9. In Figure 27.14*b* there is a dark spot at the center of the pattern of Newton's rings. By considering the phase changes that occur when light reflects from the upper curved surface and the lower flat surface, account for the dark spot.

10. A thin film of a material is floating on water ($n = 1.33$). When the material has a refractive index of $n = 1.20$, the film looks bright in reflected light as its thickness approaches zero. But when the material has a refractive index of $n = 1.45$, the film looks black in reflected light as its thickness approaches zero. Explain these observations in terms of constructive and destructive interference and the phase changes that occur when light waves undergo reflection.

11. A transparent coating is deposited on a glass plate and has a refractive index that is *larger than that of the glass,* not smaller, as it is for a typical nonreflective coating. For a certain wavelength within the coating, the thickness of the coating is a quarter wavelength. The coating *enhances* the reflection of the light corresponding to this wavelength. Explain why, referring to Example 3 in the text to guide your thinking.

12. On most cameras one can select the *f*-number setting, or *f*-stop. The *f*-number gives the ratio of the focal length of the camera lens to the diameter of the aperture through which light enters the camera. If one wishes to resolve two closely spaced objects in a picture, should a small or a large *f*-number setting be used? Account for your answer.

13. Explain why a sound wave diffracts much more than a light wave does when the two pass through the same doorway.

14. Review Conceptual Example 8 before answering this question. A person is viewing one of Seurat's paintings that consists of dots of color. She is so close to the painting that the dots are distinguishable. Without moving, however, she can squint, which makes the painting take on a more normal appearance. In terms of the Rayleigh criterion, why does squinting make the painting look more normal?

15. Four light bulbs are arranged at the corners of a rectangle that is three times longer than it is wide. You look at this arrangement perpendicular to the plane of the rectangle. From very far away, your eyes cannot resolve the individual bulbs and you see a single "smear" of light. From close in, you see the individual bulbs. Between these two extremes, what do you see? Draw two pictures to illustrate the possibilities that exist, depending on how far away you are. Explain your drawings.

16. Suppose the pupil of your eye were elliptical instead of circular in shape, with the long axis of the ellipse oriented in the vertical direction. (a) Would the resolving power of your eye be the same in the horizontal and vertical directions? (b) In which direction would the resolving power be greatest? Justify your answers by discussing how the diffraction of light waves would differ in the two directions.

17. Suppose you were designing an eye and could select the size of the pupil and the wavelength of the electromagnetic waves to which the eye is sensitive. As far as the limitation created by diffraction is concerned, rank the following design choices in order of decreasing resolving power (greatest first): (a) large pupil and ultraviolet wavelengths, (b) small pupil and infrared wavelengths, and (c) small pupil and ultraviolet wavelengths. Justify your answer.

18. In our discussion of single-slit diffraction, we considered the ratio of the wavelength λ to the width W of the slit. We ignored the height of the slit, in effect assuming that the height was much larger than the width. Suppose the height and width were the same size, so that diffraction in both dimensions occurred. How would the diffraction pattern in Figure 27.19*b* be altered? Give your reasoning.

19. What would happen to the distance between the bright fringes produced by a diffraction grating if the entire interference apparatus (light source, grating, and screen) were immersed in water? Why?

PROBLEMS

ssm Solution is in the Student Solutions Manual. **www** Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 27.1 The Principle of Linear Superposition, Section 27.2 Young's Double-Slit Experiment

1. ssm The transmitting antenna for a radio station is 7.00 km from your house. The frequency of the electromagnetic wave broadcast by this station is 536 kHz. The station builds a second transmitting antenna that broadcasts an identical electromagnetic wave in phase with the original one. The new antenna is 8.12 km from your house. Does constructive or destructive interference occur at the receiving antenna of your radio? Show your calculations.

2. A Young's double-slit experiment is performed using light that has a wavelength of 630 nm. The separation between the slits is 5.3×10^{-5} m. Find the angles that locate the (a) first-, (b) second-, and (c) third-order bright fringes on the screen.

3. In a Young's double-slit experiment, the angle that locates the second dark fringe on either side of the central bright fringe is 5.4°. Find the ratio of the slit separation d to the wavelength λ of the light.

4. Two in-phase sources of waves are separated by a distance of 4.00 m. These sources produce identical waves that have a wavelength of 5.00 m. On the line between them, there are two places at which the same type of interference occurs. (a) Is it constructive or destructive interference, and (b) where are the places located?

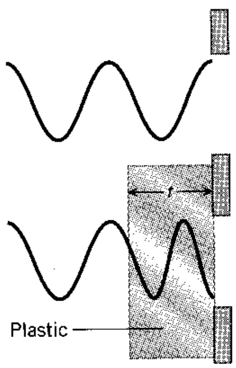
5. ssm In a Young's double-slit experiment, the angle that locates the second-order bright fringe is 2.0°. The slit separation is 3.8×10^{-5} m. What is the wavelength of the light?

***6.** Review Conceptual Example 2 before attempting this problem. Two slits are 0.158 mm apart. A mixture of red light (wavelength = 665 nm) and yellow-green light (wavelength = 565 nm) falls on the slits. A flat observation screen is located 2.24 m away. What is the distance on the screen between the third-order red fringe and the third-order yellow-green fringe?

***7.** In a Young's double-slit experiment the separation y between the first-order bright fringe and the central bright fringe on a flat screen is 0.0240 m, when the light has a wavelength of 475 nm. Assume that the angles that locate the fringes on the screen are small enough so that $\sin\theta \approx \tan\theta$. Find the separation y when the light has a wavelength of 611 nm.

****8.** In Young's experiment a mixture of orange light (611 nm) and blue light (471 nm) shines on the double slit. The centers of the first-order bright blue fringes lie at the outer edges of a screen that is located 0.500 m away from the slits. However, the first-order bright orange fringes fall off the screen. By how much and in which direction (toward or away from the slits) should the screen be moved, so that the centers of the first-order bright orange fringes just appear on the screen? It may be assumed that θ is small, so that $\sin\theta \approx \tan\theta$.

****9. ssm www** A sheet of plastic ($n = 1.60$) covers *one slit* of a double slit (see the drawing). When the double slit is illuminated by monochromatic light ($\lambda_{\text{vacuum}} = 586$ nm), the center of the screen appears dark rather than bright. What is the minimum thickness of the plastic?



Problem 9

Section 27.3 Thin-Film Interference

10. A layer of transparent plastic ($n = 1.61$) on glass ($n = 1.52$) looks dark when viewed in reflected light whose wavelength is 589 nm in vacuum. Find the two smallest possible nonzero values for the thickness of the layer.

11. ssm A nonreflective coating of magnesium fluoride ($n = 1.38$) covers the glass ($n = 1.52$) of a camera lens. Assuming that the coating prevents reflection of yellow-green light (wavelength in vacuum = 565 nm), determine the minimum nonzero thickness that the coating can have.

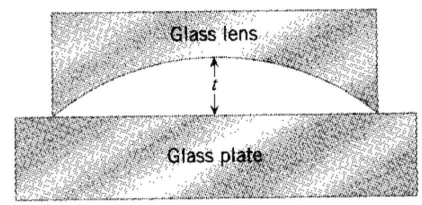
12. For background on this problem, review Conceptual Example 4. A mixture of yellow light (wavelength = 580 nm in vacuum) and violet light (wavelength = 410 nm in vacuum) falls perpendicularly on a film of gasoline that is floating on a puddle of water. For both wavelengths, the refractive index of gasoline is $n = 1.40$ and that of water is $n = 1.33$. What is the minimum nonzero thickness of the film in a spot that looks (a) yellow and (b) violet because of destructive interference?

13. Example 5(a) in the text deals with the air wedge formed between two plates of glass ($n = 1.52$). Repeat this example, assuming that the wedge of air is replaced by water ($n = 1.33$).

14. Review Conceptual Example 4 before beginning this problem. A soap film with different thicknesses at different places has an unknown refractive index n and air on both sides. In reflected light it looks multicolored. One region looks yellow because destructive interference has removed blue ($\lambda_{\text{vacuum}} = 469$ nm) from the reflected light, while another looks magenta because destructive interference has removed green ($\lambda_{\text{vacuum}} = 555$ nm). In these regions the film has the minimum nonzero thickness t required for the destructive interference to occur. Find the ratio $t_{\text{magenta}}/t_{\text{yellow}}$.

***15. ssm www** Orange light ($\lambda_{\text{vacuum}} = 611$ nm) shines on a soap film ($n = 1.33$) that has air on either side of it. The light strikes the film perpendicularly. What is the minimum thickness of the film for which constructive interference causes it to look bright in reflected light?

***16.** The drawing shows a cross section of a plano-concave lens resting on a flat glass plate. (A plano-concave lens has one surface that is a plane and the other that is concave spherical.) The thickness t is 1.37×10^{-5} m. The lens is illuminated with monochromatic light ($\lambda_{\text{vacuum}} = 550$ nm), and a series of concentric bright and dark rings is formed, much like Newton's rings. How many bright rings are there?



***17.** A film of oil lies on wet pavement. The refractive index of the oil exceeds that of the water. The film has the minimum nonzero thickness such that it appears dark due to destructive interference when viewed in red light (wavelength = 660 nm in vacuum). Assuming that the visible spectrum extends from 380 to 750 nm, what are the visible wavelength(s) (in vacuum) for which the film will appear bright due to constructive interference?

****18.** A uniform layer of water ($n = 1.33$) lies on a glass plate ($n = 1.52$). Light shines perpendicularly on the layer. Because of constructive interference, the layer looks maximally bright when the wavelength of the light is 432 nm in vacuum and *also* when it is 648 nm in vacuum. (a) Obtain the minimum thickness of the film. (b) Assuming that the film has the minimum thickness and that the visible spectrum extends from 380 to 750 nm, determine the visible wavelength(s) (in vacuum) for which the film appears completely dark.

Section 27.5 Diffraction

19. ssm A diffraction pattern forms when light passes through a single slit. The wavelength of the light is 675 nm. Determine the angle that locates the first dark fringe when the width of the slit is (a) 1.8×10^{-4} m and (b) 1.8×10^{-6} m.

20. A doorway is 0.91 m wide. (a) Obtain the angle that locates the first dark fringe in the Fraunhofer diffraction pattern formed when red light (wavelength = 660 nm) passes through the doorway. (b) Repeat part (a) for a 440-Hz sound wave (concert A), assuming that the speed of sound is 343 m/s.

21. A single slit has a width of 2.1×10^{-6} m and is used to form a diffraction pattern. Find the angle that locates the second dark fringe when the wavelength of the light is (a) 430 nm and (b) 660 nm.

22. The first dark fringe in the diffraction pattern of a single slit is located at an angle of $\theta_A = 34°$. With the same light, the first dark fringe formed with another single slit is at an angle of $\theta_B = 56°$. Find the ratio W_A/W_B of the widths of the two slits.

23. ssm www Light shines through a single slit whose width is 5.6×10^{-4} m. A diffraction pattern is formed on a flat screen located 4.0 m away. The distance between the middle of the central bright fringe and the first dark fringe is 3.5 mm. What is the wavelength of the light?

***24.** The width of a slit is 2.0×10^{-5} m. Light with a wavelength of 480 nm passes through this slit and falls on a screen that is located 0.50 m away. In the diffraction pattern, find the width of the bright fringe that is next to the central bright fringe.

***25. ssm** The central bright fringe in a single-slit diffraction pattern has a width that equals the distance between the screen and the slit. Find the ratio λ/W of the wavelength of the light to the width of the slit.

***26.** In a single-slit diffraction pattern on a flat screen, the central bright fringe is 1.2 cm wide when the slit width is 3.2×10^{-5} m. When the slit is replaced by a second slit, the wavelength of the light and the distance to the screen remaining unchanged, the central bright fringe broadens to a width of 1.9 cm. What is the width of the second slit? It may be assumed that θ is so small that $\sin\theta \approx \tan\theta$.

****27.** In a single-slit diffraction pattern, the central fringe is 450 times wider than the slit. The screen is 18 000 times farther from the slit than the slit is wide. What is the ratio λ/W, where λ is the wavelength of the light shining through the slit and W is the width of the slit? Assume that the angle that locates a dark fringe on the screen is small, so that $\sin\theta \approx \tan\theta$.

Section 27.6 Resolving Power

28. You are looking down at the earth from inside a jetliner flying at an altitude of 8690 m. The pupil of your eye has a diameter of 2.00 mm. Determine how far apart two cars must be on the ground if you are to have any hope of distinguishing between them in (a) red light (wavelength = 665 nm in vacuum) and (b) violet light (wavelength = 405 nm in vacuum).

29. It is claimed that some professional baseball players can see which way the ball is spinning as it travels toward home plate. One way to judge this claim is to estimate the distance at which a batter can first hope to resolve two points on opposite sides of a baseball, which has a diameter of 0.0738 m. (a) Estimate this distance, assuming that the pupil of the eye has a diameter of 2.0 mm and the wavelength of the light is 550 nm in vacuum. (b) Considering that the distance between the pitcher's mound and home plate is 18.4 m, can you rule out the claim based on your answer to part (a)?

30. Two asteroids are traveling close to each other through the solar system at a distance of 2.0×10^{10} m from earth. With light of wavelength 550 nm, they are just resolved by the Hubble Space Telescope, whose aperture has a diameter of 2.4 m. How far apart are the asteroids?

31. ssm The largest refracting telescope in the world is at the Yerkes Observatory in Williams Bay, Wisconsin. The objective of the telescope has a diameter of 1.02 m. Two objects are 3.75×10^4 m from the telescope. With light of wavelength 565 nm, how close can the objects be to each other so that they are just resolved by the telescope?

32. Astronomers have discovered a planetary system orbiting the star Upsilon Andromedae, which is at a distance of 4.2×10^{17} m from the earth. One planet is believed to be located at a distance of 1.2×10^{11} m from the star. Using visible light with a vacuum wavelength of 550 nm, what is the minimum necessary aperture diameter that a telescope must have so that it can resolve the planet and the star?

33. Review Conceptual Example 8 as background for this problem. In addition to the data given there, assume that the dots in the painting are separated by 1.5 mm and that the wavelength of the light is $\lambda_{vacuum} = 550$ nm. Find the distance at which the dots can just be resolved by (a) the eye and (b) the camera.

***34.** The pupil of an eagle's eye has a diameter of 6.0 mm. Two field mice are separated by 0.010 m. From a distance of 176 m, the eagle sees them as one unresolved object and dives toward them at a speed of 17 m/s. Assume that the eagle's eye detects light that has a wavelength of 550 nm in a vacuum. How much time passes until the eagle sees the mice as separate objects?

***35. ssm www** In an experiment, red light (wavelength = 694.3 nm) is sent to the moon. At the surface of the moon, which is 3.77×10^8 m away, the light strikes a reflector left there by astronauts. The reflected light returns to the earth, where it is detected. When it leaves the spotlight, the circular beam of light has a diameter of about 0.20 m, and diffraction causes the beam to spread as the light travels to the moon. In effect, the first circular dark fringe in the diffraction pattern defines the size of the central bright spot on the moon. Determine the diameter (not the radius) of the central bright spot on the moon.

****36.** Two concentric circles of light emit light whose wavelength is 555 nm. The larger circle has a radius of 4.0 cm, while the smaller circle has a radius of 1.0 cm. When taking a picture of these lighted circles, a camera admits light through an aperture whose diameter is 12.5 mm. What is the maximum distance at which the camera can (a) distinguish one circle from the other and (b) reveal that the inner circle is a circle of light rather than a solid disk of light?

Section 27.7 The Diffraction Grating, Section 27.8 Compact Discs, Digital Video Discs, and the Use of Interference

37. ssm The diffraction gratings discussed in the text are transmission gratings because light *passes through* them. There are also gratings in which the light *reflects from* the grating to form a pattern of fringes. Equation 27.7 also applies to a reflection grating with straight parallel lines when the incident light shines perpendicularly on the grating. The surface of a compact disc (CD) has a multicolored appearance because it acts like a reflection grating and spreads sunlight into its colors. The arms of the spiral track on the CD are separated by 1.1×10^{-6} m. Using Equation 27.7, estimate the angle that corresponds to the first-order maximum for a wavelength of (a) 660 nm (red) and (b) 410 nm (violet).

38. For a wavelength of 420 nm, a diffraction grating produces a bright fringe at an angle of 26°. For an unknown wavelength, the same grating produces a bright fringe at an angle of 41°. In both cases the bright fringes are of the same order m. What is the unknown wavelength?

39. A diffraction grating produces a first-order bright fringe that is 0.0894 m away from the central bright fringe on a flat screen. The separation between the slits of the grating is 4.17×10^{-6} m, and the distance between the grating and the screen is 0.625 m. What is the wavelength of the light shining on the grating?

40. When a grating is used with light that has a wavelength of 621 nm, a third-order maximum is formed at an angle of 18.0°. How many lines per centimeter does this grating have?

41. ssm The wavelength of the laser beam used in a compact disc player is 780 nm. Suppose that a diffraction grating produces first-order tracking beams that are 1.2 mm apart at a distance of 3.0 mm from the grating. Estimate the spacing between the slits of the grating.

***42.** The first-order maximum produced by a grating is located at an angle of $\theta = 16.0°$. What is the angle for the third-order maximum with the same light?

***43. ssm** Violet light (wavelength = 410 nm) and red light (wavelength = 660 nm) lie at opposite ends of the visible spectrum. (a) For each wavelength, find the angle θ that locates the first-order maximum produced by a grating with 3300 lines/cm. This grating converts a mixture of all colors between violet and red into a rainbow-like dispersion between the two angles. Repeat the calculation above for (b) the second-order maximum and (c) the third-order maximum. (d) From your results, decide whether there is an overlap between any of the "rainbows" and, if so, specify which orders overlap.

***44.** Three, and only three, bright fringes can be seen on either side of the central maximum when a grating is illuminated with light ($\lambda = 510$ nm). What is the maximum number of lines/cm for the grating?

****45.** Two gratings A and B have slit separations d_A and d_B, respectively. They are used with the same light and the same observation screen. When grating A is replaced with grating B, it is observed that the first-order maximum of A is exactly replaced by the second-order maximum of B. (a) Determine the ratio d_B/d_A of the spacings between the slits of the gratings. (b) Find the next two principal maxima of grating A and the principal maxima of B that exactly replace them when the gratings are switched. Identify these maxima by their order numbers.

ADDITIONAL PROBLEMS

46. A rock concert is being held in an open field. Two loudspeakers are separated by 7.00 m. As an aid in arranging the seating, a test is conducted in which both speakers vibrate in phase and produce an 80.0-Hz bass tone simultaneously. The speed of sound is 343 m/s. A reference line is marked out in front of the speakers, perpendicular to the midpoint of the line between the speakers. Relative to either side of this reference line, what is the smallest angle that locates the places where destructive interference occurs? People seated in these places would have trouble hearing the 80.0-Hz bass tone.

47. ssm A flat observation screen is placed at a distance of 4.5 m from a pair of slits. The separation on the screen between the central bright fringe and the first-order bright fringe is 0.037 m. The light illuminating the slits has a wavelength of 490 nm. Determine the slit separation.

48. A slit whose width is 4.30×10^{-5} m is located 1.32 m from a flat screen. Light shines through the slit and falls on the screen. Find the width of the central fringe of the diffraction pattern when the wavelength of the light is 635 nm.

49. A mixture of red light ($\lambda_{vacuum} = 661$ nm) and green light ($\lambda_{vacuum} = 551$ nm) shines perpendicularly on a soap film ($n = 1.33$) that has air on either side. What is the minimum nonzero thickness of the film, so that destructive interference causes it to look red in reflected light?

50. Two parallel slits are illuminated by light composed of two wavelengths, one of which is 645 nm. On a viewing screen, the light whose wavelength is known produces its third dark fringe at the same place where the light whose wavelength is unknown produces its fourth-order bright fringe. The fringes are counted relative to the central or zeroth-order bright fringe. What is the unknown wavelength?

51. ssm Late one night on a highway, a car speeds by you and fades into the distance. Under these conditions the pupils of your eyes have diameters of about 7.0 mm. The taillights of this car are separated by a distance of 1.2 m and emit red light (wavelength = 660 nm in vacuum). How far away from you is this car when its taillights appear to merge into a single spot of light because of the effects of diffraction?

***52.** Monochromatic light shines on a diffraction grating. When the light source and the grating are in air, the first-order maximum occurs at an angle of 33°. At what angle does the first-order maximum occur when the source and the grating are immersed in water ($n = 1.33$)?

***53.** You are using a microscope to examine a blood sample. Recall from Section 26.12 that the sample should be placed just outside the focal point of the objective lens of the microscope. (a) The specimen is being illuminated with light of wavelength λ and the diameter of the objective equals its focal length. Determine the closest distance between two blood cells that can just be resolved. Express your answer in terms of λ. (b) Based on your answer to (a), should you use light with a longer wavelength or a shorter wavelength if you wish to resolve two blood cells that are even closer together?

***54.** The separation between the slits of a grating is 2.2×10^{-6} m. This grating is used with light that contains all wavelengths between 410 and 660 nm. Rainbow-like spectra form on a screen 3.2 m away. How wide (in meters) is (a) the first-order spectrum and (b) the second-order spectrum?

***55. ssm** The same diffraction grating is used with two different wavelengths of light, λ_A and λ_B. The fourth-order principal maximum of light A exactly overlaps the third-order principal maximum of light B. Find the ratio λ_A/λ_B.

***56.** Review Conceptual Example 4 before attempting this problem. A film of gasoline ($n = 1.40$) floats on water ($n = 1.33$). Yellow light (wavelength = 580 nm in vacuum) shines perpendicularly on this film. (a) Determine the minimum nonzero thickness of the film, such that the film appears bright yellow due to constructive interference. (b) Repeat part (a), assuming that the gasoline film is on glass ($n = 1.52$) instead of water.

****57.** There are 5620 lines per centimeter in a grating that is used with light whose wavelength is 471 nm. A flat observation screen is located at a distance of 0.750 m from the grating. What is the minimum width that the screen must have so the *centers* of all the principal maxima formed on either side of the central maximum fall on the screen?

****58.** A piece of curved glass has a radius of curvature of 10.0 m and is used to form Newton's rings, as in Figure 27.14. Not counting the dark spot at the center of the pattern, there are one hundred dark fringes, the last one being at the outer edge of the curved piece of glass. The light being used has a wavelength of 654 nm in vacuum. What is the radius of the outermost dark ring in the pattern?

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

59. Concept Questions (a) Point A is the midpoint of one of the sides of a square. On the side opposite this spot, two in-phase loudspeakers are located at adjacent corners, as in Figure 27.41. Standing at point A, you hear a loud sound because constructive interference occurs between the identical sound waves coming from the speakers. Why does constructive interference occur at point A? (b) As you walk along the side of the square toward either empty corner, the loudness diminishes gradually to nothing and then increases again until you hear a maximally loud sound at the corner. Explain these observations in terms of destructive and constructive interference. (c) The general condition that leads to constructive interference entails a number of possibilities for the variable m, which designates the order of the interference maxima. Which one of those possibilities, if any, applies at either empty corner of the square? Explain.

Problem The square referred to in the Concept Questions is 4.6 m on a side. Find the wavelength of the sound waves.

60. Concept Questions (a) The screen in Figure 27.8 has a fixed width and is centered on the midpoint between the two slits. Should the screen be moved to the left or to the right to ensure that the third-order bright fringe does *not* lie on the screen? (b) Do fewer fringes lie on the screen when the distance L between the double-slit and the screen is smaller or larger? Account for your answers.

Problem In a setup like that in Figure 27.8, a wavelength of 625 nm is used in a Young's double-slit experiment. The separation between the slits is $d = 1.4 \times 10^{-5}$ m. The total width of the screen is 0.20 m. In one version of the setup, the separation between the double slit and the screen is $L_A = 0.35$ m, while in another version it is $L_B = 0.50$ m. On one side of the central bright fringe, how many bright fringes lie on the screen in the two versions of the setup? Do not include the central bright fringe in your counting. Verify that your answer is consistent with your answers to the Concept Questions.

61. Concept Questions (a) What, if any, phase change occurs when light, traveling in air, reflects from the interface between the air and a soap film ($n = 1.33$)? (b) What, if any, phase change occurs when light, traveling in a soap film, reflects from the interface between the soap film and a glass plate ($n = 1.52$)? (c) Is the wavelength of the light in a soap film greater than, smaller than, or equal to the wavelength in a vacuum?

Problem A soap film ($n = 1.33$) is 465 nm thick and lies on a glass plate ($n = 1.52$). Sunlight, whose wavelengths (in vacuum) extend from 380 to 750 nm, travels through the air and strikes the film perpendicularly. For which wavelength(s) in this range does destructive interference cause the film to look dark in reflected light?

62. Concept Questions (a) In a single-slit diffraction pattern the width of the central bright fringe is defined by the location of the first dark fringe that lies on either side of it. For a given slit width, does the width of the central bright fringe increase, decrease, or remain the same as the wavelength of the light increases? (b) For a given wavelength, does the width of the central bright fringe increase, decrease, or remain the same as the slit width increases? (c) When both the wavelength and the slit width change, it is possible for the width of the central bright fringe to remain the same. What condition must be satisfied for this to happen? In each case, give your reasoning.

Problem A slit has a width of $W_1 = 2.3 \times 10^{-6}$ m. When light with a wavelength of $\lambda_1 = 510$ nm passes through this slit, the width of the central bright fringe on a flat observation screen has a certain value. Keeping the screen in the same place, this slit is replaced with a second slit (width W_2) and a wavelength of $\lambda_2 = 740$ nm is used. The width of the central bright fringe on the screen is observed to be unchanged. Find W_2.

63. **Concept Questions** An inkjet color printer uses tiny dots of red, green, and blue ink to produce an image. At normal viewing distances, the eye does not resolve the individual dots, so that the image has a normal look. The angle θ_{min} is the minimum angle that two dots can subtend at the eye and still be resolved separately. (a) For which color does θ_{min} have the largest value? (b) For which color does θ_{min} have the smallest value? (c) Corresponding to each value of θ_{min}, there is a value for the separation distance s between the dots. How is θ_{min} related to s and the viewing distance L? (d) Assume that the dot separation on the printed page is the same for all colors and is chosen so that none of the colored dots can be seen as separate objects. Should the maximum allowable dot separation be s_{red}, s_{green}, or s_{blue}? For each answer, give your reasoning.

Problem The wavelengths for red, green, and blue are $\lambda_{red} = 660$ nm, $\lambda_{green} = 550$ nm, and $\lambda_{blue} = 470$ nm. The diameter of the pupil through which light enters the eye is 2.0 mm. For a viewing distance of 0.40 m, find the maximum separation distance that the dots can have and not be resolved separately. Check to see that your answer is consistent with your answers to the Concept Questions.

64. **Concept Questions** (a) Two diffraction gratings are located at the same distance from observation screens. Light with the same wavelength λ is used for each. The principal maxima of grating A are observed to be closer together on the screen than the principal maxima of grating B. Which grating diffracts the light to a greater extent? (b) Which grating has the smaller slit separation d? (c) Which grating has the greater number of lines per meter? Justify each of your answers.

Problem The separation between adjacent principal maxima for grating A is 2.7 cm, while for grating B it is 3.2 cm. Grating A has 2000 lines per meter. How many lines per meter does grating B have? The diffraction angles are small enough that $\sin\theta \approx \tan\theta$. Be sure that your answer is consistent with your answers to the Concept Questions.