Chapter 25: GEOMETRIC OPTICS

# 25.1 THE RAY ASPECT OF LIGHT

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| 1. | *Suppose a man stands in front of a mirror as shown in Figure 25.50. His eyes are 1.65 m above the floor, and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man’s height?* |
| Solution | From ray-tracing and the law of reflection, we know that the angle of incidence is equal to the angle of reflection, so the top of the mirror must extend to at least halfway between his eyes and the top of his head. The bottom must go down to halfway between his eyes and the floor. This result is independent of how far he stands from the wall. Therefore, ,  and  The bottom is  from the floor and the top is  from the floor. |

# 25.2 THE LAW OF REFLECTION

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| 2. | *Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated in the following figure.* |
| Solution | The incident ray reflects at an angle  with the first mirror. The first reflection ray forms a right triangle with the two mirrors. Hence . The outgoing ray makes an angle  with a line parallel to the first mirror and so the outgoing ray is parallel to the incident ray. |
| 3. | *Light shows staged with lasers use moving mirrors to swing beams and create colorful effects. Show that a light ray reflected from a mirror changes direction by  when the mirror is rotated by an angle .* |
| Solution | As shown in the figure, a ray of light that strikes a mirror at an angle  is deflected from its original path by an angle of . Therefore, rotating the mirror by an additional angle  will change the ray's direction by . |
| 4. | *A flat mirror is neither converging nor diverging. To prove this, consider two rays originating from the same point and diverging at an angle* *. Show that after striking a plane mirror, the angle between their directions remains* *.* |
| Solution | The two incident rays, along with segment  make a triangle. The projection of the reflected rays backward forms another triangle. Using the law of reflection and geometry, we can see that the two triangles have two interior angles  and  which are the same. Therefore the third angle must also be the same:  and the angle between the outgoing rays is the same as that between the incoming rays. |

# 25.3 THE LAW OF REFRACTION

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| 5. | *What is the speed of light in water? In glycerine?* |
| Solution | From Table 25.1, we find the indices of refraction: |
| 6. | *What is the speed of light in air? In crown glass?* |
| Solution | (5 sig. fig. used to show difference with value in vacuum). |
| 7. | *Calculate the index of refraction for a medium in which the speed of light is , and identify the most likely substance based on Table 25.1.* |
| Solution | Use the equation . From Table 25.1, the substance is polystyrene. |
| 8. | *In what substance in Table 25.1 is the speed of light ?* |
| Solution |  |
| 9. | *There was a major collision of an asteroid with the Moon in medieval times. It was described by monks at Canterbury Cathedral in England as a red glow on and around the Moon. How long after the asteroid hit the Moon, which is  away, would the light first arrive on Earth?* |
| Solution |  |
| 10. | *A scuba diver training in a pool looks at his instructor as shown in Figure 25.53. What angle does the ray from the instructor’s face make with the perpendicular to the water at the point where the ray enters? The angle between the ray in the water and the perpendicular to the water is* |
| Solution |  |
| 11. | *Components of some computers communicate with each other through optical fibers having an index of refraction . What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber?* |
| Solution |  |
| 12. | *(a) Given that the angle between the ray in the water and the perpendicular to the water is 25.0°, and using information in Figure 25.53, find the height of the instructor’s head above the water, noting that you will first have to calculate the angle of refraction. (b) Find the apparent depth of the diver’s head below water as seen by the instructor. Assume the diver and the diver's image are the same horizontal distance from the normal.* |
| Solution | (a)    (b) |
| 13. | *Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of , and you observe the angle of refraction to be . What is the index of refraction of the substance and its likely identity?* |
| Solution | Using the equation  , we can solve for the unknown index of refraction:  From Table 25.1, the most likely solid substance is fused quartz. |
| 14. | *On the Moon’s surface, lunar astronauts placed a corner reflector, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. What percent correction is needed to account for the delay in time due to the slowing of light in the Earth’s atmosphere? Assume the distance to the Moon is precisely , and Earth’s atmosphere (which varies in density with altitude) is equivalent to a layer 30.0 km thick with a constant index of refraction* |
| Solution | The time it would take if there were no atmosphere is  The delay time will be |
| 15. | *Suppose Figure 25.54 represents a ray of light going from air through crown glass into water, such as going into a fish tank. Calculate the amount the ray is displaced by the glass (), given that the incident angle is  and the glass is 1.00 cm thick.* |
| Solution |  |
| 16. | *Figure 25.54 shows a ray of light passing from one medium into a second and then a third. Show that  is the same as it would be if the second medium were not present (provided total internal reflection does not occur)* |
| Solution | Apply Snell’s law at each interface:  which is the same as we would get if the second medium were not present. |
| 17. | ***Unreasonable Results*** *Suppose light travels from water to another substance, with an angle of incidence of  and an angle of refraction of . (a) What is the index of refraction of the other substance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* |
| Solution | (a)  (b) We cannot have  since this would imply a speed greater than *c*.  (c) The refracted angle is too big relative to the angle of incidence. |
| 19. | ***Unreasonable Results*** *Light traveling from water to a gemstone strikes the surface at an angle of  and has an angle of refraction of . (a) What is the speed of light in the gemstone? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* |
| Solution | (a)  (b) The speed of light is too slow, since the index is much greater than that for a diamond.  (c) The angle of refraction is unreasonable relative to the angle incidence. |

# 25.4 TOTAL INTERNAL REFLECTION

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| 20. | *Verify that the critical angle for light going from water to air is , as discussed at the end of Example 25.4, regarding the critical angle for light traveling in a polystyrene (a type of plastic) pipe surrounded by air.* |
| Solution |  |
| 21. | *(a) At the end of Example 25.4, it was stated that the critical angle for light going from diamond to air is . Verify this. (b) What is the critical angle for light going from zircon to air?* |
| Solution | (a)  (b) |
| 22. | *An optical fiber uses flint glass clad with crown glass. What is the critical angle?* |
| Solution | Using the equation  and the indices of reflection from Table 25.1: |
| 23. | *At what minimum angle will you get total internal reflection of light traveling in water and reflected from ice?* |
| Solution |  |
| 24. | *Suppose you are using total internal reflection to make an efficient corner reflector. If there is air outside and the incident angle is , what must be the minimum index of refraction of the material from which the reflector is made?* |
| Solution |  |
| 25. | *You can determine the index of refraction of a substance by determining its critical angle. (a) What is the index of refraction of a substance that has a critical angle of  when submerged in water? What is the substance, based on Table 25.1? (b) What would the critical angle be for this substance in air?* |
| Solution | (a)  (b) |
| 26. | *A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown in Figure 25.55. What is the index of refraction for the liquid and its likely identification?* |
| Solution | It is likely to be Benzene. |
| 27. | *A light ray entering an optical fiber surrounded by air is first refracted and then reflected as shown in Figure25.56. Show that if the fiber is made from crown glass, any incident ray will be totally internally reflected.* |
| Solution | If  then the ray will be totally internally reflected. The maximum value for  occurs when  When  is of course just  the critical angle. Since  any incident ray will be reflected. (Stated to 4 digits, since rounding to 3 is slightly misleading.) |

# 25.5 DISPERSION: THE RAINBOW AND PRISMS

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| 28. | *(a) What is the ratio of the speed of red light to violet light in diamond, based on Table 25.2? (b) What is this ratio in polystyrene? (c) Which is more dispersive?* |
| Solution | (a)  (4 sig. fig. used, based on stated values)  (b)  (c)Diamond is more dispersive. |
| 29. | *A beam of white light goes from air into water at an incident angle of . At what angles are the red (660 nm) and violet (410 nm) parts of the light refracted?* |
| Solution |  |
| 30. | *By how much do the critical angles for red (660 nm) and violet (410 nm) light differ in a diamond surrounded by air?* |
| Solution |  |
| 31. | *(a) A narrow beam of light containing yellow (580 nm) and green (550 nm) wavelengths goes from polystyrene to air, striking the surface at a  incident angle. What is the angle between the colors when they emerge? (b) How far would they have to travel to be separated by 1.00 mm?* |
| Solution | (a)  (b) |
| 32. | *A parallel beam of light containing orange (610 nm) and violet (410 nm) wavelengths goes from fused quartz to water, striking the surface between them at a  incident angle. What is the angle between the two colors in water?* |
| Solution |  |
| 33. | *A ray of 610 nm light goes from air into fused quartz at an incident angle of . At what incident angle must 470 nm light enter flint glass to have the same angle of refraction?* |
| Solution | Using Snell’s law, we have . We can set  equal to , because the angles of refraction are equal. Combining the equations gives . We know that  because the light is entering from air. From Table 25.2, we find the 610 nm light in fused quartz has  and the 470 nm light in flint glass has . We can solve for the incident angle : |
| 34. | *A narrow beam of light containing red (660 nm) and blue (470 nm) wavelengths travels from air through a 1.00 cm thick flat piece of crown glass and back to air again. The beam strikes at a  incident angle. (a) At what angles do the two colors emerge? (b) By what distance are the red and blue separated when they emerge?* |
| Solution | Let unprimed represent red light and primed represent blue.    (a)  and similarly for : .  (b) |
| 35. | *A narrow beam of white light enters a prism made of crown glass at a  incident angle, as shown in Figure 25.57. At what angles,  and , do the red (660 nm) and violet (410 nm) components of the light emerge from the prism?* |
| Solution | Unprimed = red  Primed = violet    Thus,  and . So that  Similarly,  and |

# 25.6 IMAGE FORMATION BY LENSES

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| 36. | *What is the power in diopters of a camera lens that has a 50.0 mm focal length?* |
| Solution |  |
| 37. | *Your camera’s zoom lens has an adjustable focal length ranging from 80.0 to 200 mm. What is its range of powers?* |
| Solution |  |
| 38. | *What is the focal length of 1.75 D reading glasses found on the rack in a pharmacy?* |
| Solution |  |
| 39. | *You note that your prescription for new eyeglasses is –4.50 D. What will their focal length be?* |
| Solution |  |
| 40. | *How far from the lens must the film in a camera be, if the lens has a 35.0 mm focal length and is being used to photograph a flower 75.0 cm away? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.* |
| Solution |  |
| 41. | *A certain slide projector has a 100 mm focal length lens. (a) How far away is the screen, if a slide is placed 103 mm from the lens and produces a sharp image? (b) If the slide is 24.0 by 36.0 mm, what are the dimensions of the image? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.* |
| Solution | (a)  (b)  so that |
| 42. | *A doctor examines a mole with a 15.0 cm focal length magnifying glass held 13.5 cm from the mole. (a) Where is the image? (b) What is its magnification? (c) How big is the image of a 5.00 mm diameter mole?* |
| Solution | (a)  (on the object side of the lens).  (b)  (c) |
| 43. | *How far from a piece of paper must you hold your father’s 2.25 D reading glasses to try to burn a hole in the paper with sunlight?* |
| Solution |  |
| 44. | *A camera with a 50.0 mm focal length lens is being used to photograph a person standing 3.00 m away. (a) How far from the lens must the film be? (b) If the film is 36.0 mm high, what fraction of a 1.75 m tall person will fit on it? (c) Discuss how reasonable this seems, based on your experience in taking or posing for photographs.* |
| Solution | (a)  (b)  so the maximum height is  (c) This seems quite reasonable, since at 3.00 m it is possible to get a full length picture of a person. |
| 45. | *A camera lens used for taking close-up photographs has a focal length of 22.0 mm. The farthest it can be placed from the film is 33.0 mm. (a) What is the closest object that can be photographed? (b) What is the magnification of this closest object?* |
| Solution | (a)  (b) |
| 46. | *Suppose your 50.0 mm focal length camera lens is 51.0 mm away from the film in the camera. (a) How far away is an object that is in focus? (b) What is the height of the object if its image is 2.00 cm high?* |
| Solution | (a)  (b) |
| 47. | *(a) What is the focal length of a magnifying glass that produces a magnification of 3.00 when held 5.00 cm from an object, such as a rare coin? (b) Calculate the power of the magnifier in diopters. (c) Discuss how this power compares to those for store-bought reading glasses (typically 1.0 to 4.0 D). Is the magnifier’s power greater, and should it be?* |
| Solution | (a)  Since  and  so that  (b)  (c) This power is significantly greater than store-bought reading glasses. The magnifier’s power is greater than it should be; the object distance should be farther in order to get magnification of 3. |
| 48. | *What magnification will be produced by a lens of power –4.00 D (such as might be used to correct myopia) if an object is held 25.0 cm away?* |
| Solution |  |
| 49. | *In Example 25.7, the magnification of a book held 7.50 cm from a 10.0 cm focal length lens was found to be 4.00. (a) Find the magnification for the book when it is held 8.50 cm from the magnifier. (b) Do the same for when it is held 9.50 cm from the magnifier. (c) Comment on the trend in m as the object distance increases as in these two calculations.* |
| Solution | (a) Using  Then, we can determine the magnification,  (b)  and  (c) The magnification, , increases rapidly as you increase the object distance toward the focal length. |
| 50. | *Suppose a 200 mm focal length telephoto lens is being used to photograph mountains 10.0 km away. (a) Where is the image? (b) What is the height of the image of a 1000 m high cliff on one of the mountains?* |
| Solution | (a)  (Additional significant figures are used to show difference to focal length. The answer can be rounded to 0.200 m.)  (b) |
| 51. | *A camera with a 100 mm focal length lens is used to photograph the sun and moon. What is the height of the image of the sun on the film, given the sun is  in diameter and is  away?* |
| Solution |  |
| 52. | *Combine thin lens equations to show that the magnification for a thin lens is determined by its focal length and the object distance and is given by .* |
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# 25.7 IMAGE FORMATION BY MIRRORS

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| 53. | *What is the focal length of a makeup mirror that has a power of 1.50 D?* |
| Solution |  |
| 54. | *Some telephoto cameras use a mirror rather than a lens. What radius of curvature mirror is needed to replace a 800 mm focal length telephoto lens?* |
| Solution |  |
| 55. | *(a) Calculate the focal length of the mirror formed by the shiny back of a spoon that has a 3.00 cm radius of curvature. (b) What is its power in diopters?* |
| Solution | (a)  (b) |
| 56. | *Find the magnification of the heater element in Example 25.9. Note that its large magnitude helps spread out the reflected energy.* |
| Solution |  |
| 57. | *What is the focal length of a makeup mirror that produces a magnification of 1.50 when a person’s face is 12.0 cm away? Explicitly show how you follow the steps in the Problem-Solving Strategy for Mirrors.* |
| Solution | *Step 1*: Image formation by a mirror is involved.  *Step 2:* Draw the problem set up when possible.  *Step 3*: Use the thin lens equations to solve this problem.  Step 4: Find: .  *Step 5*: Given:  *Step 6*: No ray tracing is needed.  *Step 7*: Using  Then, .  *Step 8*: Since the focal length is greater than the object distance, we are dealing with case 2. For case 2, we should have a virtual image, a negative image distance and a positive (greater than one) magnification. Our answer is consistent with these expected properties, so it is reasonable. |
| 58. | *A shopper standing 3.00 m from a convex security mirror sees his image with a magnification of 0.250. (a) Where is his image? (b) What is the focal length of the mirror? (c) What is its radius of curvature? Explicitly show how you follow the steps in the Problem-Solving Strategy for Mirrors.* |
| Solution | (a)  (behind mirror)  (b)  (c) |
| 59. | *An object 1.50 cm high is held 3.00 cm from a person’s cornea, and its reflected image is measured to be 0.167 cm high. (a) What is the magnification? (b) Where is the image? (c) Find the radius of curvature of the convex mirror formed by the cornea. (Note that this technique is used by optometrists to measure the curvature of the cornea for contact lens fitting. The instrument used is called a keratometer, or curve measurer.)* |
| Solution | (a) For convex mirror  (b)  (behind the cornea)  (c) |
| 60. | *Ray tracing for a flat mirror shows that the image is located a distance behind the mirror equal to the distance of the object from the mirror. This is stated , since this is a negative image distance (it is a virtual image). (a) What is the focal length of a flat mirror? (b) What is its power?* |
| Solution | (a) A flat mirror can be considered as having an infinitely large radius of curvature. With  this corresponds to a focal length of infinity.  (b) |
| 61. | *Show that for a flat mirror* *, knowing that the image is a distance behind the mirror equal in magnitude to the distance of the object from the mirror.* |
| Solution |  |
| 62. | *Use the law of reflection to prove that the focal length of a mirror is half its radius of curvature. That is, prove that . Note this is true for a spherical mirror only if its diameter is small compared with its radius of curvature.* |
| Solution | For an incoming ray parallel to the axis of the mirror, the angle of incidence  will equal the angle of reflection , where the dotted line is perpendicular to the mirror surface at point . Simple geometry requires that  is equal to  and hence also equal to , making  an isosceles triangle.  and  for small angles.  . |
| 63. | *Referring to the electric room heater considered in the first example in this section, calculate the intensity of IR radiation in*  *projected by the concave mirror on a person 3.00 m away. Assume that the heating element radiates 1500 W and has an area of* *, and that half of the radiated power is reflected and focused by the mirror.* |
| Solution |  |

# Test Prep for AP® courses

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| 1. | *When light from a distant object reflects off of a concave mirror and comes to a focus some distance in front of the mirror, we model light as a \_\_\_\_\_ to explain and predict the behavior of light and the formation of an image.*   1. wave 2. particle 3. ray 4. All of the above |
| Solution | (c) |
| 2. | *Light of wavelength 500 nm is incident on a narrow slit of width 150 nm. Which model of light most accurately predicts the behavior of the light after it passes through the slit? Explain your answer.* |
| Solution | The wave model is the most accurate. The situation described involves light interacting with an object or opening that is comparable to or smaller than the wavelength of the light. The light will diffract, and depending on the nature of the light, interference patterns may also be observed. |
| 3. | *An object is 2 meters in front of a flat mirror. Ray 1 from the object travels in a direction toward the mirror and normal to the mirror’s surface. Ray 2 from the object travels at an angle of 5° from the direction of ray 1, and it also reflects off the mirror’s surface. At what distance behind the mirror do these two reflected rays appear to converge to form an image?*   1. 0.2 m 2. 0.5 m 3. 2 m 4. 4 m |
| Solution | (c) |
| 4. | *Two light rays originate from object A, at a distance of 50 cm in front of a flat mirror, diverging at an angle of 10°. Both of the rays strike a flat mirror and reflect. Two light rays originate from object B, at a distance of 50 cm in front of a convex mirror, diverging at an angle of 10°. Both of the rays strike the convex mirror and reflect. For which object do the reflected rays appear to converge behind the mirror closer to the surface of the mirror, thus forming a closer (larger) image? Explain with the help of a sketch or diagram.* |
| Solution | For object A, the drawing might look like this:    For object B, the angle of incidence with the surface for each ray will be greater, so the angle of reflection will be greater. This means that the rays will converge more quickly, forming the closer image as shown: |
| 5. | *When light travels from air into water, which of the following statements is accurate?*   1. The wavelength decreases, and the speed decreases. 2. The wavelength decreases, and the speed increases. 3. The wavelength increases, and the speed decreases. 4. The wavelength increases, and the speed increases. |
| Solution | (a) |
| 6. | *When a light ray travels from air into glass, which of the following statements is accurate after the light enters the glass?*   1. The ray bends away from the normal, and the speed decreases. 2. The ray bends away from the normal, and the speed increases. 3. The ray bends toward the normal, and the speed increases. 4. The ray bends toward the normal, and the speed decreases. |
| Solution | (d) |
| 7. | [Figure 25\_M2\_twopaths\_image]  *Two different potential paths from point A to point B are shown. Point A is in the air, and point B is in water. For which of these paths (upper or lower) would light travel from point A to point B faster? Which of the paths more accurately represents how a light ray would travel from point A to point B? Explain.* |
| Solution | Since light bends toward the norma upon entering a medium with a higher index of refraction, the upper path is a more accurate representation of a light ray moving from A to B. |
| 8. | *Students in a lab group are given a plastic cube with a hollow cube-shaped space in the middle that fills about half the volume of the cube. The index of refraction of the plastic is known. The hollow space is filled with a gas, and the students are asked to collect the data needed to find the index of refraction of the gas. The students take the following set of measurements:*  *Angle of incidence of the light in the air above the plastic block: 30°*  *Angle of refraction of the beam as it enters the plastic from the air: 45°*  *Angle of refraction of the beam as it enters the plastic from the gas: 45°*  *The three measurements are shared with a second lab group. Can the second group determine a value for the index of refraction of the gas from only this data?*   1. Yes, because they have information about the beam in air and in the plastic above the gas. 2. Yes, because they have information about the beam on both sides of the gas. 3. No, because they need additional information to determine the angle of the beam in the gas. 4. No, because they do not have multiple data points to analyze. |
| Solution | (c) |
| 9. | *Students in a lab group are given a plastic cube with a hollow cube-shaped space in the middle that fills about half the volume of the cube. The index of refraction of the plastic is known. The hollow space is filled with a gas, and the students are asked to collect the data needed to find the index of refraction of the gas. What information would you need to collect, and how would you use this information in order to deduce the index of refraction of the gas in the cube?* |
| Solution | First, measure the angle of incidence and the angle of refraction for light entering the plastic from air. Since the two angles can be measured and the index of refraction of air is known, the student can solve for the index of refraction of the plastic.  Next, measure the angle of incidence and the angle of refraction for light entering the gas from the plastic. Since the two angles can be measured and the index of refraction of the plastic is known, the student can solve for the index of refraction of the gas. |
| 10. | *Light travels through water and crosses a boundary at a non-normal angle into a different fluid with an unknown index of refraction. Which of the following is true about the path of the light after crossing the boundary?*   1. If the index of refraction of the fluid is higher than that of water, the light will speed up and turn toward the normal. 2. If the index of refraction of the fluid is higher than that of water, the light will slow down and turn away from the normal. 3. If the index of refraction of the fluid is lower than that of water, the light will speed up and turn away from the normal. 4. If the index of refraction of the fluid is lower than that of water, the light will slow down and turn toward the normal. |
| Solution | (c) |
| 11. | *A laser is fired from a submarine beneath the surface of a lake (n = 1.33). The laser emerges from the lake into air with an angle of refraction of 67°. How fast is the light moving through the water? What is the angle of incidence of the laser light when it crosses the boundary between the lake and the air?* |
| Solution | The speed of light in a medium is simply c/n, so the speed of light in water is 2.25 × 108 m/s. From Snell’s law, the angle of incidence is 44°. |
| 12. | *As light travels from air into water, what happens to the frequency of the light? Consider how the wavelength and speed of light change; then use the relationship between speed, wavelength, and frequency for a wave. What about light that is reflected off the surface of water? What happens to its wavelength, speed and frequency?* |
| Solution | Both the speed and wavelength of light decrease by a factor n, where n is the index of refraction of the water. Since the frequency depends on , and both decrease by the same amount, the frequency remains constant.  Since light reflecting off of water does not move into a new medium, its wavelength, speed, and frequency remain the same. |
| 13. | *An object is 25 cm in front of a converging lens with a focal length of 25 cm. Where will the resulting image be located?*   1. 25 cm in front of the lens 2. 25 cm behind the lens 3. 50 cm behind the lens 4. at infinity (either in front of or behind the lens) |
| Solution | (d) |
| 14. | *A detective holds a magnifying glass 5.0 cm above an object he is studying, creating an upright image twice as large as the object. What is the focal length of the lens used for the magnifying glass?* |
| Solution | Assume “below the lens” corresponds to “in front of the lens,” so that the object distance is 5.0 cm. The magnification is +2 since the image is upright and twice as large. This means the image distance is twice the object distance and the image is also in front of the lens, so the image distance is -10 cm. From the thin lens equation, the focal length is 10 cm. |
| 15. | *A student wishes to predict the magnification of an image given the distance from the object to a converging lens with an unknown index of refraction. What data must the student collect in order to make such a prediction for any object distance?*   1. A specific object distance and the image distance associated with that object distance. 2. A specific image distance and a determination of whether the image formed is upright or inverted. 3. The diameter and index of refraction of the lens. 4. The radius of curvature of each side of the lens. |
| Solution | (a) |
| 16. | *Given a converging lens of unknown focal length and unknown index of refraction, explain what materials you would need and what procedure you would follow in order to experimentally determine the focal length of the lens.* |
| Solution | The student would need some kind of light source (like a small battery-powered light bulb), a screen on which to project an image, a ruler to measure distances, and a device to hold the lens in place.  The student could place the object at various distances from the converging lens until a clear image of the object formed on the screen. The student could then measure the object distance and image distance, and from this information deduce the focal length of the lens. |
| 17. | *A student is testing the properties of a mirror with an unknown radius of curvature. The student notices that no matter how far an object is placed from the mirror, the image seen in the mirror is always upright and smaller than the object. What can the student deduce about this mirror?*   1. The mirror is convex. 2. The mirror is flat. 3. The mirror is concave. 4. More information is required to deduce the shape of the mirror. |
| Solution | (a) |
| 18. | *A student notices a small printed sentence at the bottom of the driver’s side mirror on her car. It reads, “Objects in the mirror are closer than they appear.” Which type of mirror is this (convex, concave, or flat)? How could you confirm the shape of the mirror experimentally?* |
| Solution | It must be a convex mirror. The student could place a test object at various distances from the mirror using a ruler. For each distance, the student could note that the image is always upright. This means that the object and the image are both always in front of the mirror (and therefore positive). According to the thin lens equation, the focal length of the mirror must also be positive, which indicates a convex mirror. |
| 19. | *A mirror shows an upright image twice as large as the object when the object is 10 cm away from the mirror. What is the focal length of the mirror?*   1. -10 cm 2. 10 cm 3. 20 cm 4. 40 cm |
| Solution | (b) |
| 20. | *A mirror shows an inverted image that is equal in size to the object when the object is 20 cm away from the mirror. Describe the image that will be formed if this object is moved to a distance of 5 cm away from the mirror.* |
| Solution | An inverted image of equal size to the object indicates a magnification of -1. So the image distance is equal to the object distance for the mirror. Thus, the focal length of the mirror is 10 cm.  Solving for the image distance for this mirror when the object distance is 5 cm results in an image distance of -10 cm. Thus, the image will be twice as large as the object and upright, since the magnification is now +2. |

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