Understanding Concepts

1. List the successes and failures of the particle and wave models in accounting for the behaviour of light as follows:
   (a) Name four optical phenomena adequately accounted for by both models.
   (b) Name four phenomena not adequately accounted for by the particle model.
   (c) Name one phenomenon not adequately accounted for by the wave model.
2. If the index of refraction of silicate flint glass is 1.60, what is the wavelength of violet light in the glass, if its wavelength in air is 415 nm?
3. Sound and light are waves, yet we can hear sounds around corners but we cannot see around corners. Explain why.
4. In a ripple tank, one complete wave is sent out every 0.10 s. The wave is stopped with a stroboscope, and it is found that the separation between the first and sixth crests is 12 cm. Calculate (a) the wavelength and (b) the speed of the wave.
5. An interference pattern is set up by two point sources which are in phase and of the same frequency. A point on the second nodal line is 25.0 cm from one source and 29.5 cm from the other source. The speed of the waves is 7.5 cm/s. Calculate (a) the wavelength and (b) the frequency of the sources.
6. In Young's time, why was the observation of double-slit interference more convincing evidence for the wave theory of light than the observation of diffraction?
7. You are performing Young's experiment and measure a distance of 6.0 cm between the first and seventh nodal points on a screen located 3.00 m from the slit plate. The slit separation is 2.2×10^{-4} m.
   (a) Calculate the wavelength of the light being used.
   (b) Identify the colour of the light.
8. In a Young's double-slit experiment, the angle that locates the second dark fringe on either side of the central bright fringe is 5.2°. Find the ratio of the slit separation d to the wavelength λ of the light.
9. Monochromatic light falling on two slits 0.018 mm apart produces the fifth-order dark fringe at an angle of 8.2°. Calculate the wavelength of the light.
10. The third-order fringe of 638-nm light is observed at an angle of 8.0° when the light falls on two narrow slits. Calculate the distance between the slits.
11. Red light from a helium–neon laser ($\lambda = 633$ nm) is incident on a screen containing two very narrow horizontal slits separated by 0.100 mm. A fringe pattern appears on a screen 2.10 m away. Calculate, in millimetres, the distance of the first dark fringe above and below the central axis.
12. Monochromatic light falls on two very narrow slits 0.042 mm apart. Successive minima on a screen 4.00 m away are 5.5 cm apart near the centre of the pattern. Calculate the wavelength and frequency of the light.
13. A parallel beam of light from a laser, operating at 639 nm, falls on two very narrow slits 0.048 mm apart. The slits produce an interference pattern on a screen 2.80 m away. How far is the first dark fringe from the centre of the pattern?
14. Light of wavelength 656 nm falls on two slits, producing an interference pattern on a screen 1.50 m away. Each of the fourth-order maxima is 48.0 mm from the central bright fringe. Calculate the separation of the two slits.
15. Light of wavelengths 4.80×10^2 nm and 6.20×10^2 nm falls on a pair of horizontal slits 0.68 mm apart, producing an interference pattern on a screen 1.6 m away. How far apart are the second-order maxima?
16. Light of wavelength 4.00×10^2 nm falls on two slits 5.00×10^{-4} m apart. The slits are immersed in water ($n = 1.33$), as is a viewing screen 50.0 cm away. How far apart are the fringes on the screen?
17. When white light passes through a flat piece of window glass, it is not broken down into colours, as it is by a prism. Explain why.
18. Explain why polarization was important in validating the wave theory of light.
19. Explain, with diagrams, how Polaroid sunglasses reduce reflected glare.
20. Light shines through a single slit 5.60×10^{-4} m wide. A diffraction pattern is formed on a screen 3.00 m away. The distance between the middle of the central bright fringe and the first dark fringe is 3.5 mm. Calculate the wavelength of the light.
21. 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) 1.80×10^{-4} m and (b) 1.80×10^{-6} m.

22. Light of wavelength 638 nm falls onto a single slit 4.40×10^{-4} m wide, producing a diffraction pattern onto a screen 1.45 m away. Determine the width of the central fringe.
23. (a) At what angle is the first minimum for 589-nm light falling on a single slit 1.08×10^{-6} m wide?
    (b) Does a second minimum appear? Explain your reasoning.
24. A narrow single slit is illuminated by infrared light from a helium–neon laser at 1.15×10^{-7} m. The centre of the eight dark bands lies at an angle of 8.4° off the central axis. Determine the width of the slit.
25. Light with a wavelength of 451 nm falls onto a slit 0.10 mm wide, casting a diffraction pattern onto a screen 3.50 m away. How wide is the central maximum?
26. A beam of 639-nm light is directed through a single slit 4.2×10^{-4} m wide onto a screen 3.50 m away. How far apart are the maxima?
27. The central bright fringe in a single-slit diffraction pattern has a width that is equal to the distance between the screen and the slit. Find the ratio $\frac{\lambda}{w}$ of the wavelength of the light to the width of the slit.
28. List the advantages of a diffraction grating over a prism in dispersing light for spectral analysis.
29. 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? Explain your answer.
30. The separation between the slits of a grating is 2.2×10^{-6} m. This grating is used with light whose wavelengths range from 412 nm to 661 nm. Rainbow-like spectra form on a screen 3.10 m away. How wide is the first-order spectrum?
31. Monochromatic light, falling onto a 5000-line/cm diffraction grating, produces a second maximum at 35.0°. Determine the wavelength of the light.
32. (a) Show that a 30 000-line/cm grating does not produce a maximum for visible light.
    (b) What is the longest wavelength for which this grating does produce a first-order maximum?
33. Two first-order spectral lines are measured by an 8500-line/cm spectroscope at angles, on each side of centre, of +26.6°, +41.1° and −26.8°, −41.3°. Calculate the wavelengths.
34. Calculate the minimum thickness of an oil slick on water that appears blue when illuminated by white light perpendicular to its surface (**Figure 1**). ($\lambda_{blue} = 482$ nm, $n_{oil} = 1.40$)

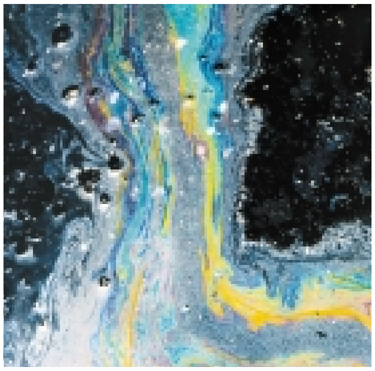

Figure 1
Oil slick on water

35. A nonreflective coating of magnesium fluoride ($n = 1.38$) covers the glass ($n = 1.52$) of a camera lens. If the coating prevents the reflection of yellow–green light ($\lambda = 565$ nm), determine the minimum nonzero thickness of the coating. Explain your calculations with a diagram.
36. A transparent coating ($n = 1.61$) on glass ($n = 1.52$) appears black when viewed in reflected light whose wavelength is 589 nm in vacuum. Calculate the two smallest possible nonzero values for the thickness of the coating.
37. A thin film of ethyl alcohol ($n = 1.36$) is spread on a flat glass plate ($n = 1.52$) and illuminated with white light, producing a colour pattern in reflection. If a region of the film reflects only green light (525 nm) strongly, how thick might it be?
38. A soap bubble is 112 nm thick and illuminated by white light whose angle of incidence is 90° (**Figure 2**). What wavelength and colour of light is most constructively reflected, assuming the same index of refraction as water?

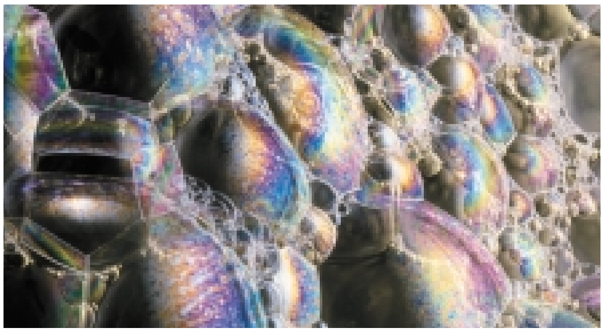

Figure 2
Soap bubbles illuminated by white light

39. A wire loop, dipped into soap solution, is viewed by the reflection of yellow light. At one instant, the appearance of the film is as in **Figure 3**.
  (a) Explain the large dark space at the top of the film.
  (b) As time goes on, what changes will occur in the pattern? Explain your answer.
  (c) Calculate the difference in thickness between adjacent bright bands. Express your answer in wavelengths.
  (d) Taking the wavelength of the yellow light in air to be 588 nm, calculate the thickness of the soap film ($n = 1.33$) in the lowest dark band.

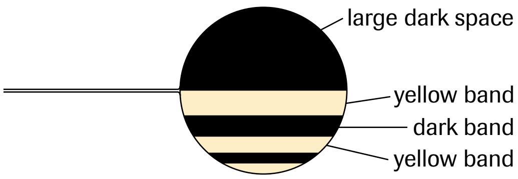

Figure 3

40. A fine metal foil separates one end of two pieces of optically flat glass. When the glass is illuminated, at essentially normal incidence, with 639-nm light, 38 dark lines are observed (with one at each end). Determine the thickness of the foil.

41. You have created a wedge-shaped air film between two sheets of glass, using a piece of paper 7.62×10^{-5} m thick as the spacer. You illuminate the wedge with 539-nm light, at essentially normal incidence. Determine the number of bright fringes you see across the wedge.

42. You form an air wedge with two glass plates, 15.8 cm long. At one end the glass plates are kept firmly together; at the other end the plates are separated by a strip of paper. You illuminate your wedge with light of wavelength 548 nm and observe the interference pattern in the reflected light. The average distance between two dark bands in the pattern is found to be 1.3 mm. Calculate the thickness of the paper strip separating the glass plates.

43. How far must the movable mirror of a Michelson interferometer, illuminated by a 589-nm source, be displaced for 2000 fringes to move past the reference point?

44. Monochromatic light is incident normally on a slit (**Figure 4**). A screen is located far away from the slit. The mirror produces a virtual image of the slit.
  (a) Is the virtual image *coherent* with the slit itself?
  (b) Is the pattern on the screen a double-slit interference pattern or a pair of single-slit diffraction patterns?
  (c) If the pattern is an interference pattern, is the fringe closest to the mirror surface bright or dark? Explain your answer. (This arrangement is known as Lloyd's mirror.)

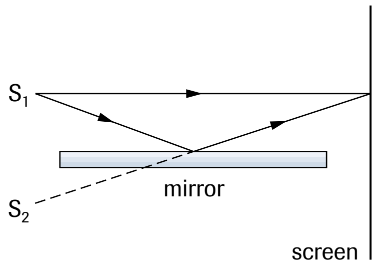

Figure 4

45. Compare radio, infrared, ultraviolet, and X rays under the following headings:
  (a) Nature of Source
  (b) Typical Means of Detection
  (c) Nonionizing or Ionizing

46. You have directed a parallel beam of microwaves at a metal screen with an opening 20.0 cm wide. As you move a microwave detector parallel to the plate, you locate a minimum at 36° from the central axis. Determine the wavelength of the microwaves.

Applying Inquiry Skills

47. Light from a small source in a certain lab passes through a single narrow slit to a distant screen, producing a diffraction pattern. **Figure 5(a)** is a graph of the intensity of light versus position on the screen. A second trial with the same equipment produced **Figure 5(b)**, drawn to the same scale. What change(s) could have produced the result? Explain your answer.

48. You are demonstrating single-slit diffraction using 10.5-GHz microwaves and a metal slit 2.0 cm wide. A screen is 0.50 m away from your microwave transmitter. Predict the numerical values for the quantities B and C in **Figure 6**.

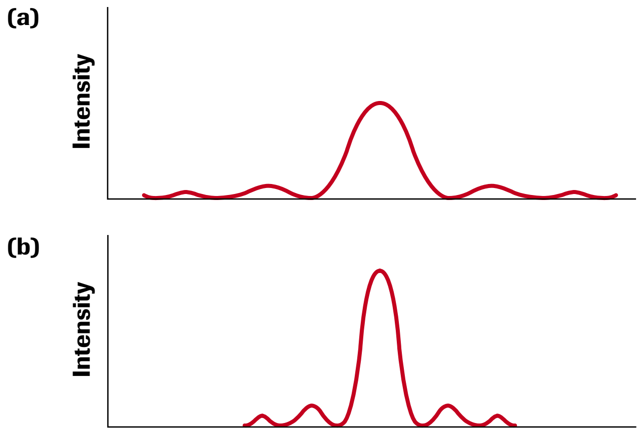

Figure 5
For question 47

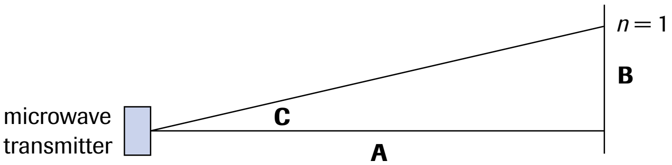

Figure 6
For question 48

Making Connections

49. Your favourite radio station, having broadcast with just one antenna, now adds a second antenna, radiating in phase with its first, at some new location. Are you guaranteed to enjoy better reception? Justify your answer.

50. A radio wave transmitter tower and a receiver tower are both 60.0 m above the ground and 0.50 km apart. The receiver can receive signals both directly from the transmitter and indirectly from signals that bounce off the ground. If the ground is level between the transmitter and receiver and a $\frac{\lambda}{2}$ phase shift occurs on reflection, determine the longest possible wavelengths that interfere (a) constructively and (b) destructively.

51. Ultrasonic waves are used to observe babies as they develop from fetus to birth (**Figure 7**). Frequencies typically range from 3.0×10^4 Hz to 4.5×10^4 Hz.
    (a) What would be the typical wavelengths if these were radio waves?
    (b) Calculate the actual wavelengths, in air, given that they are high-frequency sound waves with a speed of 3.4×10^2 m/s.

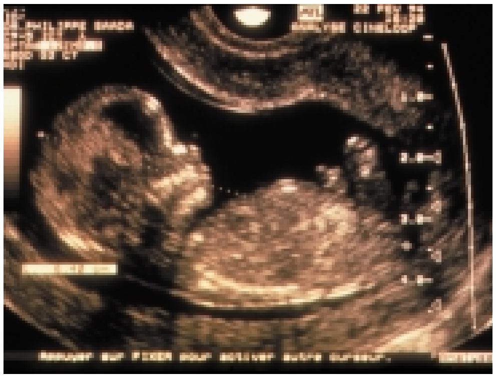

Figure 7

Extension

52. A sonar transmitter produces 14.0-kHz waves in water, creating the intensity pattern in **Figure 8**. The solid lines represent positions over which the intensity of the sound is constant. The intensity pattern is analogous to the effect of a single-slit interference pattern in optics. Taking the speed of sound in the water to be 1.40×10^3 m/s, calculate the width of the vibrating surface of the transmitter.

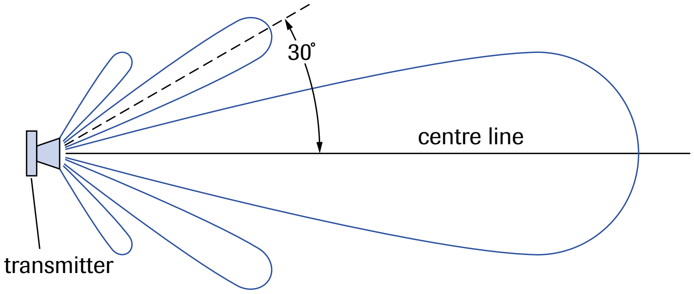

Figure 8

53. Two, and only two, full spectral orders can be seen on either side of the central maximum when white light is sent through a certain diffraction grating. Calculate the maximum possible number of lines per centimetre for this grating.

54. White light reflects normally from a soap film of refractive index 1.33, then falls upon the slit of a spectrograph. The slit illuminates a 500-line/mm diffraction grating with normal incidence. In the first-order spectrum a dark band is observed with minimum intensity at an angle of 18° to the normal. Determine the minimum possible thickness of the soap film.

55. A total of 31 dark Newton's rings (not counting the dark spot at the centre) appear when 589-nm light falls normally on a certain plano-convex lens resting on a flat glass surface. How much thicker is the centre than the edges?