CHAPTER 9 Review

REFLECTING ON CHAPTER 9

- Regular reflection occurs when light reflects from a smooth surface, such as a mirror. Diffuse reflection occurs when light reflects from a rough surface.
- The Doppler effect is the apparent change in the frequency of a sound due to relative motion of the source of sound and the observer.
- When an object is moving faster than the speed of sound in the air through which it is travelling, each new compressional wavefront is ahead of the previous one. The overlapping of wavefronts along a cone creates extremely large compressions that are heard as a "sonic boom."
- Mach number = $\frac{\text{speed of object}}{\text{speed of sound}}$
- Refraction of light, as of other waves, is the change in velocity when light passes from one medium into another.
- The index of refraction of a medium is the ratio of the speed of light in a vacuum to the speed of light in the medium: $n = \frac{c}{v}$. A medium with a high index of refraction is optically dense.
- The angle of refraction is the angle of a light ray exiting from a refractive boundary. For any two given media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant: $\frac{\sin \theta_i}{\sin \theta_R} = \text{constant}$.
- Snell's law relates angles of incidence and refraction to indices of refraction: $n_i \sin \theta_i = n_R \sin \theta_R$. The incident ray, the refracted ray, and the normal all lie in the same plane.
- The principle of reversibility of light states that, if a new ray of light is directed backwards along the path of a refracted ray, it will follow the same path after crossing the boundary between the media.
- Total internal reflection occurs when light in an optically more dense medium strikes the boundary with an optically less dense medium at an angle of incidence greater than the critical angle for the medium.
- Sound does not travel through a vacuum.
- Sound waves are longitudinal waves.
- The speed of sound in air at standard atmospheric pressure (101 kPa) is constant for a given temperature, and given by the equation $v = 331 + 0.59T_C$.
- In general, the speed of sound is slowest in gases, faster in liquids, and fastest in solids.
- When two sounds of similar frequency are sounded at the same time, alternately loud and quiet sounds are produced. This wavering effect is called beats.

  The beat frequency is given by the equation

  $$f_{beat} = |f_2 - f_1|$$
- Music is a sound made up of whole number multiples of a lowest or fundamental frequency. Noise is a sound made up of a multitude of sound frequencies with no recognizable relationship to each other.
- A closed air column (closed at one end) has resonance lengths

  $$L_n = \frac{(2n-1)\lambda}{4}$$
- An open air column (open at both ends) has resonance lengths

  $$L_n = \frac{n\lambda}{2}$$
- A closed air column of fixed length has resonance frequencies

  $$f_n = (2n-1)f_1$$

  where $f_1 = \frac{v}{4L}$.
- An open air column of fixed length has resonance frequencies

  $$f_n = nf_1$$

  where $f_1 = \frac{v}{2L}$.
- Young's double-slit experiment demonstrated that light experiences interference and forms diffraction patterns. The wavelength of a specific colour of light can be approximated by the relationship $\lambda \cong \frac{\Delta y d}{x}$.

Knowledge/Understanding

1. Sketch pairs of sound waves that illustrate the following contrasts in sound.
   (a) pitch (low versus high)
   (b) loudness (quiet versus loud)
   (c) quality (pure versus rich)
2. Sketch a diagram to model the sound waves emanating from an object that is travelling away from you at a speed that is slower than the speed of sound.
3. As the temperature of air increases, what happens to a sound's (a) speed? (b) frequency? (c) wavelength?
4. Does sound travel faster in a gas or in a solid? Explain why you think that this is the case.
5. Some animals use short pulses of high-frequency sound to locate objects. If the echo is received a time interval Δt after the pulse of sound is transmitted, how could you use the Δt and the speed of sound to calculate the distance between the animal and the object?
6. Describe the phenomenon of beats and the conditions necessary to produce them.
7. A trumpet player is tuning the instrument to concert A (440 Hz) being played by the oboe. As the trumpet player moves the tuning slide in, beat frequency increases. Is the trumpet getting closer to, or farther away from, the correct pitch? Explain.
8. How is music different from noise?
9. When a trombone player pushes the slide of the instrument out, the pitch of the sound being produced decreases. Explain why this happens.
10. When a stream of water is used to fill a graduated cylinder, a sound of steadily rising pitch is heard. Explain why this is the case.
11. When a stream of air is directed over the end of a 40 cm long piece of plastic pipe, open at both ends, a sound is produced.
    (a) Explain why this occurs.
    (b) If the bottom end of the pipe is covered, what will happen to the pitch of the sound? Explain.
12. How do the harmonics of a fixed air column closed at one end compare with the harmonics of a fixed air column open at both ends?
13. Define the term index of refraction.
14. An observer looking down at a mug at an angle is not able to see a coin resting on the bottom of the mug. As the mug is filled with water, the coin becomes visible. Explain why.
15. Light travels from medium Y to medium X. The angle of refraction is larger than the angle of incidence. In which medium does the light travel at a lower speed? Explain your logic.
16. When light passes from Plexiglass™ into ice at an angle, which will be smaller, the angle of refraction or the angle of incidence? Explain why.
17. Light travels from medium C to medium D. The angle of incidence is larger than the angle of refraction. Which medium has the lower index of refraction? Explain your logic.
18. How does the size of the critical angle change as the index of refraction decreases?
19. Which pair of media, air and water or air and glass, have the smaller critical angle? Explain why.
20. How did Thomas Young's experiment support the wave model of light?
21. An interference maximum is produced on a screen by two portions of a beam originally from the same source. If the light travelled entirely in air, what can be said about the path difference of the two beams?
22. Why is it important that monochromatic light be used in slit experiments?

Inquiry

23. Design an experiment to test the assumption that sound waves are influenced by the medium through which they travel. Be sure to identify the variables that you would control and those you would test.

24. A student constructs a home-made flute. She collects the data below, which represent different effective lengths and different harmonics, at an air temperature of 22°C. Copy the table and fill in the third column with an appropriate fraction. Should her instrument be considered an open or closed resonator?

Length at which resonance occurs (m)	Frequency of sound	Resonance length as fraction of wavelength
0.39	440 Hz	
0.67	512 Hz	
0.88	584 Hz	

25. Design an investigation to measure the index of refraction of a sample of a salt solution with a known concentration. Devise and describe a procedure that could be used to determine the concentration of a salt solution (or any other kind of solution) with an unknown concentration.

26. Devise a simple experiment to demonstrate the interference between sound waves from two sources.

Communication

27. Typically, thunder is heard a short time after lightning is observed. Describe how this time interval can be used to calculate the distance that the lightning is away. Explain why this strategy yields a reasonable answer. Would you be able to tell if a storm is approaching using this method?

28. Sketch displacement standing wave patterns for the first three resonance lengths of a closed air column.

29. While waiting at a railway crossing, you hear the approaching train sound its horn. Describe the change in frequency of the sound you hear as it approaches and then departs from your position at high speed.

30. High frequency and low frequency sounds behave differently. High frequency sounds diffract (bend) less around obstacles than lower frequency sounds. Describe why this characteristic makes it beneficial to put high frequency sirens on emergency vehicles and low frequency fog horns on boats.

31. Sketch and label a pressure versus time graph to describe how a sonic boom is able to break a window.

32. Carry out research on optical illusions caused by refraction effects. Summarize and present the general categories of illusions, using diagrams and photographs where appropriate, and explain why each type of illusion is produced.

33. Explain whether a beam of light can be made increasingly more narrow by passing it through narrower and narrower slits.

34. A friend who has never taken a physics course asks why light that passes through a double slit produces a series of bright and dark fringes. How would you explain this phenomenon?

35. Discuss how we know that the wavelength of visible light must be very much less than a centimetre.

36. Both sound and light waves diffract on passing through an open doorway. Why does a sound wave diffract much more than a light wave? In other words, why can you hear around corners, but not see around corners?

37. Suppose that, in a double-slit experiment, monochromatic blue light used to illuminate the slits was replaced by monochromatic red light. Discuss whether the fringes would be more closely or more widely spaced.

Making Connections

38. Evaluate the impact of the development of optical fibres in our modern society. In which area of application will optical fibres have the greatest influence in the near future? Summarize your findings in a report.

39. Imagine you are swimming underwater and wearing goggles. As you look up at the air beyond the water surface, what effect can you expect to see? Draw a diagram to illustrate your answer. What implications does this underwater view

of the airspace above the water have for fish? (Hint: Think about the critical angle of water.)

Problems for Understanding

40. Calculate the speed of sound in air for each temperature.
- **(a)** −40.0°C
- **(b)** 5.0°C
- **(c)** 21.0°C
- **(d)** 35.0°C

41. Calculate the temperature of the air if the speed of sound is
- **(a)** 355 m/s
- **(b)** 344 m/s
- **(c)** 333 m/s
- **(d)** 318 m/s

42. A hunter wanted to know the air temperature. The echo from a nearby cliff returned 1.5 s after he fired his rifle. If the cliff is 250 m away, calculate the air temperature.

43. On a crisp fall day, a cottager looks across the lake and sees a neighbour chopping wood. As he watches, he notices that there is a time delay of 2.1 s between the time the axe hits the log and when he hears the sound of its impact. If the air temperature is 8.0°C, how far is he from his neighbour?

44. A guitar player is tuning his guitar to A (440 Hz) on the piano. He hears 14 beats in 4.0 s when he tries to play A on his guitar.
- **(a)** What two frequencies might he be playing?
- **(b)** Explain how he could determine which of the two he was playing.

45. When a violin plays concert A, it produces a sound spectrum with a very intense line at 440 Hz, and less intense lines at 880 Hz, 1320 Hz, 1760 Hz, 2200 Hz, and 2640 Hz.
- **(a)** Explain why this sound would be described as music.
- **(b)** Sketch a possible sound spectrum (intensity against frequency) for noise.

46. A narrow plastic pipe is placed inside a large graduated cylinder almost filled with water. An 880 Hz tuning fork is held over the open end as the pipe is slowly raised out of the water.
- **(a)** Describe what will be heard as the pipe is raised.
- **(b)** Assuming the air temperature to be 22°C, calculate the first four resonance lengths.

47. A slightly smaller-diameter plastic pipe is inserted inside a second plastic pipe to produce an air column, open at both ends, whose length can be varied from 35 cm to 65 cm. A small loudspeaker, connected to an audio frequency generator, is held over one of the open ends. As the length of the air column is increased, resonance is heard first when the air column is 38 cm long and again when it is 57 cm long.
- **(a)** Calculate the wavelength of the sound produced by the audio frequency generator.
- **(b)** Assuming the air temperature to be 18°C, calculate the frequency setting of the audio frequency generator.

48. A neighbour explains that the old well behind his house is 500 m deep. You decide to see for yourself. You drop a stone from rest and measure the time interval until you hear the splash of the stone striking the water. You find it to be 6.0 s. You assume the speed of sound in air to be 343 m/s. How deep is the well?

49. The siren of an emergency vehicle produces a 5500 Hz sound. If the speed of sound is 340 m/s in air, calculate the wavelength of the sound.

50. A jet is travelling at Mach 2.4 in air, with a speed of sound of 320 m/s. How fast is the jet flying in km/h?

51. A vacant city lot sits next to a large building. You hope to convince City Council to turn the lot into a soccer field. First you need to determine how far it is from the edge of the lot to the building. You bark out a loud call and the echo returns in 0.75 s. Calculate the distance to the building if the air temperature is 31°C.

52. Some friends drop a water balloon out of a window 12.0 m above the ground. As it falls, one of the pranksters cries out to warn the person below, 1.5 s after releasing the balloon. If the air temperature is 28.0°C and if the person below is able to move infinitely fast upon hearing the warning, will the person avoid the balloon?

53. A ray of light strikes a mirror at an angle of 55° to the normal.
- **(a)** What is the angle of reflection?
- **(b)** What is the angle between the incident ray and the reflected ray?

54. What is the angle of incidence if the angle between the reflected ray and the mirror surface is 34°?

55. Light is shining on to a plane mirror at an angle of incidence of 27°. If the plane mirror is tilted such that the angle of incidence is reduced by 8°, what will be the total change in the angle of reflection from the original reflected light?

56. Light passes from water into a block of unknown material. If the angle of incidence in the water is 70.0° and the angle of refraction is 40.0°, what is the index of refraction of the unknown material?

57. A ray of light passes from Lucite™ into water at an angle of incidence of 20.0°. What is the angle of refraction in the water?

58. A light ray enters the longest side of a 45°–45° – 90° crown glass retroreflector. Assume that the light ray enters the longest side of the retroreflector at a point one quarter of the length of the side from one corner, at an angle of incidence of 30°. Use Snell's law and the law of reflection to determine the complete path of the light ray until it leaves the retroreflector. Draw an accurate diagram to show the complete path of the light ray. The length of each of the two shorter sides of the retroreflector is 10 cm.

59. Determine the time it takes for light to travel 54 cm through glycerin in an aquarium.

60.
- **(a)** What is the index of refraction in a medium if the angle of incidence in air is 57°, and the angle of refraction is 44°?
- **(b)** What is the angle of refraction if the angle of incidence in air is 27°, and the index of refraction of the medium is 2.42?
- **(c)** What is the angle of incidence in air if the angle of refraction is 28°, and the index of refraction of the medium is 1.33?

61. Light passes from crystal glass into ethyl alcohol. If the angle of refraction is 25°, determine the angle of incidence.

62. The critical angle for a special glass in air is 44°. What is the critical angle if the glass is immersed in water?

63. When astronauts first landed on the Moon, they set up a circular array of retroreflectors on the lunar surface. Scientists on Earth were then able to shoot a laser beam at the array and receive a reflection of the original laser light. By measuring the time interval for the signal's round trip, scientists were able to measure the distance between Earth and the Moon with great accuracy.
- **(a)** If the time interval could be measured to the nearest 3×10^{-10} s, how accurate would the distance measurement be? (Hint: Remember that the signal makes a round trip.)
- **(b)** Suggest two reasons why a laser beam was used for the measurement.

64. Blue light is incident on two slits separated by 1.8×10^{-5} m. A first-order line appears 21.1 mm from the central bright line on a screen, 0.80 m from the slits. What is the wavelength of the blue light?

65. A sodium-vapour lamp illuminates, with monochromatic yellow light, two narrow slits that are 1.00 mm apart. If the viewing screen is 1.00 m from the slits and the distance from the central bright line to the next bright line is 0.589 mm, what is the wavelength of the light?