PROBLEMS

ENHANCED **WebAssign** The problems in this chapter may be assigned online in Enhanced WebAssign. Selected problems also have Watch It video solutions.

1. denotes straightforward problem; 2. denotes intermediate problem;
3. denotes challenging problem

1. denotes full solution available in *Student Solutions Manual/Study Guide*

1. denotes problems most often assigned in Enhanced WebAssign

BIO denotes biomedical problems

GP denotes guided problems

M denotes Master It tutorial available in Enhanced WebAssign

Q|C denotes asking for quantitative and conceptual reasoning

S denotes symbolic reasoning problem

25.1 The Camera

1. A lens has a focal length of 28 cm and a diameter of 4.0 cm. What is the *f*-number of the lens?

2. A certain camera has *f*-numbers that range from 1.2 to 22. If the focal length of the lens is 55 mm, what is the range of aperture diameters for the camera?

3. A photographic image of a building is 0.092 0 m high. The image was made with a lens with a focal length of 52.0 mm. If the lens was 100 m from the building when the photograph was made, determine the height of the building.

4. The image area of a typical 35 mm slide is 23.5 mm by 35.0 mm. If a camera's lens has a focal length of 55.0 mm and forms an image of the constellation Orion, which is 20° across, will the full image fit on a 35-mm slide?

5. A camera is being used with a correct exposure at *f*/4 and a shutter speed of $\frac{1}{15}$ s. In addition to the *f*-numbers listed in Section 25.1, this camera has *f*-numbers *f*/1, *f*/1.4, and *f*/2. To photograph a rapidly moving subject, the shutter speed is changed to $\frac{1}{125}$ s. Find the new *f*-number setting needed on this camera to maintain satisfactory exposure.

6. (a) Use conceptual arguments to show that the intensity of light (energy per unit area per unit time) reaching the film in a camera is proportional to the square of the reciprocal of the *f*-number as

$$I \propto \frac{1}{(f/D)^2}$$

(b) The correct exposure time for a camera set to *f*/1.8 is (1/500) s. Calculate the correct exposure time if the *f*-number is changed to *f*/4 under the same lighting conditions. *Note:* "*f*/4," on a camera, means "an *f*-number of 4."

7. A certain type of film requires an exposure time of 0.010 s with an *f*/11 lens setting. Another type of film requires twice the light energy to produce the same level of exposure. What *f*-number does the second type of film need with the 0.010-s exposure time?

8. A certain camera lens has a focal length of 175 mm. Its position can be adjusted to produce images when the lens is between 180 mm and 210 mm from the plane of the film. Over what range of object distances is the lens useful?

25.2 The Eye

9. BIO The near point of a person's eye is 60.0 cm. To see objects clearly at a distance of 25.0 cm, what should be the (a) focal length and (b) power of the appropriate corrective lens? (Neglect the distance from the lens to the eye.)

10. BIO GP A patient can't see objects closer than 40.0 cm and wishes to clearly see objects that are 20.0 cm from his eye. (a) Is the patient nearsighted or farsighted? (b) If the eye–lens distance is 2.00 cm, what is the minimum object distance *p* from the lens? (c) What image position with respect to the lens will allow the patient to see the object? (d) Is the image real or virtual? Is the image distance *q* positive or negative? (e) Calculate the required focal length. (f) Find the power of the lens in diopters. (g) If a contact lens is to be prescribed instead, find *p*, *q*, and *f*, and the power of the lens.

11. BIO M The accommodation limits for Nearsighted Nick's eyes are 18.0 cm and 80.0 cm. When he wears his glasses, he is able to see faraway objects clearly. At what minimum distance is he able to see objects clearly?

12. BIO A certain child's near point is 10.0 cm; her far point (with eyes relaxed) is 125 cm. Each eye lens is 2.00 cm from the retina. (a) Between what limits, measured in diopters, does the power of this lens–cornea combination vary? (b) Calculate the power of the eyeglass lens the child should use for relaxed distance vision. Is the lens converging or diverging?

13. BIO An individual is nearsighted; his near point is 13.0 cm and his far point is 50.0 cm. (a) What lens power is needed to correct his nearsightedness? (b) When the lenses are in use, what is this person's near point?

14. BIO Q|C A patient has a near point of 45.0 cm and far point of 85.0 cm. (a) Can a single lens correct the patient's vision? Explain the patient's options. (b) Calculate the power lens needed to correct the near point so that the patient can see objects 25.0 cm away. Neglect the eye–lens distance. (c) Calculate the power lens needed to correct the patient's far point, again neglecting the eye–lens distance.

15. BIO An artificial lens is implanted in a person's eye to replace a diseased lens. The distance between the artificial lens and the retina is 2.80 cm. In the absence of

the lens, an image of a distant object (formed by refraction at the cornea) falls 5.33 cm behind the implanted lens. The lens is designed to put the image of the distant object on the retina. What is the power of the implanted lens? *Hint:* Consider the image formed by the cornea to be a virtual object.

16. BIO A person is to be fitted with bifocals. She can see clearly when the object is between 30 cm and 1.5 m from the eye. (a) The upper portions of the bifocals (Fig. P25.16) should be designed to enable her to see distant objects clearly. What power should they have? (b) The lower portions of the bifocals should enable her to see objects located 25 cm in front of the eye. What power should they have?

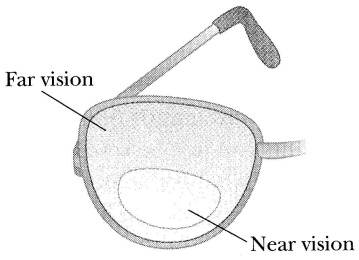

Figure P25.16

17. BIO A nearsighted woman can't see objects clearly beyond 40.0 cm (her far point). If she has no astigmatism and contact lenses are prescribed, what power and type of lens are required to correct her vision?

18. BIO QC A person sees clearly wearing eyeglasses that have a power of −4.00 diopters when the lenses are 2.00 cm in front of the eyes. (a) What is the focal length of the lens? (b) Is the person nearsighted or farsighted? (c) If the person wants to switch to contact lenses placed directly on the eyes, what lens power should be prescribed?

25.3 The Simple Magnifier

19. A stamp collector uses a lens with 7.5-cm focal length as a simple magnifier. The virtual image is produced at the normal near point (25 cm). (a) How far from the lens should the stamp be placed? (b) What is the expected angular magnification?

20. A lens that has a focal length of 5.00 cm is used as a magnifying glass. (a) To obtain maximum magnification and an image that can be seen clearly by a normal eye, where should the object be placed? (b) What is the angular magnification?

21. A biology student uses a simple magnifier to examine the structural features of an insect's wing. The wing is held 3.50 cm in front of the lens, and the image is formed 25.0 cm from the eye. (a) What is the focal length of the lens? (b) What angular magnification is achieved?

22. A jeweler's lens of focal length 5.0 cm is used as a magnifier. With the lens held near the eye, determine (a) the angular magnification when the object is at the focal point of the lens and (b) the angular magnification when the image formed by the lens is at the near point of the eye (25 cm). (c) What is the object distance giving the maximum magnification?

23. A leaf of length h is positioned 71.0 cm in front of a converging lens with a focal length of 39.0 cm. An observer views the image of the leaf from a position 1.26 m behind the lens, as shown in Figure P25.23. (a) What is the magnitude of the lateral magnification (the ratio of the image size to the object size) produced by the lens? (b) What angular magnification is achieved by viewing the image of the leaf rather than viewing the leaf directly?

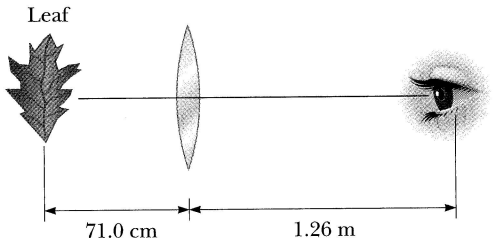

Figure P25.23

24. (a) What is the maximum angular magnification of an eyeglass lens having a focal length of 18.0 cm when used as a simple magnifier? (b) What is the magnification of this lens when the eye is relaxed?

25.4 The Compound Microscope

25.5 The Telescope

25. The desired overall magnification of a compound microscope is 140×. The objective alone produces a lateral magnification of 12×. Determine the required focal length of the eyepiece.

26. The distance between the eyepiece and the objective lens in a certain compound microscope is 20.0 cm. The focal length of the objective is 0.500 cm, and that of the eyepiece is 1.70 cm. Find the overall magnification of the microscope.

27. Find the magnification of a telescope that uses a 2.75-diopter objective lens and a 35.0-diopter eyepiece.

28. BIO A microscope has an objective lens with a focal length of 16.22 mm and an eyepiece with a focal length of 9.50 mm. With the length of the barrel set at 29.0 cm, the diameter of a red blood cell's image subtends an angle of 1.43 mrad with the eye. If the final image distance is 29.0 cm from the eyepiece, what is the actual diameter of the red blood cell? *Hint:* To solve this question, go back to basics and use the thin-lens equation.

29. A certain telescope has an objective mirror with an aperture diameter of 200 mm and a focal length of 2 000 mm. It captures the image of a nebula on

photographic film at its prime focus with an exposure time of 1.50 min. To produce the same light energy per unit area on the film, what is the required exposure time to photograph the same nebula with a smaller telescope that has an objective with a 60.0-mm diameter and a 900-mm focal length?

30. S (a) Find an equation for the length L of a refracting telescope in terms of the focal length of the objective f_o and the magnification m. (b) A knob adjusts the eyepiece forward and backward. Suppose the telescope is in focus with an eyepiece giving a magnification of 50.0. By what distance must the eyepiece be adjusted when the eyepiece is replaced, with a resulting magnification of 1.00×10^2? Must the eyepiece be adjusted backward or forward? Assume the objective lens has a focal length of 2.00 m.

31. Suppose an astronomical telescope is being designed to have an angular magnification of 34.0. If the focal length of the objective lens being used is 86.0 cm, find (a) the required focal length of the eyepiece and (b) the distance between the two lenses for a relaxed eye. *Hint:* For a relaxed eye, the image formed by the objective lens is at the focal point of the eyepiece.

32. A certain telescope has an objective of focal length 1 500 cm. If the Moon is used as an object, a 1.0-cm-long image formed by the objective corresponds to what distance, in miles, on the Moon? Assume 3.8×10^8 m for the Earth–Moon distance.

33. S Astronomers often take photographs with the objective lens or mirror of a telescope alone, without an eyepiece. (a) Show that the image size h' for a telescope used in this manner is given by $h' = fh/(f - p)$, where h is the object size, f is the objective focal length, and p is the object distance. (b) Simplify the expression in part (a) if the object distance is much greater than the objective focal length. (c) The "wingspan" of the International Space Station is 108.6 m, the overall width of its solar panel configuration. When it is orbiting at an altitude of 407 km, find the width of the image formed by a telescope objective of focal length 4.00 m.

34. BIO An elderly sailor is shipwrecked on a desert island, but manages to save his eyeglasses. The lens for one eye has a power of +1.20 diopters, and the other lens has a power of +9.00 diopters. (a) What is the magnifying power of the telescope he can construct with these lenses? (b) How far apart are the lenses when the telescope is adjusted for minimum eyestrain?

35. M A person decides to use an old pair of eyeglasses to make some optical instruments. He knows that the near point in his left eye is 50.0 cm and the near point in his right eye is 100 cm. (a) What is the maximum angular magnification he can produce in a telescope? (b) If he places the lenses 10.0 cm apart, what is the maximum overall magnification he can produce in a microscope? *Hint:* Go back to basics and use the thin-lens equation to solve part (b).

36. Q C Galileo devised a simple terrestrial telescope that produces an upright image. It consists of a converging objective lens and a diverging eyepiece at opposite ends of the telescope tube. For distant objects, the tube length is the objective focal length less the absolute value of the eyepiece focal length. (a) Does the user of the telescope see a real or virtual image? (b) Where is the final image? (c) If a telescope is to be constructed with a tube of length 10.0 cm and a magnification of 3.00, what are the focal lengths of the objective and eyepiece?

25.6 Resolution of Single-Slit and Circular Apertures

37. A converging lens with a diameter of 30.0 cm forms an image of a satellite passing overhead. The satellite has two green lights (wavelength 500 nm) spaced 1.00 m apart. If the lights can just be resolved according to the Rayleigh criterion, what is the altitude of the satellite?

38. While flying at an altitude of 9.50 km, you look out the window at various objects on the ground. If your ability to distinguish two objects is limited only by diffraction, find the smallest separation between two objects on the ground that are distinguishable. Assume your pupil has a diameter of 4.0 mm and take $\lambda = 575$ nm.

39. M To increase the resolving power of a microscope, the object and the objective are immersed in oil ($n = 1.5$). If the limiting angle of resolution without the oil is 0.60 μrad, what is the limiting angle of resolution with the oil? *Hint:* The oil changes the wavelength of the light.

40. BIO (a) Calculate the limiting angle of resolution for the eye, assuming a pupil diameter of 2.00 mm, a wavelength of 500 nm *in air*, and an index of refraction for the eye of 1.33. (b) What is the maximum distance from the eye at which two points separated by 1.00 cm could be resolved?

41. A vehicle with headlights separated by 2.00 m approaches an observer holding an infrared detector sensitive to radiation of wavelength 885 nm. What aperture diameter is required in the detector if the two headlights are to be resolved at a distance of 10.0 km?

42. Two stars located 23 light-years from Earth are barely resolved using a reflecting telescope having a mirror of diameter 68 cm. Assuming $\lambda = 575$ nm and assuming that the resolution is limited only by diffraction, find the separation between the stars.

43. Suppose a 5.00-m-diameter telescope were constructed on the Moon, where the absence of atmospheric distortion would permit excellent viewing. If observations were made using 500-nm light, what minimum separation between two objects could just be resolved on Mars at closest approach (when Mars is 8.0×10^7 km from the Moon)?

44. A spy satellite circles Earth at an altitude of 200 km and carries out surveillance with a special high-resolution telescopic camera having a lens diameter of 35 cm. If the angular resolution of this camera is limited by diffraction, estimate the separation of two small objects on Earth's surface that are just resolved in yellow-green light ($\lambda = 550$ nm).

45. A 15.0-cm-long grating has 6 000 slits per centimeter. Can two lines of wavelengths 600.000 nm and 600.003 nm be separated with this grating? Explain.

46. The H_α line in hydrogen has a wavelength of 656.20 nm. This line differs in wavelength from the corresponding spectral line in deuterium (the heavy stable isotope of hydrogen) by 0.18 nm. (a) Determine the minimum number of lines a grating must have to resolve these two wavelengths in the first order. (b) Repeat part (a) for the second order.

25.7 The Michelson Interferometer

47. Light of wavelength 550 nm is used to calibrate a Michelson interferometer. With the use of a micrometer screw, the platform on which one mirror is mounted is moved 0.180 mm. How many fringe shifts are counted?

48. Q|C Monochromatic light is beamed into a Michelson interferometer. The movable mirror is displaced 0.382 mm, causing the central spot in the interferometer pattern to change from bright to dark and back to bright $N = 1\ 700$ times. (a) Determine the wavelength of the light. What color is it? (b) If monochromatic red light is used instead and the mirror is moved the same distance, would N be larger or smaller? Explain.

49. BIO An interferometer is used to measure the length of a bacterium. The wavelength of the light used is 650 nm. As one arm of the interferometer is moved from one end of the cell to the other, 310 fringe shifts are counted. How long is the bacterium?

50. Mirror M_1 in Active Figure 25.15 is displaced a distance ΔL. During this displacement, 250 fringe shifts are counted. The light being used has a wavelength of 632.8 nm. Calculate the displacement ΔL.

51. A thin sheet of transparent material has an index of refraction of 1.40 and is 15.0 μm thick. When it is inserted in the light path along one arm of an interferometer, how many fringe shifts occur in the pattern? Assume the wavelength (in a vacuum) of the light used is 600 nm. *Hint:* The wavelength will change within the material.

52. M The Michelson interferometer can be used to measure the index of refraction of a gas by placing an evacuated transparent tube in the light path along one arm of the device. Fringe shifts occur as the gas is slowly added to the tube. Assume 600-nm light is used, the tube is 5.00 cm long, and 160 fringe shifts occur as the pressure of the gas in the tube increases to atmospheric pressure. What is the index of refraction of the gas? *Hint:* The fringe shifts occur because the wavelength of the light changes inside the gas-filled tube.

Additional Problems

53. The Yerkes refracting telescope has a 1.00-m-diameter objective lens of focal length 20.0 m. Assume it is used with an eyepiece of focal length 2.50 cm. (a) Determine the magnification of the planet Mars as seen through the telescope. (b) Are the observed Martian polar caps right side up or upside down?

54. Estimate the minimum angle subtended at the eye of a hawk flying at an altitude of 50 m necessary to recognize a mouse on the ground.

55. An American standard analog television picture (non-HDTV), also known as NTSC, is composed of approximately 485 visible horizontal lines of varying light intensity. Assume your ability to resolve the lines is limited only by the Rayleigh criterion, the pupils of your eyes are 5.00 mm in diameter, and the average wavelength of the light coming from the screen is 550 nm. Calculate the ratio of the minimum viewing distance to the vertical dimension of the picture such that you will not be able to resolve the lines.

56. BIO A person with a nearsighted eye has near and far points of 16 cm and 25 cm, respectively. (a) Assuming a lens is placed 2.0 cm from the eye, what power must the lens have to correct this condition? (b) Suppose contact lenses placed directly on the cornea are used to correct the person's eyesight. What is the power of the lens required in this case, and what is the new near point? *Hint:* The contact lens and the eyeglass lens require slightly different powers because they are at different distances from the eye.

57. BIO The near point of an eye is 75.0 cm. (a) What should be the power of a corrective lens prescribed to enable the eye to see an object clearly at 25.0 cm? (b) If, using the corrective lens, the person can see an object clearly at 26.0 cm but not at 25.0 cm, by how many diopters did the lens grinder miss the prescription?

58. BIO If a typical eyeball is 2.00 cm long and has a pupil opening that can range from about 2.00 mm to 6.00 mm, what are (a) the focal length of the eye when it is focused on objects 1.00 m away, (b) the smallest f-number of the eye when it is focused on objects 1.00 m away, and (c) the largest f-number of the eye when it is focused on objects 1.00 m away?

59. BIO M A cataract-impaired lens in an eye may be surgically removed and replaced by a manufactured lens. The focal length required for the new lens is determined by the lens-to-retina distance, which is measured by a sonarlike device, and by the requirement that the implant provide for correct distance vision. (a) If the distance from lens to retina is 22.4 mm, calculate the power of the implanted lens in diopters.

(b) Since there is no accommodation and the implant allows for correct distance vision, a corrective lens for close work or reading must be used. Assume a reading distance of 33.0 cm, and calculate the power of the lens in the reading glasses.

60. BIO If the aqueous humor of the eye has an index of refraction of 1.34 and the distance from the vertex of the cornea to the retina is 2.00 cm, what is the radius of curvature of the cornea for which distant objects will be focused on the retina? (For simplicity, assume all refraction occurs in the aqueous humor.)

61. A Boy Scout starts a fire by using a lens from his eyeglasses to focus sunlight on kindling 5.0 cm from the lens. The Boy Scout has a near point of 15 cm. When the lens is used as a simple magnifier, (a) what is the maximum magnification that can be achieved and (b) what is the magnification when the eye is relaxed? *Caution:* The equations derived in the text for a simple magnifier assume a "normal" eye.

62. A laboratory (astronomical) telescope is used to view a scale that is 300 cm from the objective, which has a focal length of 20.0 cm; the eyepiece has a focal length of 2.00 cm. Calculate the angular magnification when the telescope is adjusted for minimum eyestrain. *Note:* The object is not at infinity, so the simple expression $m = f_o/f_e$ is not sufficiently accurate for this problem. Also, assume small angles, so that $\tan\theta \approx \theta$.