

## Chapter 2: Observing the Sky: The Birth of Astronomy

### Review Questions

1. From where on Earth could you observe all of the stars during the course of the year? What fraction of the sky can be seen from the North Pole?

Answer

You can observe all of the stars from the equator over the course of a year, although high-declination stars will be difficult to see so close to the horizon. Only half the sky can be seen from the North Pole, and that half does not change throughout the year.

2. Give four ways to demonstrate that Earth is spherical.

Answer

The shadow cast on the Moon is always round in shape. Ships sailing away on the ocean appear to sink into the ocean due to the curvature of Earth's surface, rather than simply getting smaller and smaller. Orbiting satellites taking photographs of Earth show that Earth looks round from every direction. The Sun is at different altitudes in the sky for different longitudes (it would be in the same place for everyone if Earth were flat, for example), and the Sun's position in the sky depends upon the time.

3. Explain, according to both geocentric and heliocentric cosmologies, why we see retrograde motion of the planets.

Answer

In the geocentric model, Mars orbits outside of the Sun on its deferent path, but it also moves in a circular motion on its epicycle as it follows the deferent. If the planet moves faster "backward" on the epicycle than it moves forward on the deferent, then it can appear to move in a retrograde manner while still retaining the overall pattern of prograde motion in the sky. In the heliocentric model, Mars moves somewhat slower than Earth. During periods of time when Earth passes Mars, Mars appears to move backward on the sky relative to the background stars. This is confirmed by the fact that Mars appears at its brightest during this motion (due to it being at its closest approach to Earth) and is also on the opposite side of the sky from the Sun during retrograde motion.

4. In what ways did the work of Copernicus and Galileo differ from the views of the ancient Greeks and of their contemporaries?

Answer

Copernicus and Galileo believed that Earth spins on its axis and revolves around the Sun as one of the planets, both contradicting the idea that Earth is motionless at the center of the solar system. In addition, Galileo thought that the best way to understand nature is through experiments, rather than just pure thought, as the ancient Greeks did. Galileo also had a telescope with which to examine the heavens, which the ancient Greeks did not have.

5. What were four of Galileo's discoveries that were important to astronomy?

Answer

His observation of the phases of Venus, which supported the heliocentric model; his observations of Jupiter's moons, which showed not everything orbits Earth; his observations of features on the surface of the Moon, which showed it has similarities to Earth; and his discovery that the Milky Way is simply a mass of unresolved stars.

6. Explain the origin of the magnitude designation for determining the brightness of stars. Why does it seem to go backward, with smaller numbers indicating brighter stars?

Answer

The system originated with Hipparchus, who ranked the brightest stars as being “first magnitude,” fainter stars being of the “second magnitude,” then “third magnitude,” and so on as the stars grew progressively fainter.

7. Ursa Minor contains the pole star, Polaris, and the asterism known as the Little Dipper. From most locations in the Northern Hemisphere, all of the stars in Ursa Minor are circumpolar. Does that mean these stars are also above the horizon during the day? Explain.

Answer

Yes, they are always above the horizon; but during the day, the sunlight makes them invisible to us.

8. How many degrees does the Sun move per day relative to the fixed stars? How many days does it take for the Sun to return to its original location relative to the fixed stars?

Answer

The Sun moves about  $1^\circ$  per day. It takes about 360 days (actually 365.25 days) to return to its original location.

9. How many degrees does the Moon move per day relative to the fixed stars? How many days does it take for the Moon to return to its original location relative to the fixed stars?

Answer

The Moon moves about  $12^\circ$  per day. It takes the Moon about 30 days to return to its original position relative to the fixed stars (actually 27.3 days).

10. Explain how the zodiacal constellations are different from the other constellations.

Answer

These constellations intersect with the ecliptic, the Sun’s apparent annual path in the sky. So from Earth, the Sun appears to move through the zodiacal constellations, but not the others.

11. The Sun was once thought to be a planet. Explain why.

Answer

In the geocentric system, all of the objects that moved in the sky relative to the fixed stars were considered to be “wanderers,” and the Sun was no exception, so it was classified as a planet.

12. Is the ecliptic the same thing as the celestial equator? Explain.

Answer

The celestial equator is the projection of Earth’s equator onto the sky whereas the ecliptic is the Sun’s apparent annual path in the sky. These two circles are separated by an angle of  $23.5^\circ$  (see Figure 2.7 The Celestial Tilt).

13. What is an asterism? Can you name an example?

Answer

An asterism is a small, easily recognizable group of stars within a larger constellation. Examples include the Little Dipper inside Ursa Minor and the Big Dipper inside Ursa Major.

14. Why did Pythagoras believe that Earth should be spherical?

Answer

He believed circles and spheres were perfect forms and that Earth should, naturally, take one of these shapes.

15. How did Aristotle deduce that the Sun is farther away from Earth than the Moon?

Answer

He noticed during solar eclipses that the Moon passes in front of the Sun, and the opposite case never happens.

16. What are two ways in which Aristotle deduced that Earth is spherical?

Answer

He noticed that the shadow Earth casts on the Moon during a lunar eclipse is always circular, which is only possible if a spherical body casts the shadow. He also noted that as travelers go farther south, fewer stars are circumpolar and more stars are visible to them overall.

17. How did Hipparchus discover the wobble of Earth's axis, known as precession?

Answer

He compared his careful observations of the stars with those of earlier observers and noticed that the positions of the fixed stars had changed slightly and systematically over the course of about 150 years, consistent with the direction of the celestial pole changing relative to the stars.

18. Why did Ptolemy have to introduce multiple circles of motion for the planets instead of a single, simple circle to represent the planet's motion around the Earth?

Answer

He had to account for the observed occasional retrograde motion of the planets.

19. Why did Copernicus want to develop a completely new system for predicting planetary positions? Provide two reasons.

Answer

He wanted to improve upon the predictions of planetary positions because the geocentric model often gave inaccurate results. He also thought his system was simpler and more elegant—that the existing system was needlessly and implausibly complicated.

20. What two factors made it difficult, at first, for astronomers to choose between the Copernican heliocentric model and the Ptolemaic geocentric model?

Answer

Both gave inaccurate predictions of planetary positions and motions from complicated models. In those days, little weight was given to observational experimental methods of validating one model or the other.

21. What phases would Venus show if the geocentric model were correct?

Answer

Venus would only show crescent phases because the illuminated side would only ever partially be visible from Earth.

### Thought Questions

22. Describe a practical way to determine in which constellation the Sun is found at any time of the year.

Answer

Use a star chart to determine which zodiacal constellation rises at sunset (or, if it is easier, which zodiacal constellation crosses the meridian near midnight). Then, the constellation on the opposite side of the sky (with dates 6 months different from the constellation you observed) is likely the constellation in which the Sun will be found.

23. What is a constellation as astronomers define it today? What does it mean when an astronomer says, "I saw a comet in Orion last night?"

Answer

A constellation is a well-defined area of the sky with borders, much like states have borders on a map of the United States. Seeing a comet in Orion means the comet was seen in the sky within the defined borders of the constellation Orion.

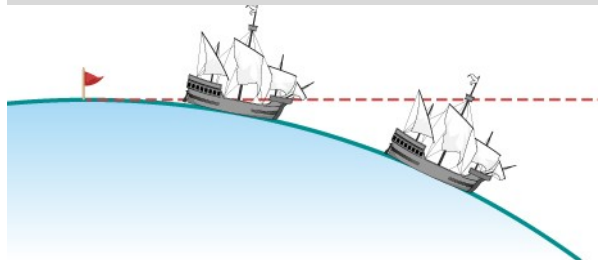
24. Draw a picture that explains why Venus goes through phases the way the Moon does, according to the heliocentric cosmology. Does Jupiter also go through phases as seen from Earth? Why?

## Answer

Refer to Figure 2.18 Phases of Venus for the picture of Venus going through its phases. Jupiter, which is farther from the Sun than Earth is, does not experience phases because it is always fully illuminated as seen from Earth.

25. Show with a simple diagram how the lower parts of a ship disappear first as it sails away from you on a spherical Earth. Use the same diagram to show why lookouts on old sailing ships could see farther from the masthead than from the deck. Would there be any advantage to posting lookouts on the mast if Earth were flat? (Note that these nautical arguments for a spherical Earth were quite familiar to Columbus and other mariners of his time.)

## Answer



For the observer at the flag, the horizontal dashed line indicates the horizon. Two ships are shown at different distances. The closer ship still has a part of the hull visible whereas the farther ship only has the crow's nest visible. Someone in the crow's nest can see much farther around the curvature of Earth. For the farther ship, the flag is visible from the crow's nest, but not from the main deck. If Earth were flat, elevation would not matter in terms of what is visible from the ship, so there would be no advantage to posting a lookout on the mast of the ship. Note that the size of the ship is greatly exaggerated in this drawing.

26. Parallax of stars were not observed by ancient astronomers. How can this fact be reconciled with the heliocentric hypothesis?

## Answer

The parallax is the shift of an object in the sky when seen from two separated vantage points. It depends inversely on the distance to the object. Stars are so far away, compared to the size of Earth's orbit, that their parallax angle could not be measured to the necessary precision attainable at the time.

27. Why do you think so many people still believe in astrology and spend money on it? What psychological needs does such a belief system satisfy?

## Answer

Student answers will vary. One concept is that people are comforted by the idea of a higher power controlling some aspects of their lives or fate so they don't have to take full responsibility. Also, such a "cosmic" system can give meaning to everyday triumphs and challenges; it can explain events in life that people find confusing, unfair, or difficult.

28. Consider three cosmological perspectives—the geocentric perspective, the heliocentric perspective, and the modern perspective—in which the Sun is a minor star on the outskirts of one galaxy among billions. Discuss some of the cultural and philosophical implications of each point of view.

## Answer

The geocentric perspective implies that humanity holds some kind of special or privileged place in the cosmos—that the universe is centered on us somehow. In the heliocentric perspective, our system of planets is still the center of things, with the Sun the center of that and not Earth. Earth

thus becomes only one planet among the others. Our modern understanding shows that our solar system, our planet, and all of us do not exist in a particularly special or privileged location and, further, there really is no such location.

29. The north celestial pole appears at an altitude above the horizon that is equal to the observer's latitude. Identify Polaris, the North Star, which lies very close to the north celestial pole. Measure its altitude. (This can be done with a protractor. Alternatively, your fist, extended at arm's length, spans a distance approximately equal to  $10^\circ$ .) Compare this estimate with your latitude. (Note that this experiment cannot be performed easily in the Southern Hemisphere because Polaris itself is not visible in the south and no bright star is located near the south celestial pole.)

Answer

Student answers will vary based on their actual latitude, but they should be able to show their measurement and determine how close that measurement is to the actual figure.

30. What were two arguments or lines of evidence in support of the geocentric model?

Answer

We do not feel any motion. There is no wind or vibration indicating that Earth is moving. Also, because we do not see stellar parallax, the simplest explanation is that there is no movement of Earth around the Sun.

31. Although the Copernican system was largely correct to place the Sun at the center of all planetary motion, the model still gave inaccurate predictions for planetary positions. Explain the flaw in the Copernican model that hindered its accuracy.

Answer

Copernicus assumed all motion must be uniform circular motion. Because planets orbit the Sun in elliptical paths with varying speeds, there is no way to reproduce that motion faithfully with the planets in circular motion at constant speed around the Sun.

32. During a retrograde loop of Mars, would you expect Mars to be brighter than usual in the sky, about average in brightness, or fainter than usual in the sky? Explain.

Answer

Retrograde motion is seen due to the faster-moving Earth passing Mars in orbit, so the two planets must be next to each other (closer to each other than usual). Thus, Mars should appear brighter than usual.

33. The Great Pyramid of Giza was constructed nearly 5000 years ago. Within the pyramid, archaeologists discovered a shaft leading from the central chamber out of the pyramid, oriented for favorable viewing of the bright star Thuban. Thinking about Earth's precession, explain why Thuban might have been an important star to the ancient Egyptians.

Answer

Five thousand years ago, Thuban occupied a position in the sky very close to the north celestial pole, so for the ancient Egyptians, it served a purpose similar to the one Polaris serves for us.

34. Explain why more stars are circumpolar for observers at higher latitudes.

Answer

Circumpolar stars tend to be higher declination stars that move in very small circles in the sky centered on the celestial poles. At higher latitudes, when the celestial pole is higher in the sky, these small circular paths are more likely to be completely above the horizon. As latitude increases and the altitude of the pole above the horizon increases, so does the size of the circular motion for stars that will remain above the horizon, and so more stars are circumpolar from higher latitudes.

35. What is the altitude of the north celestial pole in the sky from your latitude? If you do not know your latitude, look it up. If you are in the Southern Hemisphere, answer this question for the south celestial pole, since the north celestial pole is not visible from your location.

Answer

Student answers will vary; however, the altitude of the north or south celestial pole should be equal to students' latitude.

36. If you were to drive to some city south of your current location, how would the altitude of the celestial pole in the sky change?

Answer

If you are in the Northern Hemisphere, the north celestial pole should be lower in altitude. In the Southern Hemisphere, the south celestial pole should be higher in altitude.

37. Hipparchus could have warned us that the dates associated with each of the natal astrology sun signs would eventually be wrong. Explain why.

Answer

The precession of Earth changes the dates for which the Sun crosses through each of the zodiacal constellations over the course of 26,000 years.

38. Explain three lines of evidence that argue against the validity of astrology.

Answer

There are no known forces that could explain why the positions of planets should affect a person's personality or fate. The dates that supposedly correspond to a person's natal astrology sun sign have shifted significantly since the first astrological charts, and no corrections or adjustments have been made to the predictive methods, implying that they are not logical or true. Statistical tests of astrology, such as seeing whether people in certain occupations were born in just one or two sun signs, show that people are distributed randomly in their astrological characteristics.

39. What did Galileo discover about the planet Jupiter that cast doubt on exclusive geocentrism?

Answer

He discovered four visible moons orbiting Jupiter, meaning that Earth clearly is not the central focus of all motion in the universe. He showed the moons can orbit Jupiter while Jupiter moves around the Sun, so it is possible that our Moon can orbit Earth as Earth revolves around the Sun.

40. What did Galileo discover about Venus that cast doubt on geocentrism?

Answer

He discovered that Venus shows a full range of phases, from new to crescent to gibbous, and these phases are only possible if Venus orbits so that sometimes it is on the near side of the Sun with respect to us and sometimes on the far side of the Sun (where he presumed it went to full phase, although he could not see it). Thus, Venus must orbit the Sun and not Earth.

### Figuring for Yourself

41. Suppose Eratosthenes had found that, in Alexandria, at noon on the first day of summer, the line to the Sun makes an angle  $30^\circ$  with the vertical. What, then, would he have found for Earth's circumference?

Answer

Because  $30^\circ$  is  $1/12$  of  $360^\circ$ , he would have found that Earth's circumference was 12 times the distance between the two cities.

42. Suppose Eratosthenes' results for Earth's circumference were quite accurate. If the diameter of Earth is 12,740 km, what is the length of his stadium in kilometers?

Answer

Because his answer was 250,000 stadia and the circumference of Earth is  $3.14 \times 12,740 = 40,000$

$\frac{40,000}{250,000} = 0.16$  km per stadium.

km, we divide to find

43. Suppose you are on a strange planet and observe, at night, that the stars do not rise and set, but circle parallel to the horizon. Next, you walk in a constant direction for 8000 miles, and at your new location on the planet, you find that all stars rise straight up in the east and set straight down in the west, perpendicular to the horizon. How could you determine the circumference of the planet without any further observations? What is the circumference, in miles, of the planet?

Answer

You could deduce that you have walked 1/4 of the way around the planet, from the pole to the equator, so you could multiply 4 by the distance you traveled to determine the circumference:  $4 \times 8000$  miles = 32,000 miles.

This file is copyright 2016, Rice University. All Rights Reserved.