Chapter 27: wave optics

# 27.1 the wave aspect of light: interference

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| 1. | | *Show that when light passes from air to water, its wavelength decreases to 0.750 times its original value.* |
| Solution | | .  So, the wavelength of light in water is 0.750 times the wavelength in air. |
| 2. | | *Find the range of visible wavelengths of light in crown glass.* |
| Solution | |  |
| 3. | | *What is the index of refraction of a material for which the wavelength of light is 0.671 times its value in a vacuum? Identify the likely substance.* |
| Solution | | Polystyrene |
| 4. | | *Analysis of an interference effect in a clear solid shows that the wavelength of light in the solid is 329 nm. Knowing this light comes from a He-Ne laser and has a wavelength of 633 nm in air, is the substance zircon or diamond?* |
| Solution | | Zircon |
| 5. | | *What is the ratio of thicknesses of crown glass and water that would contain the same number of wavelengths of light?* |
| Solution | |  |
| 27.3 young’s double slit experiment | | |
| 6. | *At what angle is the first-order maximum for 450-nm wavelength blue light falling on double slits separated by 0.0500 mm?* | |
| Solution |  | |
| 7. | *Calculate the angle for the third-order maximum of 580-nm wavelength yellow light falling on double slits separated by 0.100 mm.* | |
| Solution | Using | |
| 8. | *What is the separation between two slits for which 610-nm orange light has its first maximum at an angle of ?* | |
| Solution |  | |
| 9. | *Find the distance between two slits that produces the first minimum for 410-nm violet light at an angle of .* | |
| Solution |  | |
| 10. | *Calculate the wavelength of light that has its third minimum at an angle of  when falling on double slits separated by . Explicitly show how you follow the steps in Problem-Solving Strategies for Wave Optics.* | |
| Solution |  | |
| 11. | *What is the wavelength of light falling on double slits separated by  if the third-order maximum is at an angle of ?* | |
| Solution |  | |
| 12. | *At what angle is the fourth-order maximum for the situation Exercise 27.6?* | |
| Solution |  | |
| 13. | *What is the highest-order maximum for 400-nm light falling on double slits separated by ?* | |
| Solution | Looking at , we notice that the highest order occurs when , so the highest order is:  Since *m* must be an integer, the highest order is then *m* = 62. | |
| 14. | *Find the largest wavelength of light falling on double slits separated by  for which there is a first-order maximum. Is this in the visible part of the spectrum?* | |
| Solution | Thus, (not visible) | |
| 15. | *What is the smallest separation between two slits that will produce a second-order maximum for 720-nm red light?* | |
| Solution | Thus, | |
| 16. | *(a) What is the smallest separation between two slits that will produce a second-order maximum for any visible light? (b) For all visible light?* | |
| Solution | (a)  So,  (b) | |
| 17. | *(a) If the first-order maximum for pure-wavelength light falling on a double slit is at an angle of , at what angle is the second-order maximum? (b) What is the angle of the first minimum? (c) What is the highest-order maximum possible here?* | |
| Solution | (a)  (b)  (c)  The highest order is *m* = 6. | |
| 18. | *Figure 27.56 shows a double slit located a distance  from a screen, with the distance from the center of the screen given by . When the distance  between the slits is relatively large, there will be numerous bright spots, called fringes. Show that, for small angles (where , with  in radians), the distance between fringes is given by .* | |
| Solution | For small angles  For two adjacent fringes we have  Subtracting these equations gives: | |
| 19. | *Using the result of the problem above, calculate the distance between fringes for 633-nm light falling on double slits separated by 0.0800 mm, located 3.00 m from a screen as in Figure 27.56.* | |
| Solution |  | |
| 20. | *Using the result of the problem two problems prior, find the wavelength of light that produces fringes 7.50 mm apart on a screen 2.00 m from double slits separated by 0.120 mm (see Figure 27.56).* | |
| Solution |  | |
| 27.4 multiple slit diffraction | | |
| 21. | *A diffraction grating has 2000 lines per centimeter. At what angle will the first-order maximum be for 520-nm-wavelength green light?* | |
| Solution | Therefore, since | |
| 22. | *Find the angle for the third-order maximum for 580-nm-wavelength yellow light falling on a diffraction grating having 1500 lines per centimeter.* | |
| Solution | Since | |
| 23. | *How many lines per centimeter are there on a diffraction grating that gives a first-order maximum for 470-nm blue light at an angle of ?* | |
| Solution | Therefore, | |
| 24. | *What is the distance between lines on a diffraction grating that produces a second-order maximum for 760-nm red light at an angle of ?* | |
| Solution |  | |
| 25. | *Calculate the wavelength of light that has its second-order maximum at  when falling on a diffraction grating that has 5000 lines per centimeter.* | |
| Solution | The second order maximum is constructive interference, so for diffraction gratings we use the equation  where the second order maximum has . Next, we need to determine the slit separation by using the fact that there are 5000 lines per centimeter:    Since , we can determine the wavelength of the light: | |
| 26. | *An electric current through hydrogen gas produces several distinct wavelengths of visible light. What are the wavelengths of the hydrogen spectrum, if they form first-order maxima at angles of , , , and  when projected on a diffraction grating having 10,000 lines per centimeter? Explicitly show how you follow the steps in Problem-Solving Strategies for Wave Optics.* | |
| Solution |  | |
| 27. | *(a) What do the four angles in the above problem become if a 5000-line-per-centimeter diffraction grating is used? (b) Using this grating, what would the angles be for the second-order maxima? (c) Discuss the relationship between integral reductions in lines per centimeter and the new angles of various order maxima.* | |
| Solution | (a)  (b)  (c) Decreasing the number of lines per centimeter by a factor of  means that the angle for the -order maximum is the same as the original angle for the first-order maximum. | |
| 28. | *What is the maximum number of lines per centimeter a diffraction grating can have and produce a complete first-order spectrum for visible light?* | |
| Solution | The maximum number of lines corresponds to the smallest , for the longest wavelength in the visible spectrum at . So, the smallest  which can accommodate the entire visible spectrum is . | |
| 29. | *The yellow light from a sodium vapor lamp seems to be of pure wavelength, but it produces two first-order maxima at  and  when projected on a 10,000 line per centimeter diffraction grating. What are the two wavelengths to an accuracy of 0.1 nm?* | |
| Solution |  | |
| 30. | *What is the spacing between structures in a feather that acts as a reflection grating, given that they produce a first-order maximum for 525-nm light at a  angle?* | |
| Solution |  | |
| 31. | *Structures on a bird feather act like a reflection grating having 8000 lines per centimeter. What is the angle of the first-order maximum for 600-nm light?* | |
| Solution |  | |
| 32. | *An opal such as that shown in Figure 27.17 acts like a reflection grating with rows separated by about . If the opal is illuminated normally, (a) at what angle will red light be seen and (b) at what angle will blue light be seen?* | |
| Solution | Constructive interference of light from rows in crystal is given by . The angle that red light (700 nm) will be seen is , or , where spacing . For blue light, , and so . | |
| 33. | *At what angle does a diffraction grating produces a second-order maximum for light having a first-order maximum at ?* | |
| Solution |  | |
| 34. | *Show that a diffraction grating cannot produce a second-order maximum for a given wavelength of light unless the first-order maximum is at an angle less than .* | |
| Solution | The largest possible second order occurs when. Using the equation we see that the value for the slit separation and wavelength are the same for the first and second order maximums, so that:  and , so that:  Now, since we know the maximum value for , we can solve for the maximum value for :  so that: | |
| 35. | *If a diffraction grating produces a first-order maximum for the shortest wavelength of visible light at , at what angle will the first-order maximum be for the longest wavelength of visible light?* | |
| Solution |  | |
| 36. | *(a) Find the maximum number of lines per centimeter a diffraction grating can have and produce a maximum for the smallest wavelength of visible light. (b) Would such a grating be useful for ultraviolet spectra? (c) For infrared spectra?* | |
| Solution | (a)  For a given the smallest corresponds to the largest    (b) For UV, and so Therefore, yes it would be useful for UV.  (c) For IR,, so no it would not be useful for IR. | |
| 37. | *(a) Show that a 30,000-line-per-centimeter grating will not produce a maximum for visible light. (b) What is the longest wavelength for which it does produce a first-order maximum? (c) What is the greatest number of lines per centimeter a diffraction grating can have and produce a complete second-order spectrum for visible light?* | |
| Solution | (a) First we need to calculate the slit separation:    Next, using the equation , we see that the longest wavelength will be for , so in that case, , which is not visible.  (b) From part (a), we know that the longest wavelength is equal to the slit separation, or 333 nm.  (c) To get the largest number of lines per cm and still produce a complete spectrum, we want the smallest slit separation that allows the longest wavelength of visible light to produce a second order maximum, so  (see Example 27.3). For there to be a second order spectrum,  so  Now, using the technique in step (a), only in reverse: | |
| 38. | *A He–Ne laser beam is reflected from the surface of a CD onto a wall. The brightest spot is the reflected beam at an angle equal to the angle of incidence. However, fringes are also observed. If the wall is 1.50 m from the CD, and the first fringe is 0.600 m from the central maximum, what is the spacing of grooves on the CD?* | |
| Solution | For the He–Ne laser . Therefore | |
| 39. | *The analysis shown in the figure below also applies to diffraction gratings with lines separated by a distance . What is the distance between fringes produced by a diffraction grating having 125 lines per centimeter for 600-nm light, if the screen is 1.50 m away?* | |
| Solution | , so that | |
| 40. | ***Unreasonable Results*** *Red light of wavelength of 700 nm falls on a double slit separated by 400 nm. (a) At what angle is the first-order maximum in the diffraction pattern? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* | |
| Solution | (a)  (b) The sine of a real angle cannot be greater than one.  (c) Assuming that you will get a diffraction pattern if is unreasonable. | |
| 41. | ***Unreasonable Results*** *(a) What visible wavelength has its fourth-order maximum at an angle of  when projected on a 25,000-line-per-centimeter diffraction grating? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* | |
| Solution | (a) For diffraction gratings, we use the equation where the fourth order maximum has . We first need to determine the slit separation by using the fact that there are 25,000 lines per centimeter:    So, since , we can determine the wavelength of the light:    (b) This wavelength is not in the visible spectrum.  (c) The number of slits in this diffraction grating is too large. Etching in integrated circuits can be done to a resolution of 50 nm, so slit separations of 400 nm are at the limit of what we can do today. This line spacing is too small to produce diffraction of light. | |
| 27.5 single slit diffraction | | |
| 43. | *(a) At what angle is the first minimum for 550-nm light falling on a single slit of width ? (b) Will there be a second minimum?* | |
| Solution | (a)  (b) | |
| 44. | *(a) Calculate the angle at which a -wide slit produces its first minimum for 410-nm violet light. (b) Where is the first minimum for 700-nm red light?* | |
| Solution | (a)  (b) | |
| 45. | *(a) How wide is a single slit that produces its first minimum for 633-nm light at an angle of ? (b) At what angle will the second minimum be?* | |
| Solution | (a)  (b) | |
| 46. | *(a) What is the width of a single slit that produces its first minimum at  for 600-nm light? (b) Find the wavelength of light that has its first minimum at .* | |
| Solution | (a)  (b) | |
| 47. | *Find the wavelength of light that has its third minimum at an angle of  when it falls on a single slit of width .* | |
| Solution |  | |
| 48. | *Calculate the wavelength of light that produces its first minimum at an angle of  when falling on a single slit of width .* | |
| Solution | Since | |
| 49. | *(a) Sodium vapor light averaging 589 nm in wavelength falls on a single slit of width . At what angle does it produces its second minimum? (b) What is the highest-order minimum produced?* | |
| Solution | (a)  (b) | |
| 50. | *(a) Find the angle of the third diffraction minimum for 633-nm light falling on a slit of width . (b) What slit width would place this minimum at ? Explicitly show how you follow the steps in Problem-Solving Strategies for Wave Optics.* | |
| Solution | (a)  (b) | |
| 51. | *(a) Find the angle between the first minima for the two sodium vapor lines, which have wavelengths of 589.1 and 589.6 nm, when they fall upon a single slit of width . (b) What is the distance between these minima if the diffraction pattern falls on a screen 1.00 m from the slit? (c) Discuss the ease or difficulty of measuring such a distance.* | |
| Solution | (a)  (b)  (c) This distance is not easily measured by human eye, but under a microscope or magnifying glass it is quite easily measurable. | |
| 52. | *(a) What is the minimum width of a single slit (in multiples of ) that will produce a first minimum for a wavelength ? (b) What is its minimum width if it produces 50 minima? (c) 1000 minima?* | |
| Solution | (a)  (b)  (c) | |
| 53. | *(a) If a single slit produces a first minimum at , at what angle is the second-order minimum? (b) What is the angle of the third-order minimum? (c) Is there a fourth-order minimum? (d) Use your answers to illustrate how the angular width of the central maximum is about twice the angular width of the next maximum (which is the angle between the first and second minima).* | |
| Solution | (a)  (b)  (c)  (d) | |
| 54. | *A double slit produces a diffraction pattern that is a combination of single and double slit interference. Find the ratio of the width of the slits to the separation between them, if the first minimum of the single slit pattern falls on the fifth maximum of the double slit pattern. (This will greatly reduce the intensity of the fifth maximum.)* | |
| Solution | The problem is asking us to find the ratio of to . For the single slit, using the equation , we have . For the double slit, using the equation  (because we have a maximum), we have . Dividing the single slit equation by double slit equation, where the angle and wavelength are the same gives:  So, the slit separation is five times the slit width. | |
| 55. | ***Integrated Concepts*** *A water break at the entrance to a harbor consists of a rock barrier with a 50.0-m-wide opening. Ocean waves of 20.0-m wavelength approach the opening straight on. At what angle to the incident direction are the boats inside the harbor most protected against wave action?* | |
| Solution | We are looking for the first minimum for single slit diffraction because the 50.0 m wide opening acts as a single slit. Using the equation , we can determine the angle for first minimum:    Since the main peak for single slit diffraction is the main problem, a boat in the harbor at an angle greater than this first diffraction minimum will feel smaller waves. At the second minimum, the boat will not be affected by the waves at all: | |
| 56. | ***Integrated Concepts*** *An aircraft maintenance technician walks past a tall hangar door that acts like a single slit for sound entering the hangar. Outside the door, on a line perpendicular to the opening in the door, a jet engine makes a 600-Hz sound. At what angle with the door will the technician observe the first minimum in sound intensity if the vertical opening is 0.800 m wide and the speed of sound is 340 m/s?* | |
| Solution | We are looking for the first minimum for single slit diffraction: | |
| 27.6 limits of resolution: the rayleigh criterion | | |
| 57. | *The 300-m-diameter Arecibo radio telescope pictured in Figure 27.28 detects radio waves with a 4.00 cm average wavelength. (a) What is the angle between two just-resolvable point sources for this telescope? (b) How close together could these point sources be at the 2 million light year distance of the Andromeda galaxy?* | |
| Solution | (a)  (b) | |
| 58. | *Assuming the angular resolution found for the Hubble Telescope in Example 27.5, what is the smallest detail that could be observed on the Moon?* | |
| Solution |  | |
| 59. | *Diffraction spreading for a flashlight is insignificant compared with other limitations in its optics, such as spherical aberrations in its mirror. To show this, calculate the minimum angular spreading of a flashlight beam that is originally 5.00 cm in diameter with an average wavelength of 600 nm.* | |
| Solution |  | |
| 60. | *(a) What is the minimum angular spread of a 633-nm wavelength He-Ne laser beam that is originally 1.00 mm in diameter? (b) If this laser is aimed at a mountain cliff 15.0 km away, how big will the illuminated spot be? (c) How big a spot would be illuminated on the Moon, neglecting atmospheric effects? (This might be done to hit a corner reflector to measure the round-trip time and, hence, distance.) Explicitly show how you follow the steps in Problem-Solving Strategies for Wave Optics.* | |
| Solution | (a)  (b)  The diameter of the spot will be  where  is the width of the spread of the spot edge due to diffraction.    (c) We can ignore since it is so small. | |
| 61. | *A telescope can be used to enlarge the diameter of a laser beam and limit diffraction spreading. The laser beam is sent through the telescope in opposite the normal direction and can then be projected onto a satellite or the Moon. (a) If this is done with the Mount Wilson telescope, producing a 2.54-m-diameter beam of 633-nm light, what is the minimum angular spread of the beam (the angle between the beam’s maximum and its first zero)? (b) Neglecting atmospheric effects, what is the size of the spot this beam would make on the Moon, assuming a lunar distance of ?* | |
| Solution | (a)  (b) | |
| 62. | *The limit to the eye’s acuity is actually related to diffraction by the pupil. (a) What is the angle between two just-resolvable points of light for a 3.00-mm-diameter pupil, assuming an average wavelength of 550 nm? (b) Take your result to be the practical limit for the eye. What is the greatest possible distance a car can be from you if you can resolve its two headlights, given they are 1.30 m apart? (c) What is the distance between two just-resolvable points held at an arm’s length (0.800 m) from your eye? (d) How does your answer to (c) compare to details you normally observe in everyday circumstances?* | |
| Solution | (a)  (b) The distance  between two objects, a distance away, separated by an angle  is , so:  (c) Using the same equation as in part (b):    (d) Holding a ruler at arm’s length, you can easily see the millimeter divisions, so you can resolve details 1.0 mm apart. Therefore, you probably can resolve details 0.2 mm apart at arm’s length. | |
| 63. | *What is the minimum diameter mirror on a telescope that would allow you to see details as small as 5.00 km on the Moon some 384,000 km away? Assume an average wavelength of 550 nm for the light received.* | |
| Solution |  | |
| 64. | *You are told not to shoot until you see the whites of their eyes. If the eyes are separated by 6.5 cm and the diameter of your pupil is 5.0 mm, at what distance can you resolve the two eyes using light of wavelength 555 nm?* | |
| Solution | Apply the Rayleigh criterion to the eyes:  . | |
| 65. | *(a) The planet Pluto and its Moon Charon are separated by 19,600 km. Neglecting atmospheric effects, should the 5.08-m-diameter Mount Palomar telescope be able to resolve these bodies when they are  from Earth? Assume an average wavelength of 550 nm. (b) In actuality, it is just barely possible to discern that Pluto and Charon are separate bodies using an Earth-based telescope. What are the reasons for this?* | |
| Solution | (a)  The telescope should be able to discern a separation at:    Yes. The telescope should easily be able to discern a separation.  (b) The fact that it is just barely possible to discern that these are separate bodies indicates the severity of atmospheric aberrations. | |
| 66. | *The headlights of a car are 1.3 m apart. What is the maximum distance at which the eye can resolve these two headlights? Take the pupil diameter to be 0.40 cm.* | |
| Solution | From , we can calculate the maximum distance at which lights can be resolved: . | |
| 67. | *When dots are placed on a page from a laser printer, they must be close enough so that you do not see the individual dots of ink. To do this, the separation of the dots must be less than Raleigh’s criterion. Take the pupil of the eye to be 3.0 mm and the distance from the paper to the eye of 35 cm; find the minimum separation of two dots such that they cannot be resolved. How many dots per inch (dpi) does this correspond to?* | |
| Solution | Resolution in dpi. These are specs found on most printers today. | |
| 68. | ***Unreasonable Results*** *An amateur astronomer wants to build a telescope with a diffraction limit that will allow him to see if there are people on the moons of Jupiter. (a) What diameter mirror is needed to be able to see 1.00 m detail on a Jovian Moon at a distance of  from Earth? The wavelength of light averages 600 nm. (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* | |
| Solution | (a)  (b) This is an unreasonably large telescope.  (c) It is unreasonable to assume you could build a telescope large enough to see such detail. | |

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| 27.7 thin film interference | | | |
| 70. | | *A soap bubble is 100 nm thick and illuminated by white light incident perpendicular to its surface. What wavelength and color of visible light is most constructively reflected, assuming the same index of refraction as water?* | |
| Solution | |  | |
| 71. | | *An oil slick on water is 120 nm thick and illuminated by white light incident perpendicular to its surface. What color does the oil appear (what is the most constructively reflected wavelength), given its index of refraction is 1.40?* | |
| Solution | |  | |
| 72. | | *Calculate the minimum thickness of an oil slick on water that appears blue when illuminated by white light perpendicular to its surface. Take the blue wavelength to be 470 nm and the index of refraction of oil to be 1.40.* | |
| Solution | |  | |
| 73. | | *Find the minimum thickness of a soap bubble that appears red when illuminated by white light perpendicular to its surface. Take the wavelength to be 680 nm, and assume the same index of refraction as water.* | |
| Solution | | The minimum thickness will occur when there is one phase change, so for light incident perpendicularly, constructive interference first occurs when. So, using the index of refraction for water from Table 25.1: | |
| 74. | | *A film of soapy water () on top of a plastic cutting board has a thickness of 233 nm. What color is most strongly reflected if it is illuminated perpendicular to its surface?* | |
| Solution | |  | |
| 75. | | *What are the three smallest non-zero thicknesses of soapy water () on Plexiglas if it appears green (constructively reflecting 520-nm light) when illuminated perpendicularly by white light? Explicitly show how you follow the steps in Problem-Solving Strategies for Wave Optics.* | |
| Solution | |  | |
| 76. | | *Suppose you have a lens system that is to be used primarily for 700-nm red light. What is the second thinnest coating of fluorite (magnesium fluoride) that would be non-reflective for this wavelength?* | |
| Solution | |  | |
| 77. | | *(a) As a soap bubble thins it becomes dark, because the path length difference becomes small compared with the wavelength of light and there is a phase shift at the top surface. If it becomes dark when the path length difference is less than one-fourth the wavelength, what is the thickest the bubble can be and appear dark at all visible wavelengths? Assume the same index of refraction as water. (b) Discuss the fragility of the film considering the thickness found.* | |
| Solution | | 1. It can be as thick as one-fourth of the longest visible wavelength in water, so that .   (b) This thickness is rather small compared to the diameter of a soap bubble, so it is rather fragile when it appears dark. | |
| 78. | | *A film of oil on water will appear dark when it is very thin, because the path length difference becomes small compared with the wavelength of light and there is a phase shift at the top surface. If it becomes dark when the path length difference is less than one-fourth the wavelength, what is the thickest the oil can be and appear dark at all visible wavelengths? Oil has an index of refraction of 1.40.* | |
| Solution | | The path length must be less than one-fourth of the shortest visible wavelength in oil. The thickness of the oil is half the path length, so it must be less than one-eighth of the shortest visible wavelength in oil. If we take 380 nm to be the shortest visible wavelength in air, | |
| 79. | | *Figure 27.34 shows two glass slides illuminated by pure-wavelength light incident perpendicularly. The top slide touches the bottom slide at one end and rests on a 0.100-mm-diameter hair at the other end, forming a wedge of air. (a) How far apart are the dark bands, if the slides are 7.50 cm long and 589-nm light is used? (b) Is there any difference if the slides are made from crown or flint glass? Explain.* | |
| Solution | | (a)  Two adjacent dark bands will have thickness differing by one wavelength, i.e.,  or  So, since  we see that  (b) The material makeup of the slides is irrelevant because it is the path difference in the air between the slides that gives rise to interference. | |
| 80. | | *Figure 27.34 shows two 7.50-cm-long glass slides illuminated by pure 589-nm wavelength light incident perpendicularly. The top slide touches the bottom slide at one end and rests on some debris at the other end, forming a wedge of air. How thick is the debris, if the dark bands are 1.00 mm apart?* | |
| Solution | | Two dark bands will have thickness differing by one wavelength, i.e., | |
| 81. | | *Repeat Exercise 27.70, but take the light to be incident at a  angle.* | |
| Solution | | (one phase change)  So, | |
| 82. | | *Repeat Exercise 27.71, but take the light to be incident at a  angle.* | |
| Solution | | For one phase change: , so    For three phase changes: , so    Therefore, the oil film will appear black, since the reflected light is not in the visible part of the spectrum. | |
| 83. | | ***Unreasonable Results*** *To save money on making military aircraft invisible to radar, an inventor decides to coat them with a non-reflective material having an index of refraction of 1.20, which is between that of air and the surface of the plane. This, he reasons, should be much cheaper than designing Stealth bombers. (a) What thickness should the coating be to inhibit the reflection of 4.00-cm wavelength radar? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* | |
| Solution | | (a) Assuming  for the plane is greater than 1.20 then there are two phase changes:    (b) It is too thick, and the plane would be too heavy.  (c) It is unreasonable to think the layer of material could be any thickness when used on a real aircraft. | |
| 27.8 polarization | | | |
| 84. | | *What angle is needed between the direction of polarized light and the axis of a polarizing filter to cut its intensity in half?* | |
| Solution | |  | |
| 85. | | *The angle between the axes of two polarizing filters is . By how much does the second filter reduce the intensity of the light coming through the first?* | |
| Solution | | therefore, | |
| 86. | | *If you have completely polarized light of intensity , what will its intensity be after passing through a polarizing filter with its axis at an  angle to the light’s polarization direction?* | |
| Solution | | Using the equation : | |
| 87. | | *What angle would the axis of a polarizing filter need to make with the direction of polarized light of intensity  to reduce the intensity to ?* | |
| Solution | |  | |
| 88. | | *At the end of Example 27.8, it was stated that the intensity of polarized light is reduced to  of its original value by passing through a polarizing filter with its axis at an angle of  to the direction of polarization. Verify this statement.* | |
| Solution | |  | |
| 89. | | *Show that if you have three polarizing filters, with the second at an angle of  to the first and the third at an angle of  to the first, the intensity of light passed by the first will be reduced to  of its value. (This is in contrast to having only the first and third, which reduces the intensity to zero, so that placing the second between them increases the intensity of the transmitted light.)* | |
| Solution | |  | |
| 90. | | *Prove that, if  is the intensity of light transmitted by two polarizing filters with axes at an angle  and  is the intensity when the axes are at an angle , then , the original intensity. (Hint: Use the trigonometric identities  and .)* | |
| Solution | |  | |
| 91. | | *At what angle will light reflected from diamond be completely polarized?* | |
| Solution | | . Therefore, | |
| 92. | | *What is Brewster’s angle for light traveling in water that is reflected from crown glass?* | |
| Solution | | Using the equation , where  is for crown glass and  is for water (see Table 25.1). Brewster’s angle is | |
| 93. | | *A scuba diver sees light reflected from the water’s surface. At what angle will this light be completely polarized?* | |
| Solution | |  | |
| 94. | | *At what angle is light inside crown glass completely polarized when reflected from water, as in a fish tank?* | |
| Solution | |  | |
| 95. | | *Light reflected at  from a window is completely polarized. What is the window’s index of refraction and the likely substance of which it is made?* | |
| Solution | | The substance is likely fused quartz. | |
| 96. | | *(a) Light reflected at  from a gemstone in a ring is completely polarized. Can the gem be a diamond? (b) At what angle would the light be completely polarized if the gem was in water?* | |
| Solution | | (a)  The gem is not a diamond (it is zircon).  (b) | |
| 97. | | *If  is Brewster’s angle for light reflected from the top of an interface between two substances, and  is Brewster’s angle for light reflected from below, prove that .* | |
| Solution | | . The equation can be solved with the trigonometric identity: | |
| 98. | | ***Integrated Concepts*** *If a polarizing filter reduces the intensity of polarized light to  of its original value, by how much are the electric and magnetic fields reduced?* | |
| Solution | | where  is some constant. | |
| 99. | | ***Integrated Concepts*** *Suppose you put on two pairs of Polaroid sunglasses with their axes at an angle of . How much longer will it take the light to deposit a given amount of energy in your eye compared with a single pair of sunglasses? Assume the lenses are clear except for their polarizing characteristics.* | |
| Solution | |  | |
| 100. | | ***Integrated Concepts*** *(a) On a day when the intensity of sunlight is , a circular lens 0.200 m in diameter focuses light onto water in a black aluminum beaker. Two polarizing sheets of plastic are placed in front of the lens with their axes at an angle of . Assuming the sunlight is unpolarized and the polarizers are  efficient, what is the initial rate of heating of the water in , assuming it is  absorbed? The aluminum beaker has a mass of 30.0 grams and contains 250 grams of water. (b) Do the polarizing filters get hot? Explain.* | |
| Solution | | (a) After passing through the two polarizers the intensity is:  This intensity is focused on the lens, producing a total power hitting the water of:  Since the water absorbs only 80.0% of the heat, the power transferred to the water is:  22.2 J of heat are transferred to the water and beaker every second. Finally, we can get an expression for the change in temperature of the water and beaker:  For the rate of heating, replace  with the power transferred:    (b) Yes, the polarizing filters get hot because they absorb some of the lost energy from the sunlight. | |
| Test Prep for AP® courses | | |
| 1. | *Which of the following statements is true about Huygens’s principle of secondary wavelets?*   1. It can be used to explain the particle behavior of waves. 2. It states that each point on a wavefront can be considered a new wave source. 3. It can be used to find the velocity of a wave. 4. All of the above. | |
| Solution | (b) | |
| 2. | *Explain why the amount of bending that occurs during diffraction depends on the width of the opening through which light passes.* | |
| Solution | The amount of bending is less for wider openings and more for smaller openings because wave characteristics are most noticeable for interactions with objects about the same size as the wavelength. | |
| 3. | *Superposition of which of the following light waves may produce interference fringes? Select two answers.*  Wave1 = A1sin(2*ωt*) Wave2 = A2sin(4*ωt*)  Wave3 = A3sin(2*ωt* + *θ*) Wave4 = A4sin(4*ωt* + *θ*).   1. Wave1 and Wave2 2. Wave2 and Wave4 3. Wave3 and Wave1 4. Wave4 and Wave3 | |
| Solution | (b), (c) | |
| 4. | *In a double slit experiment with monochromatic light, the separation between the slits is 2 mm. If the screen is moved by 100 mm toward the slits, the distance between the central bright line and the second bright line changes by 32 μm. Calculate wavelength of the light used for the experiment.* | |
| Solution | 640 nm | |
| 5. | *In a double slit experiment, a student measures the maximum and minimum intensities when two waves with equal amplitudes are used. The student then doubles the amplitudes of the two waves and performs the measurements again. Which of the following will remain unchanged?*   1. The intensity of the bright fringe 2. The intensity of the dark fringe 3. The difference in the intensities of consecutive bright and the dark fringes 4. None of the above | |
| Solution | (b) | |
| 6. | *Draw a figure to show the resultant wave produced when two coherent waves (with equal amplitudes x) interact in phase. What is the amplitude of the resultant wave? If the phase difference between the coherent waves is changed to 60º, what will be new amplitude?* | |
| Solution | C:\Users\Rick\Documents\Career\Applications&Organizations\Education\WordsAndNumbers\APPhysics\APPhysics_Art\ArtChap27\CNX_APPhysics_27_M3_inphase_img.jpg  [Figure\_27\_M3\_inphase\_img]  *A*max = 2*x*; *A* = 1.73*x* | |
| 7. | *What will be the amplitude of the central fringe if the amplitudes of the two waves in a double slit experiment are a and 3a?*   1. 2*a* 2. 4*a* 3. 8*a*2 4. 16*a*2 | |
| Solution | (b) | |
| 8. | *If the ratio of amplitudes of the two waves in a double slit experiment is 3:4, calculate the ratio of minimum intensity (dark fringe) to maximum intensity (bright fringe).* | |
| Solution | 1:49 | |
| 9. | *Which of the following cannot be a possible outcome of passing white light through several evenly spaced parallel slits?*   1. The central maximum will be white but the higher-order maxima will disperse into a rainbow of colors. 2. The central maximum and higher-order maxima will be of equal widths. 3. The lower wavelength components of light will have less diffraction compared to higher wavelength components for all maxima except central. 4. None of the above. | |
| Solution | (b) | |
| 10. | *White light is passed through a diffraction grating to a screen some distance away. The nth-order diffraction angle for the longest wavelength (760 nm) is 53.13º. Find the nth-order diffraction angle for the shortest wavelength (380 nm). What will be the change in the two angles if the distance between the screen and the grating is doubled?* | |
| Solution | 23.58º; No change. | |
| 11. | *A diffraction pattern is formed on a screen when light of wavelength 410 nm is passed through a single slit of width 1 μm. If the source light is replaced by another light of wavelength 700 nm, what should be the width of the slit so that the new light produces a pattern with the same spacing?*   1. 0.6 μm 2. 1 μm 3. 1.4 μm 4. 1.7 μm | |
| Solution | (d) | |
| 12. | *Monochromatic light passing through a single slit forms a diffraction pattern on a screen. If the second minimum occurs at an angle of 15º, find the angle for the fourth minimum.* | |
| Solution | 31.17º | |
| 13. | *What is the relationship between the width (W) of the central diffraction maximum formed through a circular aperture and the size (S) of the aperture?*   1. *W* increases as *S* increases. 2. *W* decreases as *S* increases. 3. *W* can increase or decrease as *S* decreases. 4. *W* can neither increase nor decrease as *S* decreases. | |
| Solution | (b) | |
| 14. | *Light from two sources passes through a circular aperture to form images on a screen. State the Rayleigh criterion for the images to be just resolvable and draw a figure to visually explain it.* | |
| Solution | The Rayleigh criterion states that two images are just resolvable when the center of the diffraction pattern of one is directly over the first minimum of the diffraction pattern of the other. | |
| 15. | *Which of the following best describes the cause of thin film interference?*   1. Light reflecting from a medium having an index of refraction less than that of the medium in which it is traveling. 2. Light reflecting from a medium having an index of refraction greater than that of the medium in which it is traveling. 3. Light changing its wavelength and speed after reflection. 4. Light reflecting from top and bottom surfaces of a film. | |
| Solution | (d) | |
| 16. | *A film of magnesium fluoride (n = 1.38) is used to coat a glass camera lens (n = 1.52). If the thickness of the film is 105 nm, calculate the wavelength of visible light that will have the most limited reflection.* | |
| Solution | 580 nm | |
| 17. | *Which of the following statements is true for the direction of polarization for a polarized light wave?*   1. It is parallel to the direction of propagation and perpendicular to the direction of the electric field. 2. It is perpendicular to the direction of propagation and parallel to the direction of the electric field. 3. It is parallel to the directions of propagation and the electric field. 4. It is perpendicular to the directions of propagation and the electric field. | |
| Solution | (b) | |
| 18. | *In an experiment, light is passed through two polarizing filters. The image below shows the first filter and axis of polarization.*  C:\Users\Rick\Documents\Career\Applications&Organizations\Education\WordsAndNumbers\APPhysics\APPhysics_Art\ArtChap27\CNX_APPhysics_27_M8_polar_img.jpg  [Figure\_27\_M8\_polar\_img]  *The intensity of the resulting light (after the first filter) is recorded as I. Three configurations (at different angles) are set up for the second filter, and the intensity of light is recorded for each configuration. The results are shown in the table below:*   |  |  |  | | --- | --- | --- | | Set up | Angle of second filter compared to first filter | Intensity of light after second filter | | Configuration A | *θ*1 | *I* | | Configuration B | *θ*2 | 0.5*I* | | Configuration C | *θ*3 | 0 |   *Complete the table by calculating θ1, θ2,and θ3.* | |
| Solution | 0º, 45º, and 90º | |

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