

End-of-Chapter Exercises

Exercises 1 – 12 are conceptual questions designed to see whether you understand the main concepts in the chapter.

- Red laser light shines on a double slit, creating a pattern of bright and dark spots on a screen some distance away. State whether the following changes, carried out separately, would increase, decrease, or produce no change in the distance between the bright spots on the screen, and justify each answer. (a) Replace the red laser with a green laser. (b) Decrease the spacing between the slits. (c) Decrease the distance between the slits and the screen. (d) Immerse the entire apparatus in water.
- Light of a single wavelength shines onto a double slit. A particular point on the opposite side of the double slit from the light source happens to be 1800 nm farther from one slit than the other. Assume that the point receives some light from each slit, and that the beams arriving at the point from each slit are of equal intensity. For the following wavelengths, determine whether the interference at the point is constructive, destructive, or something in between. (a) 400 nm violet light, (b) 500 nm green light, (c) 600 nm orange light, (d) 700 nm red light. Explain each of your answers.

- The graph in Figure 25.24 shows $\sin\theta$ as a function of wavelength for different orders of light. The red line corresponds to the first-order ($m = 1$) spectrum. (a) What does the blue line correspond to? (b) Copy the graph and draw the line corresponding to the third-order spectrum. (c) What is the largest wavelength for which there is a third-order spectrum for this grating?

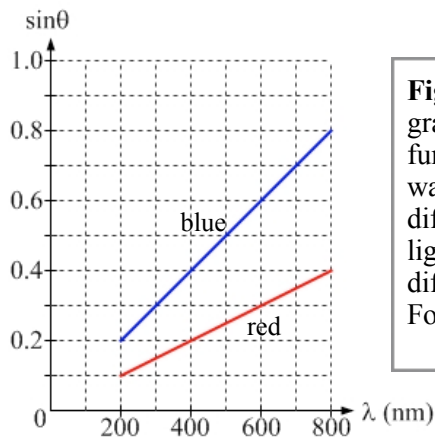


Figure 25.24: The graph shows $\sin\theta$ as a function of wavelength for different orders of light shining on a diffraction grating. For Exercise 3.

- The pattern in Figure 25.25 represents the interference pattern set up in a room by two speakers (the red circles) broadcasting identical single-frequency sound waves in phase with one another. (a) If you walk slowly along the line shown in yellow, from one end to the other, what will you hear? Explain your answer. (b) If the wavelength of the sound waves is 1.5 m, how far apart are the speakers?



Figure 25.25: An interference pattern set up in a room by two speakers broadcasting identical single-frequency waves. For Exercise 4.

- A red laser shining on something creates the pattern shown in Figure 25.26. Is the laser shining on a single slit, double slit, or a diffraction grating? Explain your answer.



Figure 25.26: The pattern at the center of a screen, produced by a red laser beam shining on a single slit, a double slit, or a diffraction grating. The distance between neighboring tick marks, shown on the screen below the pattern, is 8.00 mm. For Exercise 5.

6. A beam of white light strikes a glass prism, as shown in Figure 25.27(a). The white light is made up of only three colors. These are, in alphabetical order, green, red, and violet. The graph of the index of refraction vs. wavelength for the glass is shown below to the right of the prism. For each of the three rays labeled (a) – (c) on the diagram, label the ray with its color. Use W for white, G for green, R for red, and V for violet. (b) The prism is now replaced by a diffraction grating with a grating spacing of $d = 1300$ nm. The three colors in the beam of white light have, in order of increasing wavelength, wavelengths of 400 nm, 500 nm, and 700 nm. For the seven rays labeled (d) – (j) in Figure 25.27(b), label the ray with its color. Use W for white, G for green, R for red, and V for violet.

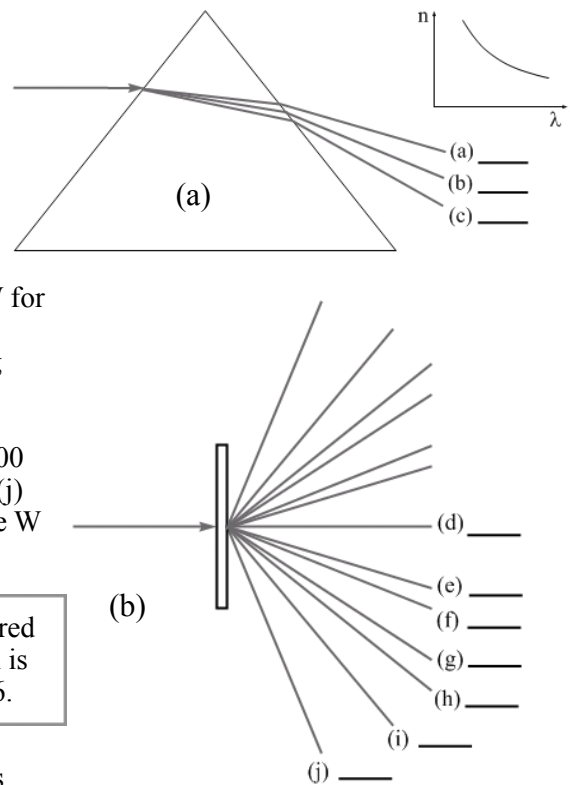


Figure 25.27: (a) A beam of violet, green, and red light is incident on a prism. (b) The same beam is incident on a diffraction grating. For Exercise 6.

7. Figure 25.28 shows the $m = 0$ through $m = 2$ lines that result when green light is incident on a diffraction grating. The squares on the grid in the figure measure $10\text{ cm} \times 10\text{ cm}$. The horizontal blue line at the top of the figure represents a screen, which is 1.0 m long and 90 cm from the grating. Approximately how far from the grating should the screen be located so that the two second-order green lines are just visible at the left and right edges of the screen?

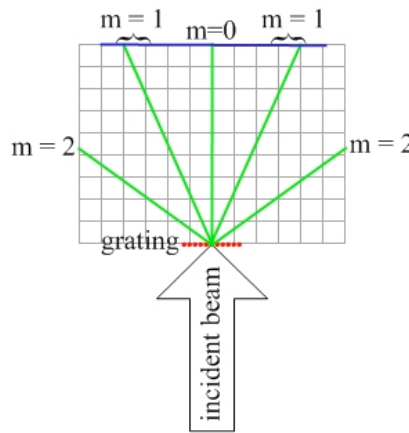


Figure 25.28: The $m = 0$ through $m = 2$ lines that result when green light with a wavelength of 540 nm is incident on a diffraction grating. The horizontal line at the top represents a screen, which is 1.0 m long. The squares on the grid measure $10\text{ cm} \times 10\text{ cm}$. For Exercise 7.

8. Two speakers send out identical single-frequency sound waves, in phase, that have a wavelength of 0.80 m . As shown in Figure 25.29, the speakers are separated by 3.6 m . Three lines, labeled A through C, are also shown in the figure. Line A is part of the perpendicular bisector of the line connecting the two sources. If you were to walk along these lines, would you observe completely constructive interference, completely destructive interference, or something else? Answer this question for (a) line A, (b) line B, and (c) line C. Briefly justify each of your answers.

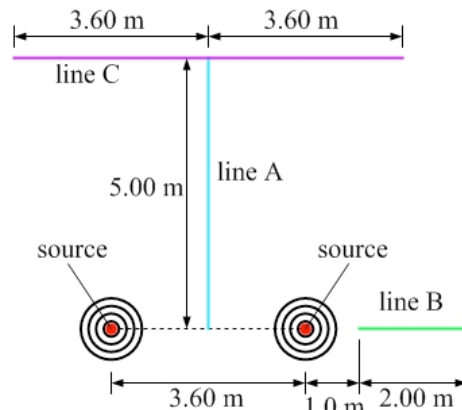


Figure 25.29: Three lines located near two speakers (each labeled “source”) that are broadcasting identical single-frequency sounds, for Exercise 8.

9. Figure 25.30 shows, at the top, the pattern resulting from light with a wavelength of 480 nm passing through only one slit of a double slit. In the middle of the figure is the pattern that would result if both slits were illuminated and the slits sent out light uniformly in all directions. At the bottom of the figure is the actual pattern observed when the light illuminates both slits. What is the ratio of the distance between the slits to the width of one of the slits?

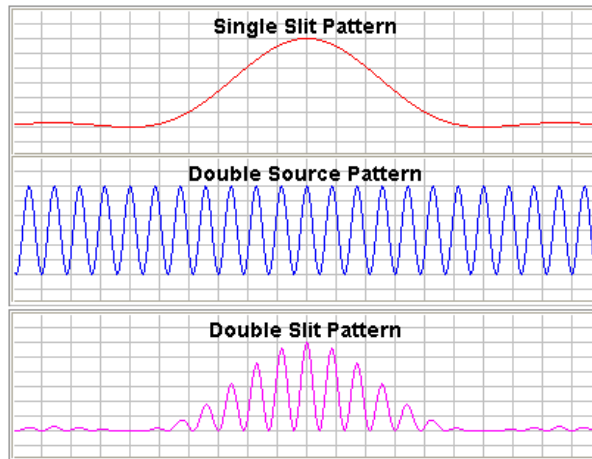


Figure 25.30: The pattern on a screen that results from 480 nm light illuminating a double slit is shown at the bottom. This pattern is a combination of the single slit pattern (top) and double source pattern (middle). For Exercise 9.

10. Figure 25.31 shows four situations in which light is incident perpendicularly on a thin film (the middle layer in each case). The indices of refraction are $n_1 = 1.50$ and $n_2 = 2.00$. In the limit that the thickness of the thin film approaches zero, determine whether the light that reflects from the top and bottom surfaces of the film interferes constructively or destructively in (a) case A, (b) case B, (c) case C, and (d) case D.

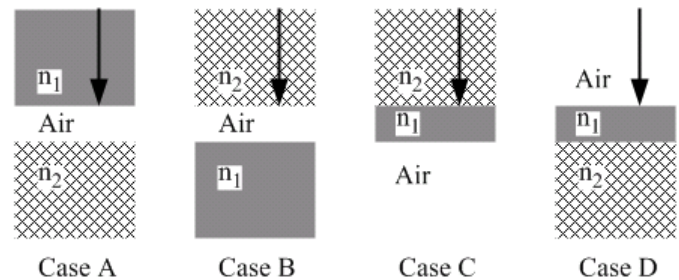
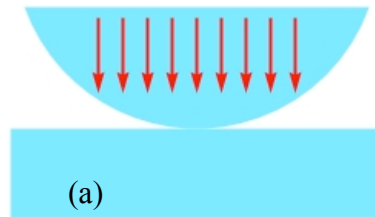


Figure 25.31: Four thin-film situations involving different arrangements of the same three media, for Exercise 10.

11. A soap film, surrounded by air, is held vertically so that, from top to bottom, its thickness varies from a few nm to a few hundred nm. The film is illuminated by white light. Which is closer to the top of the film, the location of the first band of red light, produced by completely constructive thin-film interference, or the first band of blue light? Explain.



12. Figure 25.32 illustrates a phenomenon known as Newton's rings, in which a bull's-eye pattern is created by thin-film interference. The film in this case is a thin film of air that is between a piece of glass with a spherical surface (such as a watch glass) that is placed on top of a flat piece of glass. Two possible patterns, one with a dark center and one with a bright center, are shown in the figure. (a) Which pattern would you see when you look down on the rings from above, and which would you see when you look up at them from below? Explain.

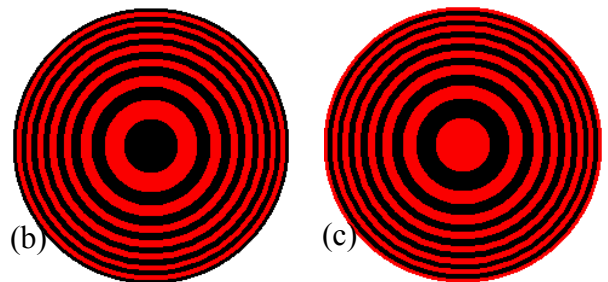


Figure 25.32: The phenomenon of Newton's rings comes from light shining through an object with a spherical surface that rests on a flat surface (a). Interference between light reflecting from the top surface of the film (between the spherical surface and the flat surface) and light reflecting from the bottom surface produces a bull's-eye pattern. Two possible patterns are shown in (b) and (c). For Exercise 12.

Exercises 13 – 15 deal with the interference from two sources.

13. Two speakers broadcasting identical single-frequency sound waves, in phase with one another, are placed 4.8 m apart. The speed of sound is 340 m/s. You are located at a point that is 10.0 m from one speaker, and 8.4 m from the other speaker. What is the lowest frequency for which you observe (a) completely constructive interference? (b) completely destructive interference?
14. Two speakers broadcasting identical single-frequency sound waves, in phase with one another, are placed 6.5 m apart. The wavelength of the sound waves is 3.0 m. You stand directly in front of the speaker on the left (along the dashed line in Figure 25.33), at a distance of 4.5 m from it. Your friend then changes the wavelength of the identical waves being emitted by the speakers. What are the two largest wavelengths that, at your location, result in (a) completely constructive interference, and (b) completely destructive interference?
15. Two speakers broadcasting identical single-frequency sound waves, in phase with one another, are placed 6.5 m apart. The wavelength of the sound waves is 3.0 m. You stand directly in front of the speaker on the left (along the dashed line in Figure 25.33), but some distance from it. How far are you from that speaker if the interference at your location is (a) completely constructive? (b) completely destructive? Find all the possible answers in each case.

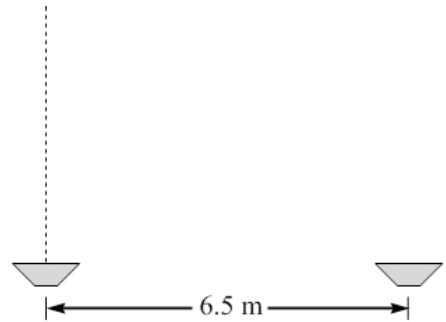


Figure 25.33: Two speakers broadcasting identical single-frequency waves, for Exercises 14 and 15.

Exercises 16 – 18 involve double slits and diffraction gratings.

16. When the beam of a red laser is incident on a particular diffraction grating, the $m = 1$ bright fringe is observed at an angle of 28.0° . At what angle is the (b) $m = 2$ bright fringe, and (c) the $m = 3$ bright fringe?
17. Light with a wavelength of 540 nm shines on two narrow slits that are $4.40 \mu\text{m}$ apart. At what angle does the fifth dark spot occur on a screen on the far side of the slits from the light source?
18. Laser light shines onto a diffraction grating, creating the pattern of bright lines shown in Figure 25.34. The lines strike a screen (in blue in the figure) that is a distance L away from the grating, creating some bright spots on the screen. The distance between the central spot and the m th bright spot to either side is denoted y_m . (a) What is the relationship between θ_m (the angle between the m th bright line and the $m = 0$ line) and y_m ? (b) Show that, in the limit that θ_m is small, y_m is given by $y_m = \frac{m\lambda L}{d}$.

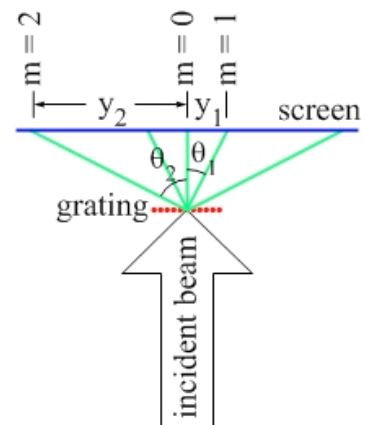


Figure 25.34: Single-frequency light shining on a double slit, for Exercise 18.

Exercises 19 – 23 involve single slits and diffraction by circular openings.

19. Light of a particular wavelength is incident on a single slit that has a width of $2.00\ \mu\text{m}$. If the second zero in the diffraction pattern occurs at an angle of 30° , what is the wavelength of the light?
20. The label on a green laser pointer states that the wavelength of the laser is $532\ \text{nm}$. You shine the laser into an aquarium filled with water, with an index of refraction of 1.33 , and onto a single slit (in the water) that has a width of $1.60\ \mu\text{m}$. At what angle is the first zero in the diffraction pattern?
21. Light with a wavelength of $600\ \text{nm}$ shines onto a single slit, and the diffraction pattern is observed on a screen $2.5\ \text{m}$ away from the slit. The distance, on the screen, between the dark spots to either side of the central maximum in the pattern is $25\ \text{mm}$. (a) What is the distance between the same dark spots when the screen is moved so it is only $1.5\ \text{m}$ from the slit? (b) What is the width of the slit?
22. On a dark night, you watch a car drive away from you on a long straight road. If the car's red tail lights are LED's emitting a wavelength of $640\ \text{nm}$, the distance between the lights is $1.50\ \text{m}$, and your pupils are $6\ \text{mm}$ in diameter, what is the maximum distance the car can get away from you before the two individual lights look like one light to you?
23. A spy satellite takes in light through a circular opening $2.0\ \text{m}$ in diameter. (a) If the wavelength of the light is $540\ \text{nm}$, and the satellite is $250\ \text{km}$ above the ground, how close together can two small objects be on the ground for the satellite to be able to resolve them? (b) If the pupils in your eyes are $4.0\ \text{mm}$ in diameter, how far above the ground would you be to achieve the same resolution as the satellite?

Exercises 24 – 28 are designed to give you practice with applying the five-step method for thin-film interference. For each of these problems, carry out the following steps. (a) Determine Δ_t , the shift for the wave reflecting from the top surface of the film. (b) Determine Δ_b , the shift for the wave reflecting from the bottom surface of the film. (c) Determine Δ , the effective path-length difference. (d) Bring in the interference condition appropriate to the situation. (e) Solve the resulting equation to solve the problem.

24. When you shine red light, with a wavelength of $640\ \text{nm}$, straight down through air onto a thin film of oil that coats a water surface, the film looks dark because of destructive interference. The index of refraction of the oil is 1.60 , while that of water is 1.33 . The goal of the problem is to determine the smallest non-zero film thickness. Carry out the five-step method as outlined above.
25. A ring is dipped into a soap solution, resulting in a circular soap film in the ring. When the plane of the ring is horizontal, the film looks green to you when you look straight down onto the film from above. The soap film is surrounded on both sides by air, and the index of refraction of the film is that of water, 1.33 . If the film thickness is such that it produces completely constructive interference for green light with a wavelength, in vacuum, of $532\ \text{nm}$, what is the minimum non-zero thickness of the film? Carry out the five-step method, as outlined above, to solve the problem.

26. A thin film of glass, with an index of refraction of 1.5, is used to coat diamond, which has an index of refraction of 2.4. The thickness of the thin film is 200 nm. Light, traveling through air, shines down along the normal to the film, as shown in Figure 25.35. If we define the visible spectrum as extending from 400 nm to 700 nm (measured in air), for which wavelength in the visible spectrum (measured in air) does the film produce completely constructive interference? Carry out the five-step method, as outlined above, to solve the problem.

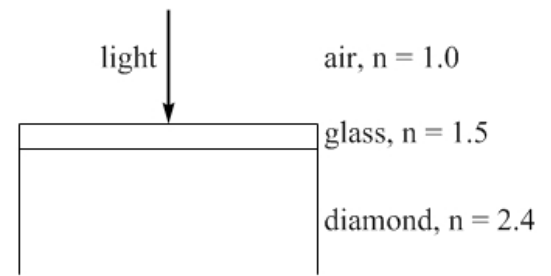


Figure 25.35: A 200-nm-thick film of glass is placed on top of diamond. For Exercises 26 and 27.

27. Return to the situation shown in Figure 25.35 and described in Exercise 26. Now determine for which wavelength in the visible spectrum (measured in air) the film produces completely destructive interference. Carry out the five-step method, as outlined above, to solve the problem.
28. A thin film with an index of refraction of 1.70 is used as a non-reflective coating on a glass lens that has an index of refraction of 1.50. What are the three smallest non-zero thicknesses of the film that will produce completely destructive interference for light that has a wavelength of 510 nm in vacuum? Assume the light is traveling in air before encountering the film, and that it strikes the film at normal incidence. Carry out the five-step method, as outlined above, to solve the problem.

Exercises 29 – 33 involve practical applications of the interference of light.

29. Understanding a particular spectrum is important in many areas of science, including physics and chemistry, where it can be used to identify a gas, for instance. To create a spectrum, light is generally sent through a diffraction grating, splitting the light into the various wavelengths that make it up. (a) The first step in the process is to calibrate the grating, so we know the grating spacing. Sodium has two yellow lines that are very close together in wavelength at 590 nm. When light from a sodium source is passed through a particular diffraction grating, the two yellow lines overlap, looking like one line at an angle of 33.7° in the first-order spectrum. What is the grating spacing? (b) The hydrogen atom is the simplest atom there is, consisting of one electron and one proton, and it has thus been well studied. When hydrogen gas is excited by means of a high voltage, three of the prominent lines in the spectrum are found at wavelengths of 658 nm, 487 nm, and 435 nm. When the light is passed through the diffraction grating we calibrated with sodium, at what angles will these three lines appear in the first-order spectrum? Scientists observing these lines can be confident that the source of the light contains hydrogen.
30. Return to the situation described in Exercise 29. Another application of spectra produced by a diffraction grating is in astrophysics, where the Doppler shift of a particular galaxy can be measured to determine the velocity of the galaxy with respect to us. (a) If the red hydrogen line in the galaxy's spectrum is observed at 690 nm instead of 658 nm, is the galaxy moving toward us or away from us? (b) Recalling that the Doppler equation for electromagnetic waves states that the magnitude of the shift in frequency associated with relative motion between a source and observer is $|f' - f| = vf/c$, determine v , the relative speed of the galaxy with respect to us.

31. Thin coatings are often applied to materials to protect them. In a particular manufacturing process, a company wants to deposit a 200-nm-thick coating onto glass mirrors to protect the mirrors during shipping. The coating material has an index of refraction of 1.30, while that of the glass is 1.53. White light in air is incident on the film along the normal to the surface, and the film looks the color of the wavelength that is experiencing completely constructive interference. If the technician observing the coating as it is being deposited, and gradually increasing in thickness, views the light reflecting from the coating, at which of the following points should the technician stop the deposition process? When the reflected light is violet (400 nm), green (520 nm), orange-red (612 nm), or none of these? Explain.

32. As shown in Figure 25.36(a), two flat pieces of glass are touching at their left edges, and are separated at their right edges by a cylindrical wire. This apparatus can be used to determine the diameter of the wire. When the apparatus is illuminated from above with yellow light with a wavelength of 590 nm, you see the thin-film interference pattern shown in Figure 25.36(b) when you look down on the apparatus from above. Note that the third dark fringe from the left is exactly halfway between the left and right edges of the pieces of glass. At the point where the third dark film from the left appears, (a) how many wavelengths thick is the film, and (b) how thick is the film? (c) How is the diameter of the wire related to the answer to part (b)? (d) What is the diameter of the wire?

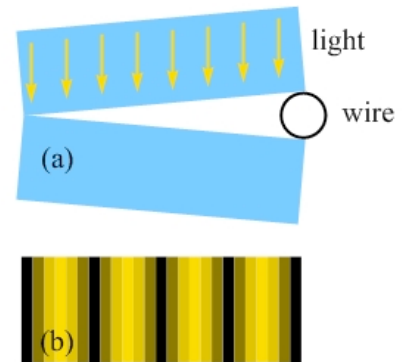


Figure 25.36: (a) A thin film of air is trapped between two flat pieces of glass. The pieces of glass are in contact at their left edges, and are separated at their right edges by a thin wire. (b) The interference pattern you observe when you look down on the film from above, when the film is illuminated from above with 590-nm light, for Exercise 32.

33. In a compact disk (CD) player, to read the information on a CD an infrared laser, with a wavelength of 780 nm in air, reflects from flat-topped bumps and the flat surroundings (known as the land) on the CD. When the laser beam reflects solely from the top of a bump, or solely from the land, a significant signal is reflected back. However, when the beam is moving from a bump to the land, or vice versa, destructive interference between the two parts of the beam, one part which travels a shorter distance than the other, results in a low signal. Thus, music can be encoded as a binary (two-state) signal. What is the height of the bumps on a CD, if the transparent polycarbonate coating on the CD has an index of refraction of 1.55? The bump height is designed to be the smallest needed to produce completely destructive interference between waves reflecting from the bumps and waves reflecting from the land.

General problems and conceptual questions

34. Christiaan Huygens made a number of important contributions to our understanding of the wave nature of light. Do some research about him and his contributions, and write a couple of paragraphs about what you find.

35. The graph in Figure 25.37 shows $\sin\theta$ as a function of wavelength for different orders of light. Let's say that the red line corresponds to the first-order ($m = 1$) spectrum. At what angle is (a) the third-order spot for 500 nm light? (b) the fourth-order spot for 400 nm light?
36. The graph in Figure 25.37 shows $\sin\theta$ as a function of wavelength for different orders of light. What is the grating spacing if the red line corresponds to (a) the first-order ($m = 1$) spectrum? (b) the fifth-order ($m = 5$) spectrum?

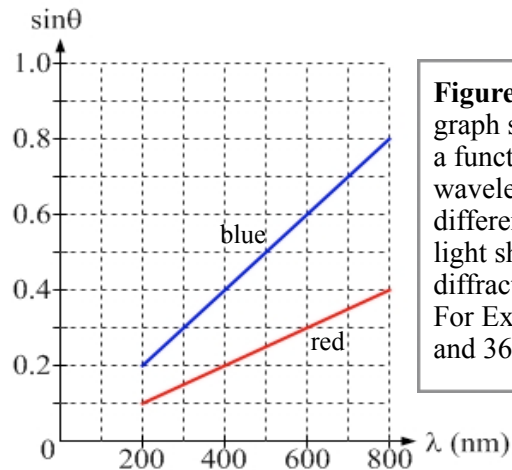


Figure 25.37: The graph shows $\sin\theta$ as a function of wavelength for different orders of light shining on a diffraction grating. For Exercises 35 and 36.

37. A laser with a wavelength of 600 nm is incident on a pair of narrow slits that are separated by a distance of $d = 3.00 \times 10^{-5}$ m. The resulting interference pattern is projected onto a screen 2.00 m from the slits. (a) How far is one of the first-order bright spots from the central bright spot on the screen (measuring from the center of each spot)? Note that for small angles $\sin\theta \approx \tan\theta$. (b) Does the answer change if the entire apparatus is immersed in water, which has an index of refraction of $4/3$? If so, how does it change?

38. Figure 25.38 shows the $m = 0$ through $m = 2$ lines that result when green light with a wavelength of 540 nm is incident on a diffraction grating. Also shown, as dashed lines, are the two $m = 1$ lines for a second wavelength. The squares on the grid in the figure measure $10 \text{ cm} \times 10 \text{ cm}$. (a) What is the second wavelength? (b) What is the grating spacing? (c) Will there be $m = 3$ lines for either the green light or the second wavelength in this situation? Explain.

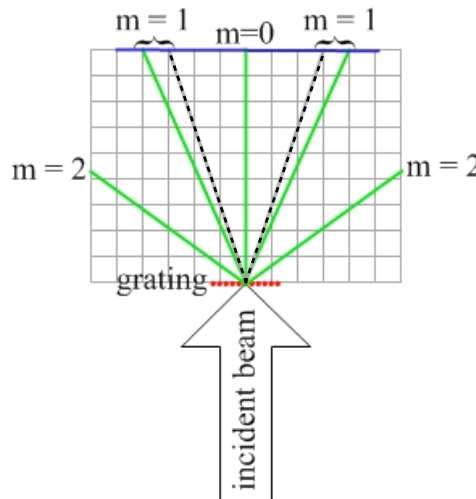


Figure 25.38: The $m = 0$ through $m = 2$ lines that result when green light with a wavelength of 540 nm is incident on a diffraction grating. The two $m = 1$ lines (dashed lines) are for a second wavelength. The horizontal line at the top represents a screen, which is 1.0 m long. The squares on the grid measure $10 \text{ cm} \times 10 \text{ cm}$. For Exercise 38.

39. Light with a wavelength of 400 nm shines onto a double slit. A particular point on the far side of the double slit from the light source happens to be exactly 6 wavelengths farther from one slit than the other. (a) At this particular point, do we expect to see constructive interference or destructive interference? (b) For which wavelengths in the visible spectrum (400 – 700 nm) will the interference be completely constructive at the point? (c) For which wavelengths in the visible spectrum will the interference be completely destructive at the point?

40. Figure 25.39 shows the $m = 0$ and $m = 1$ lines coming from a red laser beam, with a wavelength of 632 nm, that shines on a diffraction grating. The squares in the grid measure $10\text{ cm} \times 10\text{ cm}$. Duplicate the figure, and show all the lines resulting from 450 nm blue light shining on the same grating.

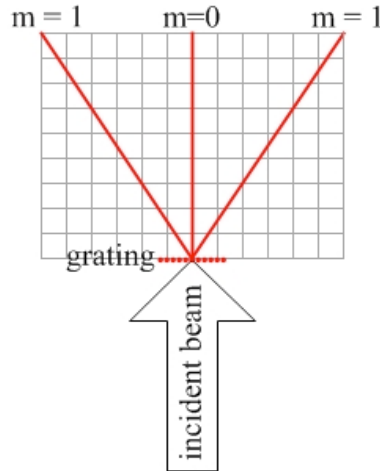


Figure 25.39: The $m = 0$ and $m = 1$ lines that result when red light with a wavelength of 632 nm is incident on a diffraction grating. The squares on the grid measure $10\text{ cm} \times 10\text{ cm}$. For Exercises 40 and 41.

41. Return to the situation described in Exercise 40, and shown in Figure 25.39. (a) Determine the grating spacing. (b) For what range of grating spacings would there be three, and only three, orders to either side of the central maximum with 632 nm red light?

42. A red laser, shining on a double slit, creates the pattern shown in Figure 25.40 at the center of a screen placed 2.00 m on the opposite side of the double slit from the laser. If the laser wavelength is 632 nm, what is the distance between the two slits in the double slit?

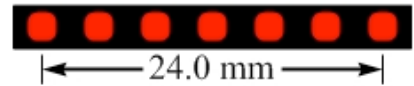


Figure 25.40: The pattern of dots created on a screen a distance 2.00 m from a double slit, when a red laser shines on the slits. For Exercises 42 and 43.

43. Return to the situation described in Exercise 42, and shown in Figure 25.40. When the red laser is replaced by a second laser, exactly 5 dots are observed within a distance of 24.0 mm at the center of the screen, instead of having exactly 7 dots in that distance, as in Figure 25.33. What is the wavelength of the second laser?

44. Laser light with a wavelength of 632 nm is incident on a pair of identical slits that are $5.60\ \mu\text{m}$ apart. (a) If the slits are very narrow, how many bright fringes would you expect to see on one side of the central maximum? (b) In the pattern on a screen, you notice that, instead of a bright fringe where you expect the fourth bright fringe to be, there is a dark spot. The first three bright fringes are where you expect them to be, however. What is the width of each slit? (c) Are there any other fringes missing, in addition to the fourth one on each side?

45. Repeat Exercise 44, but, this time, use a wavelength of 440 nm.

46. Red light, with a wavelength of 650 nm, is incident on a double slit. The resulting pattern on the screen 1.2 m behind the double slit is shown in Figure 25.41. If the slits are $2.40\ \mu\text{m}$ apart, what is the width of each of the slits?



Figure 25.41: The pattern on a screen resulting from red light illuminating a double slit. For Exercise 46.

47. Light with a wavelength of 440 nm illuminates a double slit. When you shine a second beam of light on the double slit, you notice that the 4th-order bright spot for that light occurs at the same angle as the 5th-order bright spot for the 440 nm light. (a) What is the wavelength of the second beam? (b) If the angle of these beams is 40.0° , what is the distance between the two slits in the double slit?

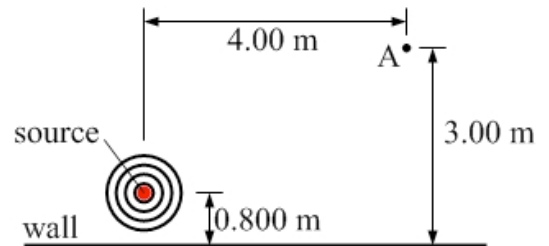
48. When light from a red laser, with a wavelength of 632 nm, is incident on a diffraction grating, the second-order maximum occurs at an angle of 15.4° . (a) What is d , the grating spacing for the diffraction grating? (b) At what angle is the second-order maximum if the red laser is replaced by a green laser with a wavelength of 532 nm?

49. Figure 25.42 shows the pattern at the center of a screen, produced by a red laser beam shining on either a single slit, a double slit, or a diffraction grating. If the laser has a wavelength of 632 nm, and the screen is 1.4 m away, determine the width of the single slit (if the laser shines on a single slit) or the distance between the slits in the double slit (if the laser shines on a double slit) or the grating spacing (if the laser shines on a diffraction grating).



Figure 25.42: The pattern at the center of a screen, produced by a red laser beam shining on a single slit, a double slit, or a diffraction grating. The distance between neighboring tick marks, shown on the screen below the pattern, is 8.00 mm. For Exercise 49.

50. Figure 25.43 shows a source of sound that is located 0.800 m from a wall. The source is emitting waves of a single frequency. Point A is located some distance from the source, as shown. If the speed of sound in air is 340 m/s, find the three lowest frequencies that produce, at A, (a) completely constructive interference, and (b) completely destructive interference.



51. Return to the situation described in Exercise 50, and shown in Figure 25.43. If the source is emitting the lowest frequency sound wave to produce completely destructive interference at point A, what is the minimum distance the source can be moved, directly toward the wall, so the interference becomes completely constructive at A? It is acceptable to answer this by approximating that A is a long way from the source.

Figure 25.43: A source of single-frequency waves is located 0.800 m from a wall, for Exercises 50 and 51.

52. Two speakers send out identical single-frequency sound waves, in phase, that have a wavelength of 0.80 m. As shown in Figure 25.44, the speakers are separated by 3.6 m. Three lines, labeled A through C, are also shown in the figure. Line A is part of the perpendicular bisector of the line connecting the two sources. (a) How many points are there along line C at which the interference between the waves from the two speakers is completely destructive? (b) Relative to the midpoint of line C, approximately where are the points of destructive interference?

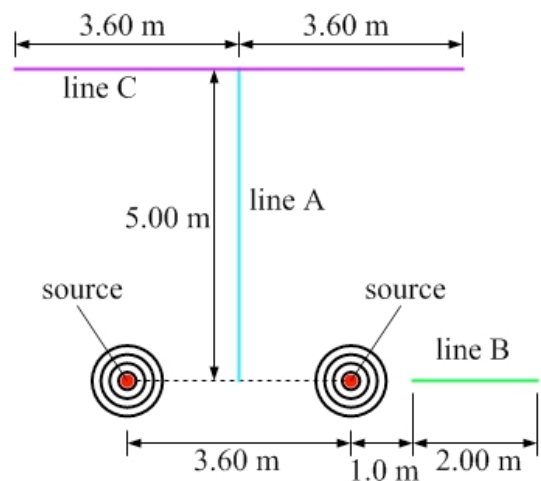
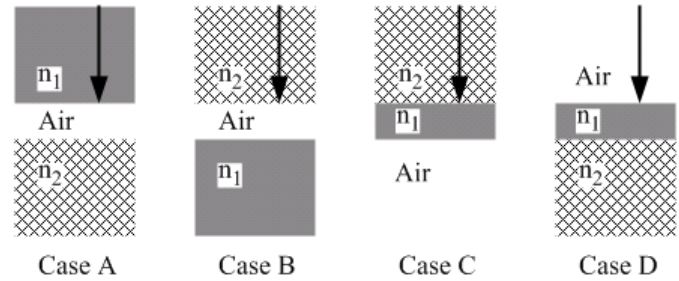


Figure 25.44: Three lines located near two speakers (each labeled “source”) that are broadcasting identical single-frequency sounds, for Exercise 52.

53. Figure 25.45 shows four situations in which light is incident perpendicularly on a thin film (the middle layer in each case). The indices of refraction are $n_1 = 1.50$ and $n_2 = 2.00$. (a)



- Determine the minimum non-zero thickness of the film that results in constructive interference for 450 nm light (measured in vacuum) that reflects from the top and bottom surfaces of the film in case C. (b) Does this film thickness also produce constructive interference for 450 nm light in any of the other cases? Explain why or why not.

Figure 25.45: Four thin-film situations involving different arrangements of the same three media, for Exercise 53.

54. A thin piece of glass with an index of refraction of $n_2 = 1.50$ is placed on top of a medium that has an index of refraction $n_3 = 2.00$, as shown in Figure 25.46. A beam of light traveling in air ($n_1 = 1.00$) shines perpendicularly down on the glass. The beam contains light of only two colors, blue light with a wavelength in air of 450 nm and orange light with a wavelength in air of 600 nm. What is the minimum non-zero thickness of the glass that gives completely constructive interference for (a) the blue light reflecting from the film? (b) BOTH the blue and orange light simultaneously?

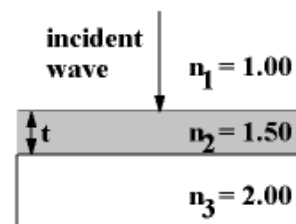


Figure 25.46: A thin film of glass on top of a medium that has an index of refraction of $n_3 = 2.00$. For Exercise 54.

55. Light traveling in air is incident along the normal to a thin film of unknown material that sits on a thick piece of glass ($n = 1.50$). The index of refraction of a typical medium is in the range 1.0 – 2.4. Confining ourselves to this range, what is the index of refraction of the unknown material if the film is 120 nm thick, and it produces completely destructive interference for light, in air, with a wavelength of 540 nm? Find all the possible answers.
56. Sound waves traveling in air encounter a mesh screen. Some of the waves reflect from the screen, while the rest pass through and reflect from a wall that is 30.0 cm behind the mesh screen. You observe completely destructive interference between the two reflected waves when the frequency of the sound waves is 275 Hz. (a) Do the sound waves experience an inversion when they reflect from the mesh screen and from the wall? Explain. (b) What is the speed of sound in this situation?
57. Return to the situation described in Exercise 56. What are the next two frequencies, above 275 Hz, that will also produce completely destructive interference?
58. It is somewhat ironic that the phenomenon of Newton's rings (see Exercises 12 and 59), which provide evidence for the wave behavior of light, are named after Newton, because Sir Isaac Newton was a firm believer in the particle model of light. Do some research on Newton's contributions to optics, and write a couple of paragraphs about it.
59. Figure 25.47 illustrates a phenomenon known as Newton's rings, in which a bull's-eye pattern is created by thin-film interference. The film in this case is a thin film of air that is between a piece of glass with a spherical surface (such as a watch glass) that is placed on top of a flat piece of glass. The spherical surface of the top piece of glass has a radius of curvature of 500 cm. (a) How many wavelengths of 500 nm light (measured in air) fit in the film of air at a point 1.00 cm from the point where the top piece of glass makes

contact with the bottom piece? (b) Would you expect constructive or destructive interference to occur at this point? (c) Would your answers change if the air was replaced with a fluid with an index of refraction of 1.25? If so, how? Assume that the two pieces of glass have indices of refraction of about 1.5.

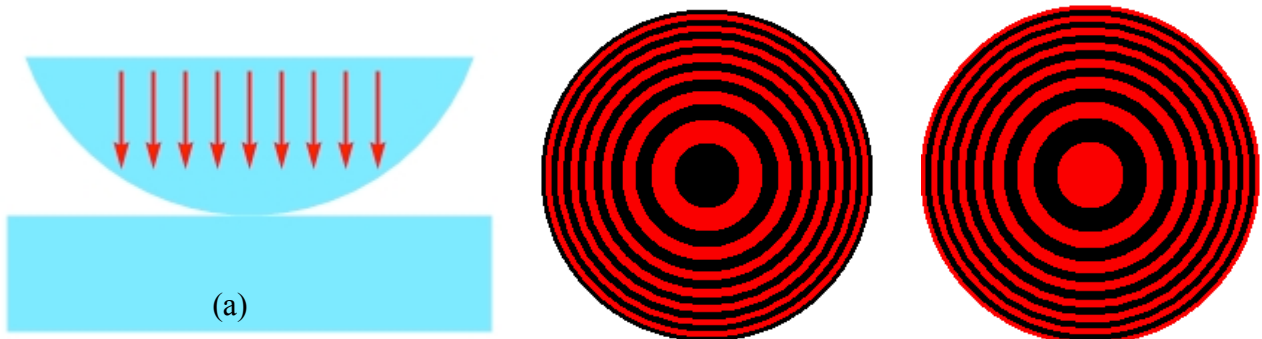


Figure 25.47: The phenomenon of Newton's rings comes from light shining through an object with a spherical surface that rests on a flat surface. Interference between light reflecting from the top surface of the film (between the spherical surface and the flat surface) and light reflecting from the bottom surface produces a bull's-eye shaped pattern. For Exercise 59.

60. A particular metal ruler has thin lines on it every half millimeter. As shown in Figure 25.48, laser light is incident on the ruler at an angle of $\alpha = 4.00^\circ$ with respect to the ruler. (a) For the situation shown in the figure, find the relationship between the wavelength of the incident light and the angles (β values) at which constructive interference occurs. Use d to represent the spacing between the lines on the ruler. (b) If the first-order maximum occurs at an angle of $\beta = 4.93^\circ$, what is the wavelength of the laser light?

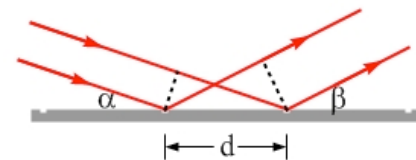


Figure 25.48: Laser light is incident on a metal ruler. The light is incident at an angle of 4.00° , measured from the ruler. After interacting with the ruler, the rays of light leaving the ruler interfere constructively with one another when the rays make an angle β with the ruler surface. The dashed lines on the left and right are perpendicular to the incoming and outgoing rays, respectively. For Exercise 60.

61. Three students are working together on a problem involving thin-film interference. Comment on the part of their conversation that is reported below.

Evan: Do you know the equation for constructive interference in a thin-film situation?

Alison: There isn't one equation that works all the time – it depends on how the different indices of refraction compare.

Christian: Here's one, though, $2t$ equals m plus a half wavelengths. That's what we worked out in class when we did the soap film.

Evan: Isn't m plus a half for destructive interference?

Christian: Usually, it is, but with thin films you always get one of the waves flipping upside down when it reflects, which is like shifting it half a wavelength.