15 Traveling Waves and Sound

15.1 The Wave Model

15.2 Traveling Waves

1. a. In your own words, define what a *transverse wave* is.

In a transverse wave, the quantity that is oscillating, such as the particles of a string, oscillate in a direction that is perpendicular to the direction of propagation of the wave.

b. Give an example of a wave that, from your own experience, you know is a transverse wave. What observations or evidence tells you this is a transverse wave?

Vibrations of a bass guitar string are a form of transverse wave. You can see that the oscillation is perpendicular to the string.

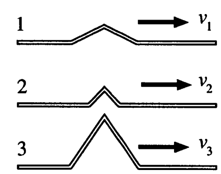
2. a. In your own words, define what a *longitudinal wave* is.

In a longitudinal wave, the oscillations are parallel to the direction of propagation of the wave.

b. Give an example of a wave that, from your own experience, you know is a longitudinal wave. What observations or evidence tells you this is a longitudinal wave?

Waves on a slinky created by pushing and pulling along the length of the slinky are longitudinal. You can observe that the slinky remains straight, with no transverse disturbance as the wave propagates.

3. Three wave pulses travel along the same string. Rank in order, from largest to smallest, their wave speeds v_1, v_2, and v_3.



Order: $v_1 = v_2 = v_3$

Explanation:

Wave speed is independent of wave amplitude.

4. A wave pulse travels along a string at a speed of 200 cm/s. What will be the speed if:
   Note: Each part below is independent and refers to changes made to the original string.

   a. The string's tension is doubled?

   $v = \sqrt{\frac{T}{\mu}}$ so $v' = \sqrt{\frac{2T}{\mu}} = \sqrt{2}\sqrt{\frac{T}{\mu}} = \sqrt{2}\,v$ or $v' = 1.4v$

   $\boxed{v' = 280 \text{ cm/s}}$

   b. The string's mass is quadrupled (but its length is unchanged)?

   $\mu = \frac{m}{L}$; $v' = \sqrt{\frac{T}{4\mu}} = \frac{1}{2}\sqrt{\frac{T}{\mu}} = \frac{v}{2}$ so $\boxed{v' = 100 \text{ cm/s}}$

   c. The string's length is quadrupled (but its mass is unchanged)?

   $\mu = \frac{m}{L}$ so $\mu' = \frac{m}{4L} = \mu/4$. $v' = \sqrt{\frac{T}{\mu/4}} = 2\sqrt{\frac{T}{\mu}}$

   $\boxed{v' = 400 \text{ cm/s}}$

   d. The string's mass and length are both quadrupled?

   $\mu' = \frac{4m}{4L} = \frac{m}{L}$ so the speed is unchanged.

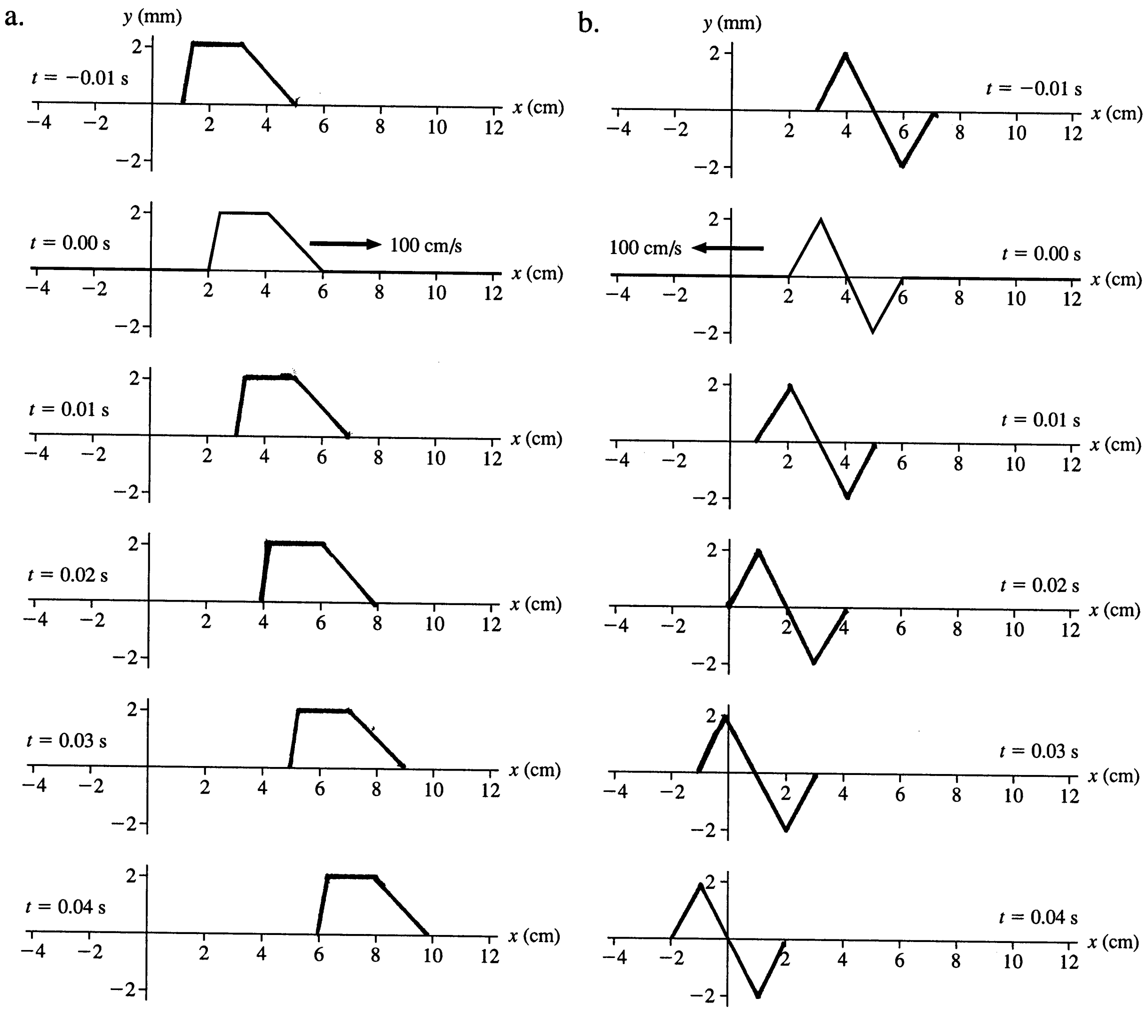
   $\boxed{v' = 200 \text{ cm/s}}$

5. Sound travels through a 300 K gas at 400 m/s. What will be the sound speed if the gas temperature is increased to 600 K? Explain.

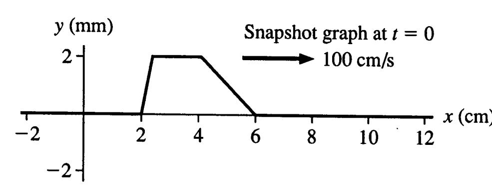
   $564 \frac{m}{s}$ The speed of sound in a gas is proportional to the square root of the temperature and so increases by $\sqrt{2}$ when the temperature doubles.

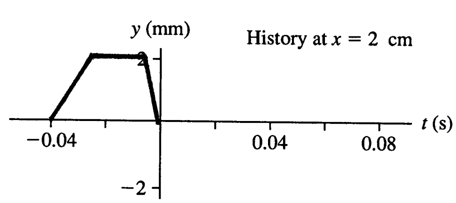
15.3 Graphical and Mathematical Descriptions of Waves

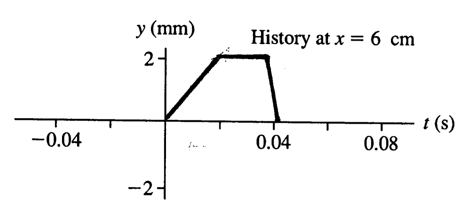
6. Each figure below shows a snapshot graph at time $t = 0$ s of a wave pulse on a string. The pulse on the left is traveling to the right at 100 cm/s; the pulse on the right is traveling to the left at 100 cm/s. Draw snapshot graphs of the wave pulse at the times shown next to the axes.



7. This snapshot graph is taken from Exercise 6a. On the axes below, draw the *history* graphs $y(x = 2\text{ cm}, t)$ and $y(x = 6\text{ cm}, t)$ showing the displacement at $x = 2$ cm and $x = 6$ cm as functions of time. Refer to your graphs in Exercise 6a to see what is happening at different instants of time.

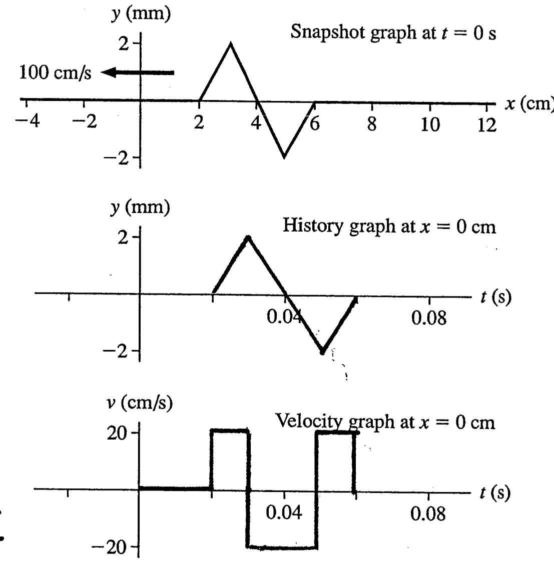






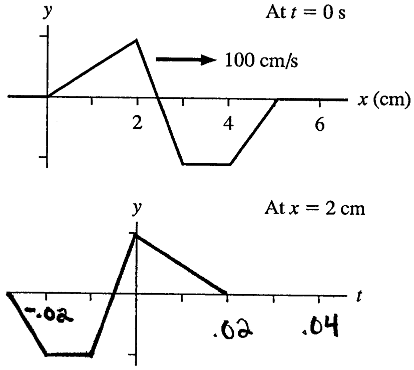
8. This snapshot graph is from Exercise 6b.
   a. Draw the history graph $y(x = 0\text{ cm}, t)$ for this wave at the point $x = 0$ cm.
   b. Draw the *velocity*-versus-time graph for the piece of the string at $x = 0$ cm. Imagine painting a dot on the string at $x = 0$ cm. What is the velocity of this dot as a function of time as the wave passes by?
   c. As a wave passes through a medium, is the speed of a particle in the medium the same as or different from the speed of the wave through the medium? Explain.

Different. The particle is undergoing changing motion even if the wave is moving at constant speed.

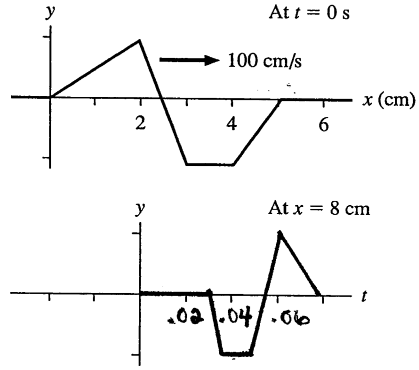


9. Below are four snapshot graphs of wave pulses on a string. For each, draw the history graph at the specified point on the x-axis. No time scale is provided on the t-axis, so you must determine an appropriate time scale and label the t-axis appropriately.

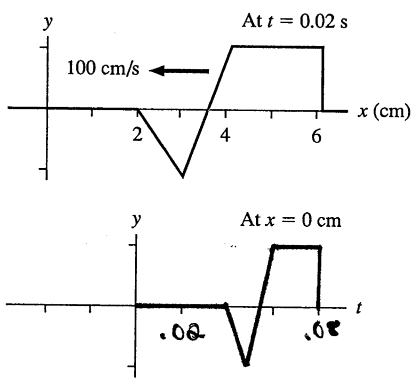
a.



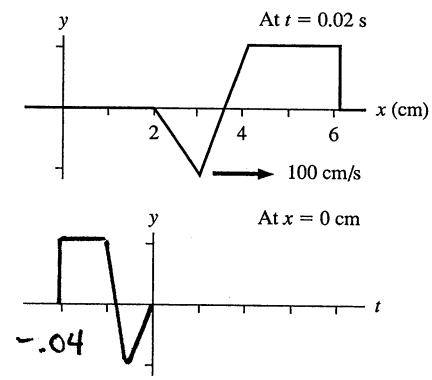
b.



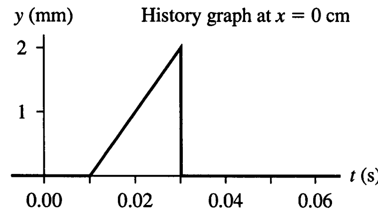
c.



d.



10. A history graph $y(x = 0 \text{ cm}, t)$ is shown for the $x = 0$ cm point on a string. The pulse is moving to the right at 100 cm/s.



a. Does the $x = 0$ cm point on the string rise quickly and then fall slowly, or rise slowly and then fall quickly? Explain.

It rises slowly and then falls quickly. The rise appears at earlier times.

b. At what time does the leading edge of the wave pulse arrive at $x = 0$ cm? 0.01s

c. At $t = 0$ s, how far is the leading edge of the wave pulse from $x = 0$ cm? Explain.

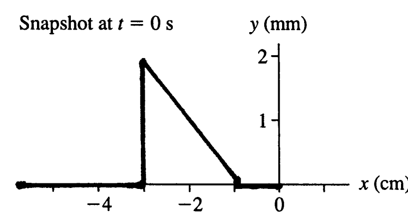
$\Delta x = v\Delta t$; $\boxed{1\text{cm}} = (100\frac{\text{cm}}{\text{s}}) \times (.01\text{s})$

d. At $t = 0$ s, is the leading edge to the right or to the left of $x = 0$ cm? left

e. At what time does the trailing edge of the wave pulse leave $x = 0$ cm? 0.03s

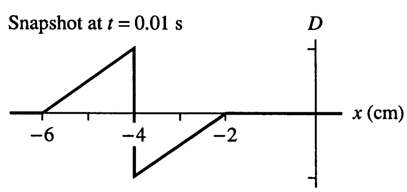
f. At $t = 0$ s, how far is the trailing edge of the pulse from $x = 0$ cm? Explain.

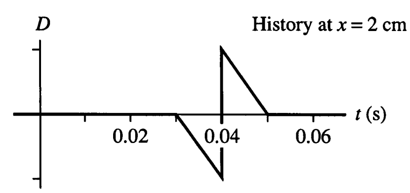
$(100\frac{\text{cm}}{\text{s}}) \times (.03\text{s}) = \boxed{3\text{cm}}$



g. By referring to the answers you've just given, draw a snapshot graph $y(x = 0 \text{ s})$ showing the wave pulse on the string at $t = 0$ s.

11. These are a history graph *and* a snapshot graph for a wave pulse on a string. They describe the same wave from two perspectives.

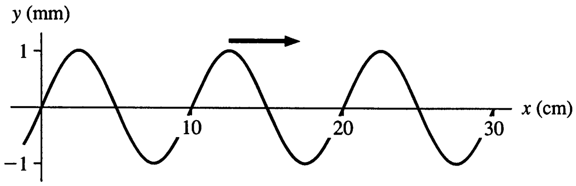




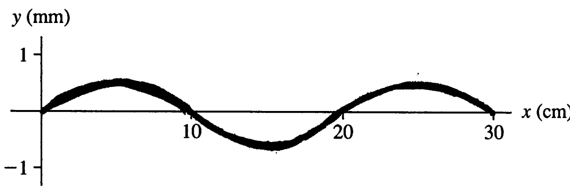
What is the speed of this wave?

$200\frac{\text{cm}}{\text{s}}$ The leading edge reaches the 2cm point at t = 0.03s. At t = 0.01s, it was 4cm to the left at −2cm. $v = \frac{\Delta x}{\Delta t} = \frac{4\text{ cm}}{(0.03\text{s} - 0.01\text{s})} = 200\frac{\text{cm}}{\text{s}}$

12. The figure shows a sinusoidal traveling wave. Draw a graph of the wave if:

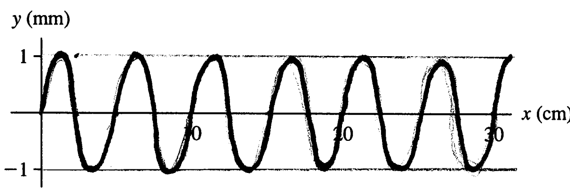


a. Its amplitude is halved and its wavelength is doubled.



b. Its speed is doubled and its frequency is quadrupled. $v = f\lambda$ or $\lambda = \frac{v}{f}$

$\lambda' = \frac{2v}{4f} = \frac{1}{2}\lambda$



13. The wave shown at time $t = 0$ s is traveling to the right at a speed of 25 cm/s.

a. Draw snapshot graphs of this wave at times $t = 0.1$ s, $t = 0.2$ s, $t = 0.3$ s, and $t = 0.4$ s.

b. What is the wavelength of the wave? 10 cm

c. Based on your graphs, what is the period of the wave? 0.4 s

d. What is the frequency of the wave?

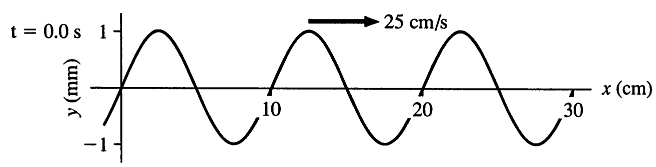
$\frac{1}{T} = f = 2.5$ Hz $(T = 0.4\text{s})$

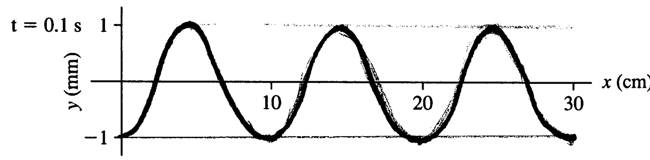
e. What is the value of the product λf?

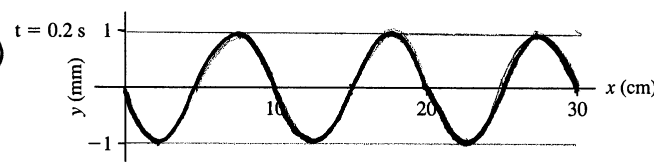
$\lambda f = (10\text{cm})(2.5\text{s}^{-1}) = 25\text{cm/s}$

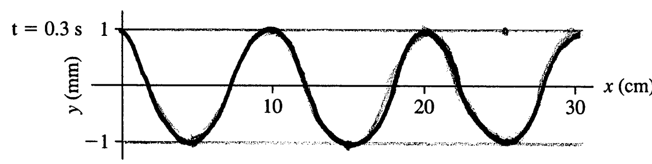
f. How does this value of λf compare to the speed of the wave?

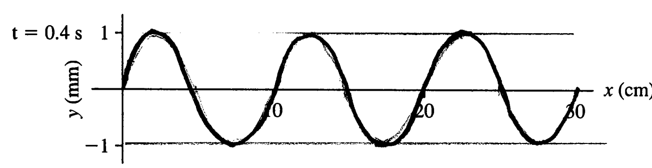
λf is the speed of the wave.





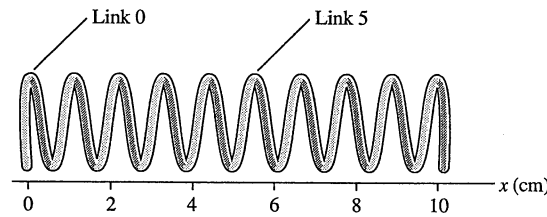


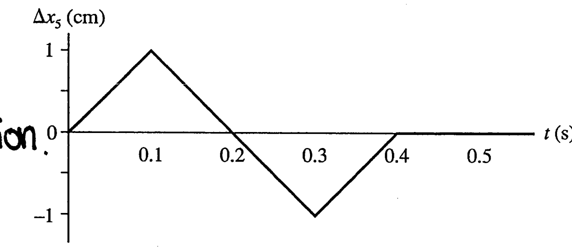




15.4 Sound and Light Waves

14. A horizontal Slinky is at rest on a table. A wave pulse is sent along the Slinky, causing the top of link 5 to move *horizontally* with the *displacement* from equilibrium shown in the graph.





a. Is this a transverse or a longitudinal wave? Explain.

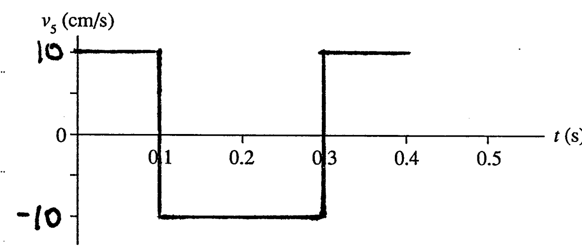
Longitudinal, because the particle motion is parallel to the wave motion.

b. What is the *position* of link 5 at $t = 0.1$ s? 6.5 cm

What is the *position* of link 5 at $t = 0.2$ s? 5.5 cm

What is the *position* of link 5 at $t = 0.3$ s? 4.5 cm

Note: *Position*, not displacement.

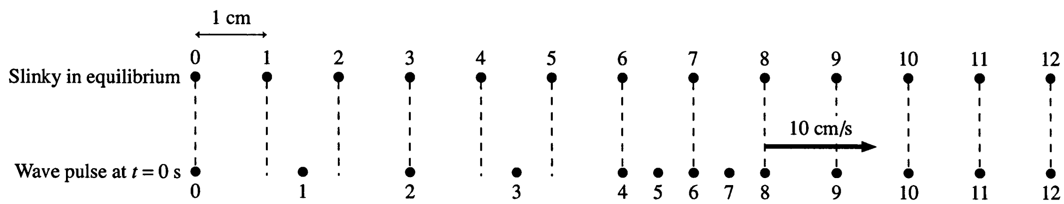


c. Draw a velocity-versus-time graph of link 5. Add an appropriate scale to the vertical axis. (Recall how velocity graphs are related to the slopes of position graphs.)

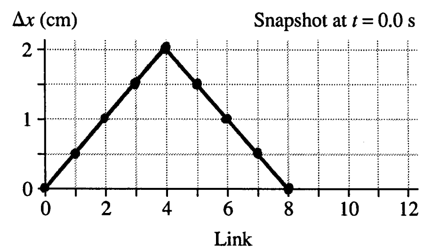
d. Can you determine, from the information given, the speed of the wave? If so, give the speed and explain how you found it. If not, why not?

You cannot determine the speed without more information about the motion of other points.

15. We can use a series of dots to represent the positions of the links in a Slinky. The top set of dots shows a Slinky in equilibrium with a 1-cm spacing between the links. A wave pulse is sent down the Slinky, traveling to the right at 10 cm/s. The second set of dots shows the Slinky at $t = 0$ s. The links are numbered, and you can measure the displacement Δx of each link from its equilibrium position.



a. Draw a snapshot graph showing the displacement Δx of each link at $t = 0$ s. There are 13 links, so your graph should have 13 dots. Connect your dots with lines to make a continuous graph.



b. Is your graph a "picture" of the wave or a "representation" of the wave? Explain.

The graph is a representation of the wave. The displacement is not perpendicular to the length.

c. Which links are in compression? (list their numbers) 4-8

Which links are in rarefaction? (list their numbers) 0-4

16. Rank in order, from largest to smallest, the wavelengths λ_1 to λ_3 for sound waves having frequencies $f_1 = 100$ Hz, $f_2 = 1000$ Hz, and $f_3 = 10{,}000$ Hz.

Order: $\lambda_1 > \lambda_2 > \lambda_3$

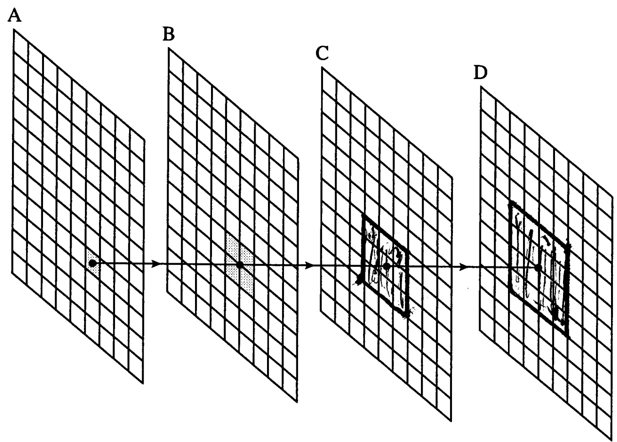
Explanation:

$v = f\lambda$ so the higher the frequency, the shorter the wavelength.

15.5 Energy and Intensity

15.6 Loudness of Sound

17. The figure shows the path of a light wave past a series of equally spaced *transparent* grids. The portion of the first two grids that would be illuminated by the light is represented by the shaded area in the first two grids.
    a. Complete the figure by shading in the spaces that would be illuminated in the remaining two grids.



    b. Is the energy of the light wave passing through the fourth transparent grid (D) greater than, less than, or equal to the energy passing through the first transparent grid (A)? Explain.

The energy is the same, but it is spread over a larger area.

    c. What is the ratio I_D/I_A of the intensity of the light at the fourth grid (D) to the intensity at the first grid (A)? Explain.

$I_D/I_A = 1/16$ The same energy is distributed in D over an area that is 16 times larger.

18. A laser beam has intensity I_0.
    a. What is the intensity, in terms of I_0, if a lens focuses the laser beam to $\frac{1}{10}$ its initial diameter?

$100 I_0$. The area is reduced by $\frac{1}{10^2}$. $(A = \pi (d/2)^2)$

    b. What is the intensity, in terms of I_0, if a lens defocuses the laser beam to 10 times its initial diameter?

$\frac{I_0}{100}$. The area is increased by a factor of 100.

19. Sound wave A delivers 2 J of energy in 2 s. Sound wave B delivers 10 J of energy in 5 s. Sound wave C delivers 2 mJ of energy in 1 ms. Rank in order, from largest to smallest, the sound powers P_A, P_B, and P_C of these three sound waves.

Order: $P_C = P_B > P_A$

Explanation:

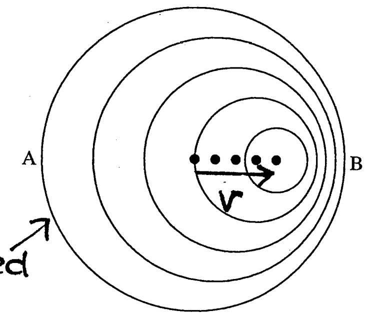
$P_A = \frac{2J}{2s} = 1W$; $P_B = \frac{10J}{5s} = 2W$; $P_C = \frac{2mJ}{1ms} = 2W$

20. A giant chorus of 1000 male vocalists is singing the same note. Suddenly, 999 vocalists stop, leaving one soloist. By how many decibels does the sound intensity level decrease? Explain.

The sound level decreases by 30 decibels. The intensity is reduced by a factor of 1000 and $(10\,dB)\log_{10}1000 = 30\,dB$.

15.7 The Doppler Effect and Shock Waves

21. Five expanding wave fronts from a moving sound source are shown. The dots represent the centers of the respective circular wave fronts, which is the location of the source when that wave front was emitted. The frequency of the sound emitted by the source is constant.



a. Indicate on the figure the direction of motion of the source. Which sound wave front was produced first? How do you know? Explain.

The source is moving to the left because the larger circles represent sound wave crests that were emitted earlier and have propogated further.

b. Do the observers at locations A and B hear the same frequency of sound? If not, which one hears a higher frequency? Explain.

No. The sound wave crests are closer together at B, so the frequency heard is higher at B than A.

c. Assume that the sound wave you identified in part a as the first wave front produced marks the beginning of the sound. Do the observers at A and B first hear the sound at the same time? If not, which one hears the sound first? Explain.

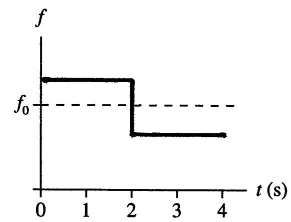
Yes. The source was midway between A and B (at the left most dot) originally and both A and B are at the edge of that first crest.

d. The speed of sound in the medium is v. Is the speed v_s of the source greater than, less than, or equal to v? Explain.

The spacing of the crests to the left is twice the separation between dots so

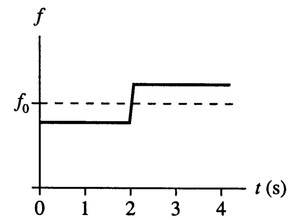
$$V_{source} = \frac{V_{sound}}{2}.$$

22. You are standing at $x = 0$ m, listening to a sound that is emitted at a frequency f_0. At $t = 0$ s, the sound source is at $x = 20$ m and moving toward you at a steady 10 m/s. Draw a graph showing the frequency you hear from $t = 0$ s to $t = 4$ s. Only the shape of the graph is important, not the numerical values of f.



The source passes you at $t = \frac{x_0}{v} = 2s$

23. You are standing at $x = 0$ m, listening to a sound that is emitted at frequency f_0. The graph shows the frequency you hear during a four-second interval. Which of the following describes the sound source?

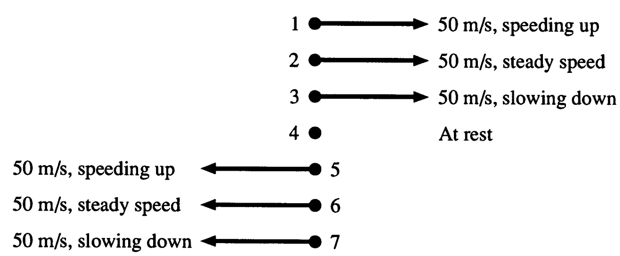


i. It moves from left to right and passes you at $t = 2$ s.
ii. It moves from right to left and passes you at $t = 2$ s.
iii. It moves toward you but doesn't reach you. It then reverses direction at $t = 2$ s.
(iv.) It moves away from you until $t = 2$ s. It then reverses direction and moves toward you but doesn't reach you.

Explain your choice.

The shift is to a lower frequency at first and so the source must be moving away for the first 2 seconds.

24. You are standing at $x = 0$ m, listening to seven identical sound sources. At $t = 0$ s, all seven are at $x = 343$ m and moving as shown below. The sound from all seven will reach your ear at $t = 1$ s.



Rank in order, from highest to lowest, the seven frequencies f_1 to f_7 that you hear at $t = 1$ s.

Order: $f_5 = f_6 = f_7 > f_4 > f_3 = f_2 = f_1$

Explanation:

The frequency depends upon the source's speed, not its acceleration. If we assume that x=343 m/s to the right, then 5-7 are moving towards you and 1-3 are moving away from you, all at equal speeds.