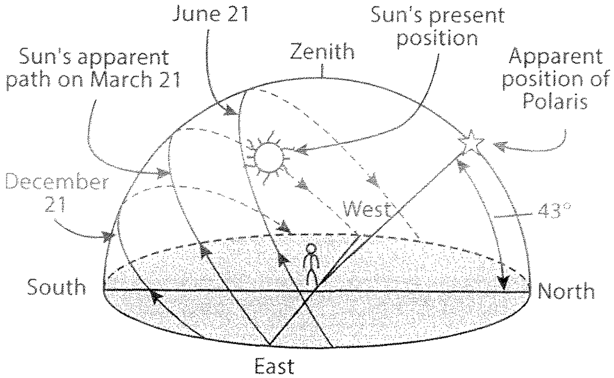
(4)

24 On the United States time zone map provided below, indicate the standard time in *each* time zone when it is 9 A.M. in the Central Time Zone. The dashed lines represent the standard time meridians for each time zone. Be sure to indicate the time for all *three* zones.



25 Draw and fully label a diagram showing a total eclipse of the sun. Include labels for the shadows, all solar system members shown, and phase of the moon. [4]

Use this information to answer questions 26 through 29. The following diagram represents the apparent path of the sun for an observer in New York State on the dates indicated. The diagram also shows the angle of Polaris above the horizon.



(Not drawn to scale)

26 On the diagram, draw the apparent path of the sun on May 21. [1]

27 On the diagram, mark and label the position of sunrise on May 21. [1]

28 State the latitude of the location represented by the diagram to the nearest degree. Include the latitude direction in your answer. [1]

29 At approximately what hour of day would the sun be at the position shown in the diagram? [1]

Part C

Using the following statement, answer questions 30 through 33.

Suppose that Earth does not have and has never had a moon.

30 Why would Earth still have ocean water tides? [1]

31 How would Earth's ocean tides be different than they are with the presence of the moon? [1]

32 Would people on Earth experience lunar and/or solar eclipses? Explain why or why not. [2]

33 Infer how the lack of a moon would have affected time keeping throughout the history of humans. What specific time period would have been affected? [1]

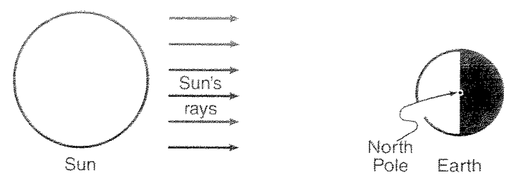
Using the following statement, answer questions 34 and 35.

Through accurate measurements of time and studies of growth patterns of fossil life forms, it has been determined that Earth's rate of rotation is slowing down.

34 What unit of time would be most altered by this change in Earth's rotation? [1]

35 List two completely different types of apparent motions observed on Earth today that would not exist if Earth were to stop rotating. [2]

36 The diagram provided below represents the Sun and Earth as viewed from space on a certain date.

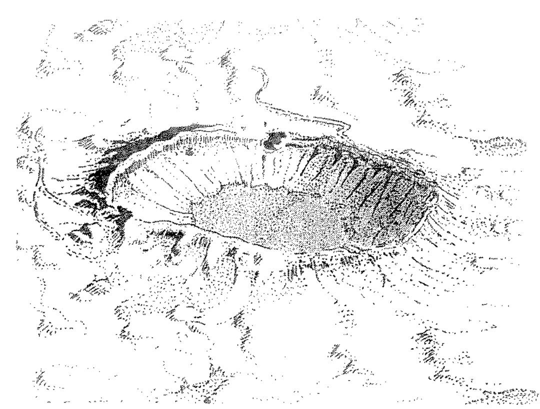


(Not drawn to scale)

(a) Using a symbol for the Moon of approximately this size (◯), draw the position of the Moon on the diagram provided *above* at the time when the full-Moon phase is observed from Earth. [1]

(b) Draw an arrow on the diagram provided *above* that shows the motion of Earth that causes surface ocean currents and surface winds to curve (Coriolis effect). [1]

37 The drawing below shows the mile-wide Barringer impact crater located in Diablo Canyon, Arizona. Describe the event that produced this crater. [1]



Base your answers to questions 38 through 40 on the reading passage below and on your knowledge of Earth science.

The Blue Moon

A "Blue Moon" is the name given to the second full moon in a calendar month. Because there are roughly 29.5 days between full moons, it is unusual for two full moons to "fit" into a 30 or 31 day month (and impossible to fit into a 28 or 29 day month, so February can never have a Blue Moon). The saying "Once in a Blue Moon" means a rare occurrence, and predates the current astronomical use of the term, which is quite recent. In fact, Blue Moons are not all that rare, on average there will be one Blue Moon every 2.5 years. After 1999, the next Blue Moons will be in November 2001; July 2004; and June 2007. The last one before 1999 was in July 1996.

The term Blue Moon is believed to have originated in 1883 after the eruption of Krakatoa. The volcano put so much dust in the atmosphere that the Moon actually looked blue in color. This was so unusual that the term "once in a Blue Moon" was coined.

"The Blue Moon"
David R. Williams
nssdc. gsfc.nasa.gov/planetary/lunar/blue_moon.html

38 Explain why a Blue Moon never occurs during the month of February. [1]

39 What is the greatest number of full-Moon phases, visible from Earth, that are possible in a span of 1 year? [1]

40 Draw the relative positions of Earth, the Moon, and the Sun, as viewed from space, so that a full-Moon phase would be visible to an observer on Earth. Label Earth, the Moon, and the Sun in your drawing. [1]

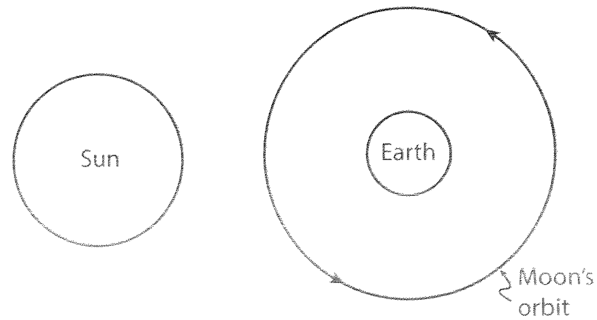
Base your answers to questions 41 and 42 on the information below and on your knowledge of Earth science.

Accurate observations of the Sun were made by a New York State observer. This person observed the time of sunrise and the position of sunrise along the eastern horizon for each day during the month of May.

41 Describe how the time of sunrise changed for the observer each day during the month of May. [1]

42 State the actual Earth motion that causes the Sun to appear to rise each day. [1]

Base your answer to questions 43 through 45 on the diagram provided below and on your knowledge of Earth science. The diagram shows the Sun, Earth, and the Moon's orbit around Earth as viewed from space.



(Not drawn to scale)

43 On the diagram above draw a circle of approximately this size (◯) to represent the Moon's position in its orbit when a solar eclipse is viewed from Earth. [1]

44 Approximately how many complete revolutions does the Moon make around Earth each month? [1]

45 Explain why solar eclipses do not occur every time the Moon revolves around Earth. [1]

Base your answers to questions 46 and 47 on the data table below, which provides information about four of Jupiter's moons.

Data Table

Moons of Jupiter	Density (g/cm^3)	Diameter (km)	Distance from Jupiter (km)
Io	3.5	3630	421,600
Europa	3.0	3138	670,900
Ganymede	1.9	5262	1,070,000
Callisto	1.9	4800	1,883,000

46 Identify the planet in our solar system that is closest in diameter to Callisto. [1]

47 In 1610, Galileo was the first person to observe, with the aid of a telescope, these four moons orbiting Jupiter. Explain why Galileo's observation of this motion did *not* support the geocentric model of our solar system. [1]