**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 α =  × 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:

 α =  × 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 α =  × 360°.)

Answer: We are given α = 0.5° and d = 380,000. Thus, we must first solve the angular separation equation for *s*:

 α =  × 360° ⇒ *s =*  × α

Now we substitute the numbers.

 *s* =  × 0.5° = 3,316 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