Periodic Wave Phenomena

By observing two types of mechanical waves, transverse and longitudinal, one can discover some characteristics of waves and the behavior of waves under various conditions. Some of these characteristics and behaviors are discussed below.

Wave Fronts

When water drips from a leaky faucet into a water-filled sink, waves spread, or radiate, in concentric circles along the surface of the water from the point where the drips strike the surface. In a three-dimensional medium such as air, waves radiate in concentric spheres from a vibrating point. All points on a wave that are in phase comprise a wave front. A **wave front** is the locus of all adjacent points on a wave that are in phase. For example, in the waves in the sink, all of the points on one of the crests constitute a wave front. Two successive crests are separated by a distance of one wavelength and, therefore, are in phase.

Doppler Effect

When a source and an observer (receiver) of waves are moving relative to each other, the observed frequency is different from the frequency of the vibrating source. This change in observed or apparent frequency due to relative motion of source and observer is called the **Doppler effect.**

If the source is approaching the observer, or if the observer is approaching the source, the frequency appears to increase. If the source is receding from the observer or the observer is receding from the source, the frequency appears to decrease. Because the speed of the waves in the medium is not affected by the Doppler effect, it can be seen from the formula $v = f\lambda$ that the change in apparent wavelength is inversely proportional to the change in apparent frequency.

The wave front diagrams in Figure 5-8 illustrate the changes in apparent frequency and wavelength caused by the Doppler effect. In Figure 5-8A, the source is stationary, and the four successive wave fronts (1, 2, 3, and 4) are equally spaced circles in all directions. The observed wavelength and frequency are the same for all stationary observers. In Figure 5-8B, the source is moving from right to left. Each successive wave front has a different center. To a stationary observer at the left, the wavelengths appear shorter and the frequency higher; to a stationary observer at the right, the effect is the opposite.

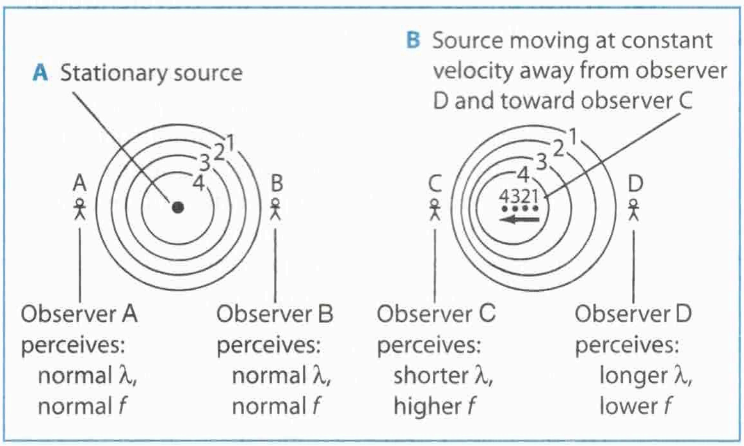


Figure 5-8. The Doppler effect: (A) When the source is stationary, the wave fronts are equally spaced in all directions. (B) When the source is moving, the wave fronts are closer together in the direction in which the source is moving.

The Doppler effect can cause changes in the apparent pitch of a sound wave because the ear perceives a sound wave of higher frequency as a sound of higher pitch. Thus the pitch of an approaching sound source is higher than its pitch when the source is stationary, and the pitch drops lower as the source passes the observer and begins to recede.

Visible light waves are subject to a similar effect. The human eye perceives light waves of different frequencies as differences in color. Light waves of the lowest frequency (longest wavelength) that the eye can detect are seen as red, while those of highest frequency (shortest wavelength) are seen as blue-violet. Other colors are distributed between these extremes in the visible spectrum. Because of the Doppler effect, the apparent color of an approaching light source is shifted toward the blue-violet end of the spectrum, while that of a receding source is shifted toward the red end. If the light source is a mixture of many frequencies, such as the light from a star, its light appears slightly bluer if it is approaching an observer, or slightly redder if it is receding, than it would appear if it were not moving relative to the observer.

Applications of the Doppler Effect The Doppler effect has practical applications in weather forecasting and police work. For example, the speed of a car can be determined by a computerized radar system. If a car is at rest and a beam of radio waves is directed at the car from a stationary source, the incident and reflected waves have the same frequency. If the car is moving toward the source of the radar, however, the reflected waves have a higher frequency than the waves emitted by the source. The greater the car's speed toward the radar source, the greater the Doppler shift in frequency. In a similar way, if the car is moving away from the source of radar, the frequency of the reflected waves decreases by an amount that depends upon the speed of the car. Thus, equipped with a "radar gun," a law-enforcement officer can detect speed-limit violators "coming or going."

Interference

Superposition occurs when two or more waves travel through the same medium simultaneously. The **principle of superposition** states that the resultant displacement at any point is the algebraic sum of the displacements of the individual waves. The effect of the superposition is called **interference,** which may be constructive or destructive. Although any number of waves may superpose, the discussion that follows is restricted to two waves.

Constructive interference occurs when the wave displacements of two in-phase waves in the same medium are in the same direction. The algebraic sum of the displacements is an amplitude greater than that of either of the original waves. Maximum constructive interference occurs when the waves are in phase and crest superposes on crest. Thus, maximum constructive interference occurs when the phase difference is equal to 0°, as shown in Figure 5-9A. The point of maximum displacement of a medium when two waves are interacting is called an **antinode.**

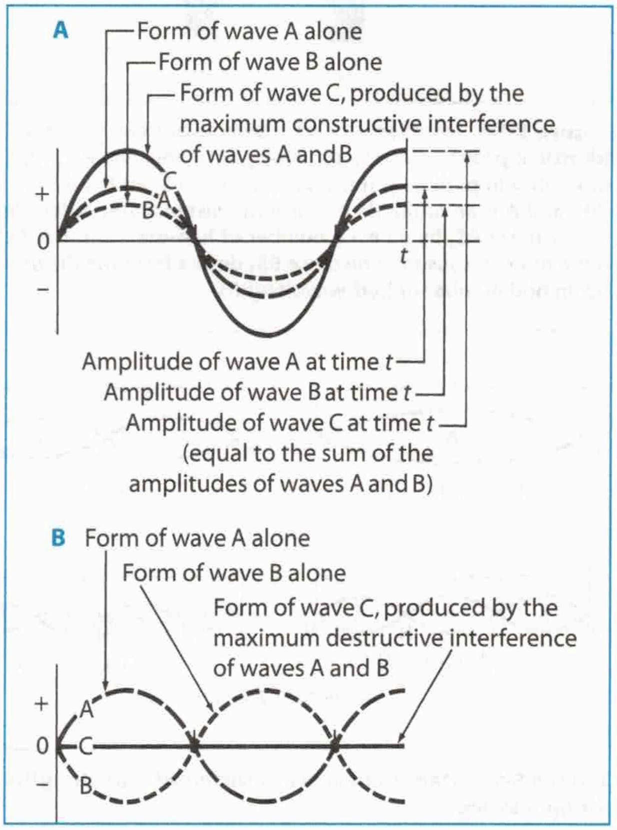


Figure 5-9. Constructive and Destructive Interference: (A) Waves A and B have the same frequency and a phase difference of 0°. As a result, they show maximum constructive interference, producing wave C. Note that the amplitudes of A and B always add up to the amplitude of C at every instant of time. This is demonstrated for the time *t* at the extreme right of the graph. (B) Waves A and B have the same frequency and the same amplitude, but a phase difference of 180°. As a result, they show maximum destructive interference. Notice that waves A and B cancel each other.

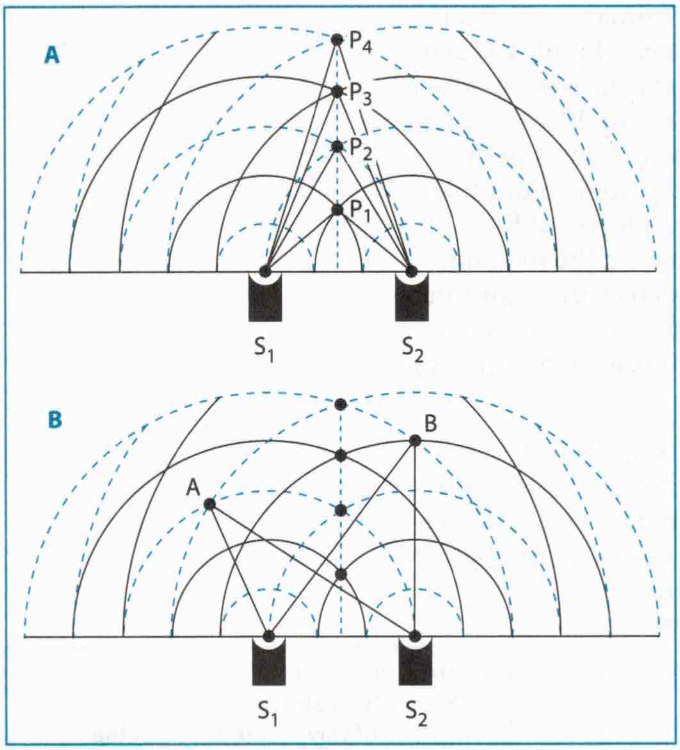


Figure 5-10. Interference of waves produced by two identical point sources: (A) Along antinodal line P_1P_4, the difference in path length from any point to S_1 and S_2 is 0λ. **(B)** Point A is an antinode because the distance AS_1 differs from the distance AS_2 by an even number of half-wavelengths. Point B is a node because the distance BS_1 differs from the distance BS_2 by an odd number of half-wavelengths.

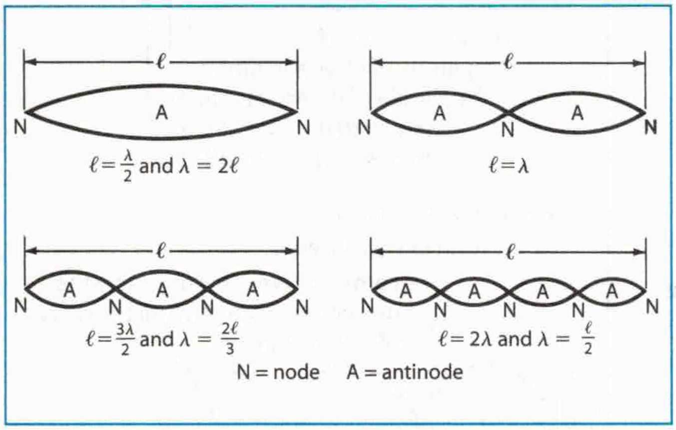


Figure 5-11. Standing waves of different wavelengths along a string

When two waves of equal frequency and amplitude whose phase difference is 180° or $\frac{1}{2}\lambda$ meet at a point (for example, crest to trough), there is maximum **destructive interference,** as shown in Figure 5-9B. Maximum destructive interference results in the formation of **nodes** (points or lines), which are regions of zero displacement of the medium. Intermediate degrees of interference occur between the regions of maximum constructive interference and maximum destructive interference.

Two Sources in Phase in the Same Medium When two in-phase point sources generate waves in the same medium, a symmetrical interference pattern results because of maximum constructive and destructive interference. Figure 5-10A shows two identical point sources, S_1 and S_2, producing wave crests (solid lines) and wave troughs (dashed lines) that interfere. The path difference from any point of constructive interference to the sources, S_1 and S_2, is an even number of half-wavelengths. For example, along antinodal line P_1P_4, the difference in path length from any point on the line to S_1 and S_2 is 0λ. In Figure 5-10B, point A is on an antinodal line because distance AS_1 differs from distance AS_2 by two half-wavelengths. On the other hand, point B is on a nodal line because distance BS_1 differs from distance BS_2 by an odd number of half-wavelengths. Nodal lines occur midway between antinodal lines.

Standing Waves

When two waves having the same amplitude and frequency travel in opposite directions through a uniform medium, a standing wave is formed. A **standing wave** is a pattern of wave crests and troughs that remains stationary in a medium. The nodes and antinodes are stationary and the wave appears to stand still. Standing waves are easily produced in a stretched string that is fixed at both ends. Wave trains traveling along the string are reflected at the ends and travel back with the same frequency and amplitude. Figure 5-11 illustrates several possible standing waves in a string. Note that a node appears at each end of the string. The distance between two successive nodes is equal to $\frac{1}{2}\lambda$.

Resonance

Every elastic body has a particular frequency called its **natural frequency** at which it will vibrate if disturbed. When a periodic force is applied to an elastic body, it absorbs energy and the amplitude of its vibration increases. The vibration of a body at its natural frequency because of the action of a vibrating source of the same frequency is called **resonance.** For example, a nonvibrating tuning fork, having a natural frequency of 512 hertz, will resonate when a vibrating tuning fork with a natural frequency of 512 hertz is brought near it. Furthermore, it is possible for an opera singer to shatter a glass by maintaining a note with a frequency equal to the natural frequency of the glass. The transfer of energy by resonance increases the amplitude of vibrations in the glass until its structural strength is exceeded. Probably the most dramatic example of resonance was the collapse of the Tacoma Narrows Bridge in the state of Washington in 1940. High winds set up standing waves in the bridge in addition to vibrations in a torsional (twisting) mode. Resonance increased the amplitude of vibrations until the bridge collapsed.

Diffraction

The spreading of waves into the region behind a barrier in the wave's path is called **diffraction.** Parallel water wave fronts incident on a small opening are diffracted to form concentric semicircular fronts. These semicircular fronts have the same wavelength as the incident wave if the medium is uniform throughout, as shown in Figure 5-12A. If the opening through which the wave is diffracted is much larger than one wavelength of the incident wave, diffraction effects are small, as shown in Figure 5-12B.

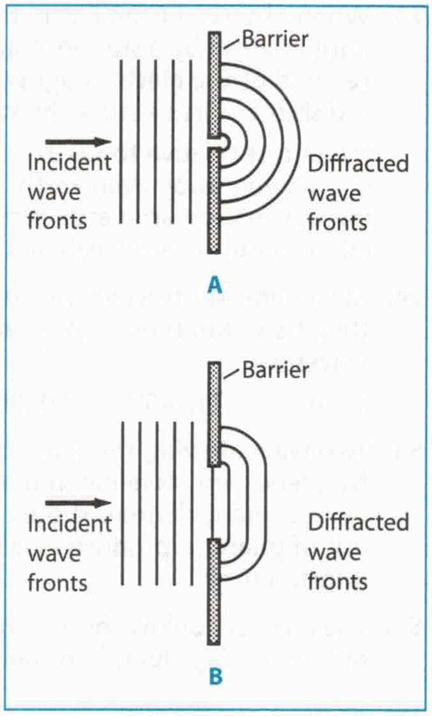


Figure 5-12. Diffraction of parallel wave fronts resulting from different sized openings in a barrier

Review Questions

48. What term describes the variations in the observed frequency of a sound wave when there is relative motion between the source and the receiver?

49. A source of waves and an observer are moving relative to each other. The observer will detect a steadily increasing frequency if

(1) he moves toward the source at a constant speed
(2) the source moves away from him at a constant speed
(3) he accelerates toward the source
(4) the source accelerates away from him

50. The driver of a car hears the siren of an ambulance that is moving away from her. If the actual frequency of the siren is 2000. hertz, the frequency heard by the driver may be

(1) 1900. Hz
(2) 2000. Hz
(3) 2100. Hz
(4) 4000. Hz

51. A police officer's stationary radar device indicates that the frequency of the radar wave reflected from an automobile is less than the frequency emitted by the radar device. This indicates that the automobile is

(1) moving toward the police officer
(2) moving away from the police officer
(3) not moving

52. A stationary person makes observations of the periodic waves produced by a moving source. When the wave source recedes from the observer, he observes an apparent increase in the wave's

(1) speed
(2) frequency
(3) wavelength
(4) amplitude

53. When observed from Earth, the wavelengths of light emitted by a star are shifted toward the red end of the electromagnetic spectrum. This red shift occurs because the star is

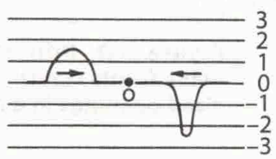
(1) at rest relative to Earth
(2) moving away from Earth
(3) moving toward Earth at decreasing speed
(4) moving toward Earth at increasing speed

54. Maximum constructive interference occurs when the phase difference between the interfering waves is

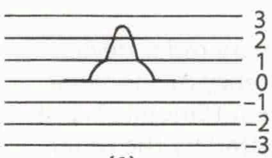
(1) 0° (2) 45° (3) 90° (4) 180°

55. Two waves having the same amplitude and frequency are traveling in the same medium. By how many degrees should the waves be out of phase to produce maximum destructive interference?

56. The diagram below shows a rope with two pulses moving along it in the directions shown.



What is the resultant wave pattern at the instant when the maximum displacement of both pulses is at point O on the rope?



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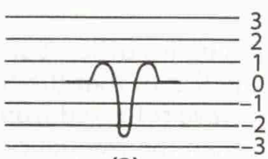

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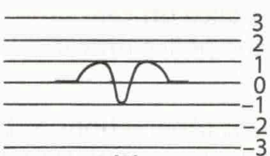

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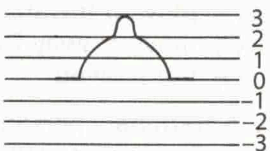

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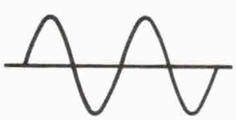
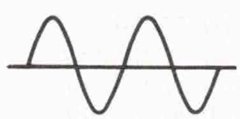
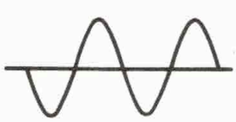
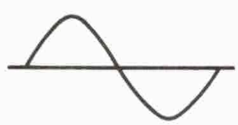
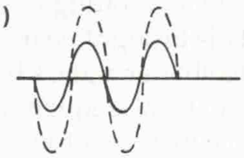
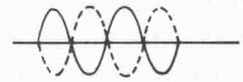
57. The diagram below shows four waves that pass simultaneously through a region.

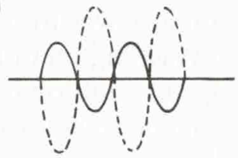
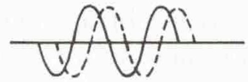
A  **C** 

B  **D** 

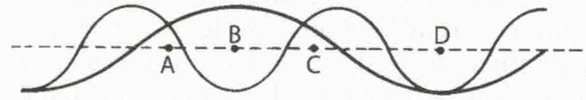
Which two waves will produce maximum constructive interference if they are combined?

58. Which pair of waves will produce a resultant wave with the smallest amplitude?

(1)  **(3)** 

(2)  **(4)** 

59. The diagram below represents two waves traveling simultaneously in the same medium.

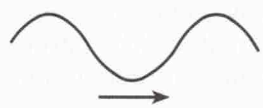


At which of the given points will maximum constructive interference occur?

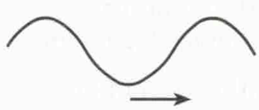
60. Standing waves are produced by two waves traveling in opposite directions in the same medium. The two waves must have

(1) the same amplitude and the same frequency
(2) the same amplitude and different frequencies
(3) different amplitudes and the same frequency
(4) different amplitudes and different frequencies

61. The diagram below represents a wave moving toward the right side of this page.



Which wave shown below could produce a standing wave with the original wave?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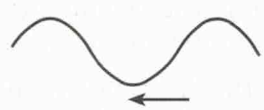
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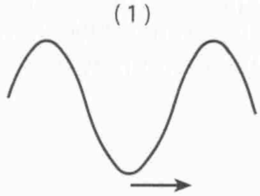
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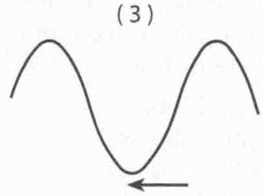
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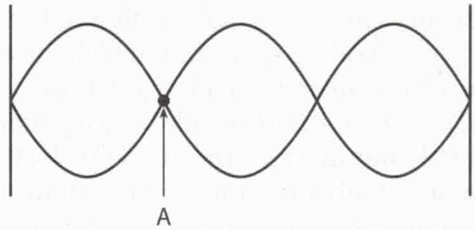
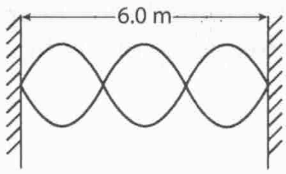
62. The diagram below shows a standing wave.



Point *A* on the standing wave is

(1) a node resulting from constructive interference
(2) a node resulting from destructive interference
(3) an antinode resulting from constructive interference
(4) an antinode resulting from destructive interference

Base your answers to questions 63 and 64 on the diagram below, which shows a standing wave in a rope.



63. How many nodes are represented?

64. If the rope is 6.0 meters long, what is the wavelength of the standing wave?

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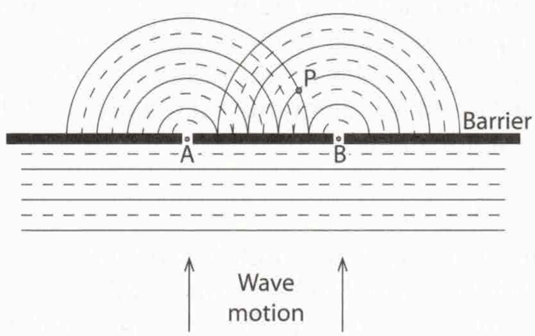
65. Two waves traveling in the same medium and having the same wavelength (λ) interfere to create a standing wave. What is the distance between two consecutive nodes on this standing wave?

(1) λ (2) $\frac{3\lambda}{4}$ (3) $\frac{\lambda}{2}$ (4) $\frac{\lambda}{4}$

66. The diagram below represents shallow water waves interacting with two slits in a barrier.



Identify *two* wave phenomena illustrated in the diagram.

67. An opera singer's voice is able to break a thin crystal glass if a note sung and the glass have the same natural

(1) speed (3) amplitude
(2) frequency (4) wavelength

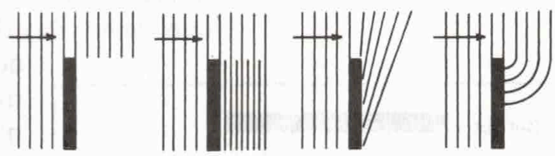
68. When an opera singer hits a high-pitch note, a glass on the opposite side of the opera hall shatters. Which statement best explains this phenomenon?

(1) The amplitude of the note increases before it reaches the glass.
(2) The singer and the glass are separated by an integral number of wavelengths.
(3) The frequency of the note and the natural frequency of the glass are equal.
(4) The sound produced by the singer slows down as it travels from the air into the glass.

69. A wave is diffracted as it passes through an opening in a barrier. The amount of diffraction that the wave undergoes depends on both the

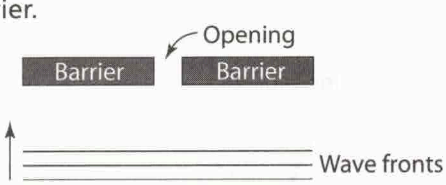
(1) amplitude and frequency of the incident wave
(2) wavelength and speed of the incident wave
(3) wavelength of the incident wave and the size of the opening
(4) amplitude of the incident wave and the size of the opening

70. Which diagram best illustrates diffraction of waves incident on a barrier?

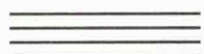


(1) **(2)** **(3)** **(4)**

71. The diagram below represents straight wave fronts approaching a narrow opening in a barrier.



Which diagram best represents the shape of the waves after passing through the opening?

(1) 

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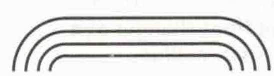
(2) 

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