Chapter 26: VISION AND OPTICAL INSTRUMENTS

# 26.1 PHYSICS OF THE EYE

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| 1. | | *What is the power of the eye when viewing an object 50.0 cm away?* | | |
| Solution | |  | | |
| 2. | | *Calculate the power of the eye when viewing an object 3.00 m away.* | | |
| Solution | | Using the lens-to-retina distance of 2.00 cm and the equation, we can determine the power at an object distance of 3.00 m: | | |
| 3. | | *(a) The print in many books averages 3.50 mm in height. How high is the image of the print on the retina when the book is held 30.0 cm from the eye? (b) Compare the size of the print to the sizes of rods and cones in the fovea and discuss the possible details observable in the letters. (The eye-brain system can perform better because of interconnections and higher order image processing.)* | | |
| Solution | | (a)  (b) The size of the rods and the cones is smaller than the image height so we can distinguish letters on a page. | | |
| 4. | | *Suppose a certain person’s visual acuity is such that he can see objects clearly that form an image  high on his retina. What is the maximum distance at which he can read the 75.0 cm high letters on the side of an airplane?* | | |
| Solution | |  | | |
| 5. | | *People who do very detailed work close up, such as jewellers, often can see objects clearly at much closer distance than the normal 25 cm. (a) What is the power of the eyes of a woman who can see an object clearly at a distance of only 8.00 cm? (b) What is the size of an image of a 1.00 mm object, such as lettering inside a ring, held at this distance? (c) What would the size of the image be if the object were held at the normal 25.0 cm distance?* | | |
| Solution | | (a)  (b)  (c) | | |
| 26.2 VISION CORRECTION | | | | |
| 6. | | *What is the far point of a person whose eyes have a relaxed power of 50.5 D?* | | |
| Solution | |  | | |
| 7. | | *What is the near point of a person whose eyes have an accommodated power of 53.5 D?* | | |
| Solution | |  | | |
| 8. | | *(a) A laser vision correction reshaping the cornea of a myopic patient reduces the power of his eye by 9.00 D, with a  uncertainty in the final correction. What is the range of diopters for spectacle lenses that this person might need after LASIK procedure? (b) Was the person nearsighted or farsighted before the procedure? How do you know?* | | |
| Solution | | (a) , so the range of spectacle lenses that this person might need after this LASIK procedure would be 0.90 D.  (b) The person was nearsighted because he was myopic and the power was reduced. | | |
| 9. | | *In a LASIK vision correction, the power of a patient’s eye is increased by 3.00 D. Assuming this produces normal close vision, what was the patient’s near point before the procedure?* | | |
| Solution | | The power for normal close vision is 54.0 D (Example 26.2), so originally, the close vision was 51.0 D. Therefore, | | |
| 10. | | *What was the previous far point of a patient who had laser vision correction that reduced the power of her eye by 7.00 D, producing normal distant vision for her?* | | |
| Solution | | Since normal distant vision has a power of 50.0 D (Example 26.2) and the laser vision correction reduced the power of her eye by 7.00 D, she originally had a power of 57.0 D. We can determine her original far point using  Originally, without corrective lenses, she could only see images 14.3 cm (or closer) to her eye. | | |
| 11. | | *A severely myopic patient has a far point of 5.00 cm. By how many diopters should the power of his eye be reduced in laser vision correction to obtain normal distant vision for him?* | | |
| Solution | | Originally,  The power for normal distant vision is 50.0 D (Example 26.2), so the power should be decreased by 20.0 D. | | |
| 12. | | *A student’s eyes, while reading the blackboard, have a power of 51.0 D. How far is the board from his eyes?* | | |
| Solution | |  | | |
| 13. | | *The power of a physician’s eyes is 53.0 D while examining a patient. How far from her eyes is the feature being examined?* | | |
| Solution | |  | | |
| 14. | | *A young woman with normal distant vision has a 10.0% ability to accommodate (that is, increase) the power of her eyes. What is the closest object she can see clearly?* | | |
| Solution | | From Example 26.2, the normal power for distant vision is 50.0 D. For this woman, since she has a 10.0% ability to accommodate, . Thus using | | |
| 15. | | *The far point of a myopic administrator is 50.0 cm. (a) What is the relaxed power of his eyes? (b) If he has the normal 8.00% ability to accommodate, what is the closest object he can see clearly?* | | |
| Solution | | (a)  (b) | | |
| 16. | | *A very myopic man has a far point of 20.0 cm. What power contact lens (when on the eye) will correct his distant vision?* | | |
| Solution | | We need  when  , so | | |
| 17. | | *Repeat the previous problem for eyeglasses held 1.50 cm from the eyes.* | | |
| Solution | | We need when , so | | |
| 18. | | *A myopic person sees that her contact lens prescription is . What is her far point?* | | |
| Solution | | Far point is | | |
| 19. | | *Repeat the previous problem for glasses that are 1.75 cm from the eyes.* | | |
| Solution | | Let = far point | | |
| 20. | | *The contact lens prescription for a mildly farsighted person is 0.750 D, and the person has a near point of 29.0 cm. What is the power of the tear layer between the cornea and the lens if the correction is ideal, taking the tear layer into account?* | | |
| Solution | | When an object is held 25.0 cm from the person’s eyes, the contact lens and tear layer must produce an image 29.0 cm away. Since the correction mechanism is contact lenses, . The object distance is 25.0 cm and positive, so that . Therefore,  Since the contact lens has a power of , | | |
| 21. | | *A nearsighted man cannot see objects clearly beyond 20 cm from his eyes. How close must he stand to a mirror in order to see what he is doing when he shaves?* | | |
| Solution | | The plane mirror has an infinite focal point, so that . The total apparent distance of the man in the mirror will be his actual distance, plus the apparent image distance, or . If this distance must be less than 20 cm, he should stand at . | | |
| 22. | | *A mother sees that her child’s contact lens prescription is 0.750 D. What is the child’s near point?* | | |
| Solution | | To correct the child’s vision to normal, an object at 25 cm will produce an image at the near point, so    near point | | |
| 23. | | *Repeat the previous problem for glasses that are 2.20 cm from the eyes.* | | |
| Solution | | Here we want  If = near point  So, , or , so that    Finally,  near point = 29.7 cm. | | |
| 24. | | *The contact lens prescription for a nearsighted person is  and the person has a far point of 22.5 cm. What is the power of the tear layer between the cornea and the lens if the correction is ideal, taking the tear layer into account?* | | |
| Solution | | Since the contact lens provides –4.00 D, the tear layer must provide —0.444 D of correction. | | |
| 25. | | ***Unreasonable Results*** *A boy has a near point of 50 cm and a far point of 500 cm. Will a  lens correct his far point to infinity?* | | |
| Solution | | Assuming a lens at  from the boy’s eye, the image distance must be . For an infinite distance object, the required power is . Therefore, the  lens will correct the nearsightedness. | | |
| 26.4 MICROSCOPES | | | | |
| 26. | | *A microscope with an overall magnification of 800 has an objective that magnifies by 200. (a) What is the magnification of the eyepiece? (b) If there are two other objectives that can be used, having magnifications of 100 and 400, what other total magnifications are possible?* | | |
| Solution | | (a)  (b)  (last digit uncertain) | | |
| 27. | | *(a) What magnification is produced by a 0.150 cm focal length microscope objective that is 0.155 cm from the object being viewed? (b) What is the overall magnification if an  eyepiece (one that produces a magnification of 8.00) is used?* | | |
| Solution | | (a)  (b) | | |
| 28. | | *(a) Where does an object need to be placed relative to a microscope for its 0.500 cm focal length objective to produce a magnification of ? (b) Where should the 5.00 cm focal length eyepiece be placed to produce a further fourfold (4.00) magnification?* | | |
| Solution | | (a)  (b)  The eyepiece should be 204 cm behind the objective lens. | | |
| 29. | | *You switch from a  oil immersion objective to a  air immersion objective. What are the acceptance angles for each? Compare and comment on the values. Which would you use first to locate the target area on your specimen?* | | |
| Solution | | The acceptance angle  is related to the numerical aperture  by the equation . For air, , and for oil . Thus, the values for  are:    The second value is smaller than the first. The second lens would be more useful for locating the target area, because it will show less detail of a larger area. | | |
| 30. | | *An amoeba is 0.305 cm away from the 0.300 cm focal length objective lens of a microscope. (a) Where is the image formed by the objective lens? (b) What is this image’s magnification? (c) An eyepiece with a 2.00 cm focal length is placed 20.0 cm from the objective. Where is the final image? (d) What magnification is produced by the eyepiece? (e) What is the overall magnification? (See Figure 26.16.)* | | |
| Solution | | (a)  (behind the objective lens)  (b)  (c)  (in front of the eyepiece)  (d)  (e) | | |
| 31. | | *You are using a standard microscope with a  objective and switch to a  objective. What are the acceptance angles for each? Compare and comment on the values. Which would you use first to locate the target area on of your specimen? (See Figure 26.17)* | | |
| Solution | | The acceptance angle  is related to the numerical aperture  by the equation . For air, . Thus, the values for  are:    The first value is much smaller than the second. The first lens would be more useful for locating the target area, because it will show less detail of a larger area. | | |
| 32. | | ***Unreasonable Results*** *Your friends show you an image through a microscope. They tell you that the microscope has an objective with a 0.500 cm focal length and an eyepiece with a 5.00 cm focal length. The resulting overall magnification is 250,000. Are these viable values for a microscope?* | | |
| Solution | | No, they require too great a distance between the lenses. The objective forms a real image magnified by the eyepiece. The image distance would be excessive. | | |
| 26.5 TELESCOPES | | | | |
| 33. | | *What is the angular magnification of a telescope that has a 100 cm focal length objective and a 2.50 cm focal length eyepiece?* | | |
| Solution | |  | | |
| 34. | | *Find the distance between the objective and eyepiece lenses in the telescope in the above problem needed to produce a final image very far from the observer, where vision is most relaxed. Note that a telescope is normally used to view very distant objects.* | | |
| Solution | | The first image must be inside the focal point of the eyepiece. Hence, the distance between the lenses must be less than that sum of the two focal lengths: | | |
| 35. | | *A large reflecting telescope has an objective mirror with a  radius of curvature. What angular magnification does it produce when a  focal length eyepiece is used?* | | |
| Solution | |  | | |
| 36. | | *A small telescope has a concave mirror with a 2.00 m radius of curvature for its objective. Its eyepiece is a 4.00 cm focal length lens. (a) What is the telescope’s angular magnification? (b) What angle is subtended by a 25,000 km diameter sunspot? (c) What is the angle of its telescopic image?* | | |
| Solution | | (a)  (b)    Angle subtended is  (c) | | |
| 37. | | *A  binocular produces an angular magnification of , acting like a telescope. (Mirrors are used to make the image upright.) If the binoculars have objective lenses with a 75.0 cm focal length, what is the focal length of the eyepiece lenses?* | | |
| Solution | | Using | | |
| 26.6 ABERRATIONS | | | | |
| 39. | | ***Integrated Concepts*** *(a) During laser vision correction, a brief burst of 193 nm ultraviolet light is projected onto the cornea of the patient. It makes a spot 1.00 mm in diameter and deposits 0.500 mJ of energy. Calculate the depth of the layer ablated, assuming the corneal tissue has the same properties as water and is initially at . The tissue’s temperature is increased to  and evaporated without further temperature increase. (b) Does your answer imply that the shape of the cornea can be finely controlled?* | | |
| Solution | | (a) We can get an expression for the heat transfer in terms of the mass of tissue ablated: , where the heat capacity is given in Table 14.1, , and the latent heat of vaporization is given in Table 14.2, . Solving for the mass gives:  Now, since the corneal tissue has the same properties as water, its density is  . Since we know the diameter of the spot, we can determine the thickness of the layer ablated: , so that:  (b) Yes, this thickness implies that the shape of the cornea can be very finely controlled, producing normal distant vision in more than 90% of patients. | | |
| Test Prep for AP® courses | | |
| 1. | | *A tree that is 3 m tall is viewed from a distance of 25 m. If the cornea-to-retina distance of an ideal eye is 2 cm, how tall is the image of the tree on the observer’s retina?*   * 1. 0.24 cm   2. 0.5 cm   3. 0.5 m   4. 0.08 cm |
| Solution | | (a) |
| 2. | | *Often people with lens-to-retina distances smaller than 2 cm purchase glasses to place in front of their eyes.*   1. *Explain why people with lens-to-retina distances smaller than 2 cm need glasses.* 2. *Explain whether the glasses should be composed of converging or diverging lenses.* 3. *Draw a ray diagram demonstrating the ability to see with and without the glasses.* |
| Solution | | a. Refraction at the cornea and lens of the eye causes light rays to converge at a distance of 2 cm behind the lens. Because the retina is less than 2 cm from the lens, the light rays will not converge upon the retina. As a result, a blurry image will appear. Glasses (or contact lenses) are designed to provide an additional layer of refraction so that the light bent by the cornea and lens will converge directly on the retina.  b. A converging lens should be placed in front of each eye in order to provide additional refraction toward the eye’s center prior to light entering the cornea.  c. Student responses may vary slightly. However, a diagram for seeing with glasses should be similar to Figure 26.7, while a diagram for seeing without glasses should be similar to Figure 26.5(b). |
| 3. | | *Which of the following types of light have a wavelength greater than that of visible light?*   1. gamma rays 2. infrared 3. radio 4. ultraviolet    1. I, II, and III    2. I and IV only    3. II and III only    4. III only |
| Solution | | (c) |
| 4. | | *In LASIK surgery, a coherent UV light of 193 nm is focused on the corneal tissue.*   1. *Explain the importance of using light that is all the same wavelength.* 2. *Explain why UV light is more effective than infrared light at evaporating the corneal tissue.* |
| Solution | | a. Because all of the emitted light has the same wavelength, all light waves can be in phase. As a result, the amplitude of the UV light will be increased, providing the corneal tissue with a much greater amount of energy.  b. UV light has a greater frequency than infrared light. Therefore, using the equation , each individual light wave will provide more energy. The increased amount of energy will result in a greater ease in evaporating corneal tissue. |
| 5. | | *A student sees a piece of paper sitting on a table. Which of the following would not result in the student observing the paper as yellow?*   * 1. Yellow light shines on a black paper.   2. White light shines on a yellow paper.   3. Yellow light shines on a white paper.   4. Red and green lights shine on a white paper. |
| Solution | | (a) |
| 6. | | *A white light is projected onto a tablecloth. Using the light reflecting off the tablecloth, an observer determines that the color of the tablecloth is blue.*   * 1. *Using the wave model of light, explain how the observer is capable of making this judgment.*   2. *Describe how using the particle model of light limits our explanation of the observer’s judgment.* |
| Solution | | a. With the exception of those wavelengths associated with the color blue, the tablecloth absorbs all wavelengths of light. The blue wavelengths are reflected off the tablecloth surface and into the observer’s eye. As a result, the observer perceives the tablecloth as blue.  b. The particle model of light does not have an equivalent explanation for why certain colors exist. While the original particle theory tied the color of light to its inertia, the wave model of light is much more consistent with physical observation. |
| 7. | | *Which of the following correctly describes the image created by a microscope?*   1. The image is real, inverted, and magnified. 2. The image is virtual, inverted, and magnified. 3. The image is real, upright, and magnified. 4. The image is virtual, upright, and magnified. |
| Solution | | (b) |
| 8. | | *Use the diagram shown below to answer the following questions.*    *Draw two rays leaving the arrow shown to the left of both lenses. Use ray tracing to draw the images created by the objective and eyepiece lenses. Label the images as io and ie.* |
| Solution | | Ray tracing should be similar to the rays shown in Figure 26.16. Both images drawn must be inverted. The image created by the objective must be smaller than the original arrow, while the image created by the eyepiece must be larger than the original arrow. |
| 9. | | *Which of the following is an advantage to using a concave mirror in the construction of a telescope?*   1. The telescope can gather more light than a telescope using lenses. 2. The telescope does not suffer from chromatic aberration. 3. The telescope can provide greater magnification than a telescope using lenses. 4. I and III only 5. II only 6. I and II only 7. I, II, and III |
| Solution | | (d) |
| 10. | | *A spherical mirror is used to construct a telescope.*   * 1. *Using the picture below, draw two rays incident on the object mirror and continue their path through the eye lens.*      * 1. *The plane mirror is replaced with a concave lens. Using the picture below, draw the path of two incident rays.*      * 1. *Using the concave lens setup, describe the final image created by the concave lens.* |
| Solution | | a. Ray tracing should be similar to that shown in Figure 26.25.  b. Ray tracing should be similar to that shown below.    c. The image will be upright, real, and shrunk. |
| 11. | | *Two concave lenses, of focal lengths 500 mm and 20 mm, are used in the construction of a telescope. Given any potential arrangement, what is the largest possible magnification the telescope may have?*   1. 100× 2. 10,000× 3. 25× 4. 4× |
| Solution | | (c) |

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