Chapter 18 - Superposition and Standing Waves

Note Title 9/18/2006

1. Two traveling sinusoidal waves are described by the wave functions

$$y_1 = (5.00\ \text{m})\sin[\pi(4.00x - 1\,200t)]$$

and

$$y_2 = (5.00\ \text{m})\sin[\pi(4.00x - 1\,200t - 0.250)]$$

where x, y_1, and y_2 are in meters and t is in seconds. (a) What is the amplitude of the resultant wave? (b) What is the frequency of the resultant wave?

(a) Resultant wave is:

$$y = (10.0\ \text{m})\cos\left(\frac{0.250\pi}{2}\right)\sin(\pi 4.00x - 1200\pi t)$$

$$\therefore \text{Amplitude} = 10.0\cos\left(\frac{0.250\pi}{2}\right) = \underline{9.24\ \text{m}}$$

(b) $2\pi f = 1200\pi$, $f = \underline{600\ \text{Hz}}$

4. Two identical sinusoidal waves with wavelengths of 3.00 m travel in the same direction at a speed of 2.00 m/s. The second wave originates from the same point as the first, but at a later time. Determine the minimum possible time interval between the starting moments of the two waves if the amplitude of the resultant wave is the same as that of each of the two initial waves.

$$y_1 = A\sin\left(\frac{2\pi}{3.00}x - 2.00t\right)$$

$$y_2 = A\sin\left(\frac{2\pi}{3.00}x - 2.00t + \phi\right)$$

Superimposed, amplitude $= 2A\cos\left(\frac{\phi}{2}\right)$

$\therefore$ want $\cos\left(\frac{\phi}{2}\right) = \frac{1}{2}$, $\therefore \frac{\phi}{2} = \pm\frac{\pi}{3}$, $\phi = \pm\frac{2}{3}\pi$

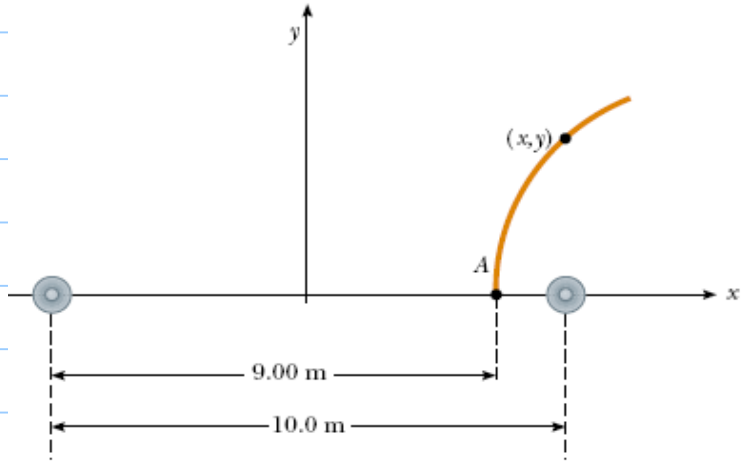
$\therefore$ Waves out of phase by $\frac{2}{3}\pi$

By wavelengths, $\frac{\lambda}{2\pi} = \frac{x}{\frac{2}{3}\pi}$, $x = \frac{\lambda}{3} = \frac{3.00}{3} = 1.00\text{ m}$

The wave travels this distance in $\frac{1.0\text{ m}}{2.0\text{ m/sec}} = 0.500\text{ sec}$

$\therefore$ wait 0.500 sec to start second wave.

6. Two identical speakers 10.0 m apart are driven by the same oscillator with a frequency of $f = 21.5$ Hz (Fig. P18.12). (a) Explain why a receiver at point A records a minimum in sound intensity from the two speakers. (b) If the receiver is moved in the plane of the speakers, what path should it take so that the intensity remains at a minimum? That is, determine the relationship between x and y (the coordinates of the receiver) that causes the receiver to record a minimum in sound intensity. Take the speed of sound to be 344 m/s.



(a) Sound intensity will be a minimum if superimposed waves at A will cancel each other out. When path difference is an odd multiple of $\frac{\lambda}{2}$, then cancellation occurs.

Here $\lambda = \frac{343\ m/sec}{21.5\ Hz} = 16.0\ m$, so $\frac{\lambda}{2} = 8.0$

The path difference is $\Delta r = 9.0 - 1.0 = 8.0$.

$\therefore \Delta r = \frac{\lambda}{2}$, so waves cancel.

(b) Choosing midpoint as origin as shown, we want $\Delta r = \lambda/2$

$$\therefore \|(x,y)-(-5,0)\| - \|(x,y)-(5,0)\| = \frac{\lambda}{2}$$

$$\therefore \sqrt{(x+5)^2+y^2} - \sqrt{(x-5)^2+y^2} = \frac{\lambda}{2} = 8$$

$$\therefore (x+5)^2+y^2 = 64 + (x-5)^2+y^2 + 16\sqrt{(x-5)^2+y^2}$$

$$20x - 64 = 16\sqrt{(x-5)^2+y^2}$$

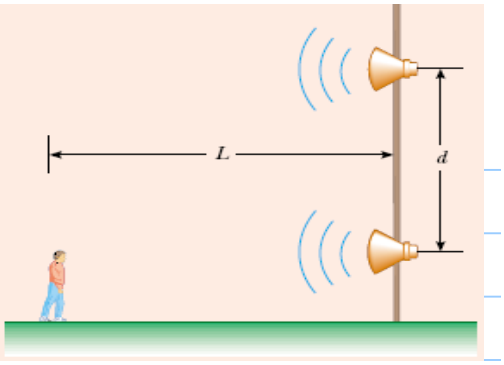
$$5x - 16 = 4\sqrt{(x-5)^2+y^2}$$

$$25x^2 - 160x + 256 = 16\left[(x-5)^2+y^2\right]$$

$$= 16x^2 - 160x + 400 + y^2$$

$$\therefore 9x^2 - y^2 = 144$$

8. Two speakers are driven by the same oscillator whose frequency is f. They are located a distance d from each other on a vertical pole. A man walks straight toward the lower speaker in a direction perpendicular to the pole, as shown in Figure P18.9. (a) How many times will he hear a minimum in sound intensity? (b) How far is he from the pole at these moments? Let v represent the speed of sound, and assume that the ground does not reflect sound.



(a) Minimum occurs when path length = odd multiple of $\lambda/2$

$\Delta r = \sqrt{L^2 + d^2} - L$, assuming person's ears at height of lower speaker.

$\therefore \sqrt{L^2 + d^2} - L = (2n-1)\frac{\lambda}{2}, \quad n = 1, 2, \ldots$

$V_{sound} = \lambda f$, so $\lambda = \frac{V_s}{f}$

$\therefore \sqrt{L^2 + d^2} - L = (n - \frac{1}{2})\left(\frac{V_s}{f}\right), \quad n = 1, 2, \ldots$

$\therefore \sqrt{L^2 + d^2} = (n - \frac{1}{2})\left(\frac{V_s}{f}\right) + L$

$L^2 + d^2 = (n-\frac{1}{2})^2\left(\frac{V_s}{f}\right)^2 + L^2 + 2(n-\frac{1}{2})\left(\frac{V_s}{f}\right)L$

$\therefore d^2 = (n-\frac{1}{2})^2\left(\frac{V_s}{f}\right)^2 + 2(n-\frac{1}{2})\left(\frac{V_s}{f}\right)L$

$$\therefore L = \frac{d^2 - \left(n-\frac{1}{2}\right)^2\left(\frac{v_s}{f}\right)^2}{2\left(n-\frac{1}{2}\right)\left(\frac{v_s}{f}\right)}$$

for $L \geq 0$, all solutions of n exist.

for this to be true, $d^2 \geq \left(n-\frac{1}{2}\right)^2\left(\frac{v_s}{f}\right)^2$,

or, $d \geq \left(n-\frac{1}{2}\right)\left(\frac{v_s}{f}\right)$, or $\frac{fd}{v_s} \geq n-\frac{1}{2}$,

or $n \leq \frac{fd}{v_s} + \frac{1}{2}$

$\therefore$ largest integer $\leq \frac{fd}{v_s} + \frac{1}{2}$ will be # of minima heard.

(b) as above, $L = \frac{d^2 - \left(n-\frac{1}{2}\right)^2\left(\frac{v_s}{f}\right)^2}{2\left(n-\frac{1}{2}\right)\left(\frac{v_s}{f}\right)}$

9. Two sinusoidal waves traveling in opposite directions interfere to produce a standing wave with the wave function

$$y = (1.50\ \text{m})\sin(0.400x)\cos(200t)$$

where x is in meters and t is in seconds. Determine the wavelength, frequency, and speed of the interfering waves.

For a standing wave, $y(x,t) = 2A\sin(kx)\cos(\omega t)$

$\therefore k = \frac{2\pi}{\lambda} = 0.400$, so $\lambda = \frac{2\pi}{0.400} = \underline{15.7\ m}$

$\omega = 2\pi f = 200$, so $f = \frac{200}{2\pi} = \underline{31.8\ Hz}$

$\therefore v = \lambda f = \underline{500\ m/sec}$

10. Two waves in a long string have wave functions given by

$$y_1 = (0.015\ 0\ \text{m}) \cos\left(\frac{x}{2} - 40t\right)$$

and

$$y_2 = (0.015\ 0\ \text{m}) \cos\left(\frac{x}{2} + 40t\right)$$

where y_1, y_2, and x are in meters and t is in seconds. (a) Determine the positions of the nodes of the resulting standing wave. (b) What is the maximum transverse position of an element of the string at the position $x = 0.400$ m?

(a) $\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$

$\therefore y_1 = 0.0150 \cos\frac{x}{2} \cos 40t + \sin\frac{x}{2} \sin 40t$

$y_2 = 0.0150 \cos\frac{x}{2} \cos 40t - \sin\frac{x}{2} \sin 40t$

$y(x,t) = 0.0300 \cos\frac{x}{2} \cos 40t$

$\therefore$ nodes when $\cos\frac{x}{2} = 0$, or $\frac{x}{2} = \frac{\pi}{2}, \frac{3}{2}\pi, \ldots$

$\therefore$ nodes at $x = (2n+1)\pi$, $n = 0, 1, 2, \ldots$

(b) from (a), $0.0300 \cos \frac{0.400}{2} = 0.0294\ m$

(This is the max up & down motion from horizontal).

11. Two speakers are driven in phase by a common oscillator at 800 Hz and face each other at a distance of 1.25 m. Locate the points along a line joining the two speakers where relative minima of sound pressure amplitude would be expected. (Use $v = 343$ m/s.)

Here, $\lambda = \frac{v}{f} = \frac{343}{800} = 0.429\ m$

Nodes will occur when path length difference is $\lambda/2$, or odd multiple of $\lambda/2$

Let left speaker be $x=0$, $\therefore$ path from left speaker is x, from right speaker $1.25-x$

$\therefore |(1.25-x)-x| = (2n+1)\frac{\lambda}{2}$, $n = 0, 1, 2, \ldots$

$\therefore 1.25-2x = \pm\frac{(2n+1)}{2}(0.429)$

$\therefore 2x = 1.25 \pm (2n+1)(0.214)$, and $0 \le x \le 1.25$

$\therefore x = 0.625 \pm (2n+1)(0.107)$

so, $n = 0, 1, 2$

$\therefore$ $x = 0.732\ m$ $(n=0)$
$x = 0.946\ m$ $(n=1)$
$x = 1.16\ m$ $(n=2)$
} adding

$x = 0.518\ m$ $(n=0)$
$x = 6.304\ m$ $(n=1)$
$x = 0.090\ m$ $(n=2)$
} subtracting

12. Two waves that set up a standing wave in a long string are given by the wave functions

$$y_1 = A\sin(kx - \omega t + \phi) \qquad \text{and} \qquad y_2 = A\sin(kx + \omega t)$$

Show (a) that the addition of the arbitrary phase constant ϕ changes only the position of the nodes and, in particular, (b) that the distance between nodes is still one half the wavelength.

(a) $\sin a + \sin b = 2\sin\left(\frac{a+b}{2}\right)\cos\left(\frac{a-b}{2}\right)$

$\therefore y_1 + y_2 = 2A\sin\left(kx + \frac{\phi}{2}\right)\cos\left(-\omega t + \frac{\phi}{2}\right)$

$= 2A\sin\left(kx + \frac{\phi}{2}\right)\cos\left(\omega t - \frac{\phi}{2}\right)$

$\therefore \cos\left(\omega t - \frac{\phi}{2}\right)$ still varies from -1 to 1.

The nodes are now where $kx + \frac{\phi}{2} = 0, \pi, 2\pi, \ldots$

or $kx = -\frac{\phi}{2}, \pi - \frac{\phi}{2}, 2\pi - \frac{\phi}{2}, \ldots$

or $x = -\frac{\phi}{4\pi}\lambda, \frac{\lambda}{2} - \frac{\phi}{4\pi}\lambda, \ldots$

so each node is shifted to left by $\frac{-\phi}{4\pi}\lambda$

(b) Clearly, from (a), each node separated by $\frac{\lambda}{2}$

19. A cello A-string vibrates in its first normal mode with a frequency of 220 Hz. The vibrating segment is 70.0 cm long and has a mass of 1.20 g. (a) Find the tension in the string. (b) Determine the frequency of vibration when the string vibrates in three segments.

(a) $\lambda = 2L = 140\ cm = 1.4\ m$

$\therefore\ v = \lambda f = (1.4)(220) = 308\ m/sec$

$\therefore\ v = \sqrt{\frac{T}{\mu}}, \quad T = v^2\mu = (308)^2\left(\frac{0.00120}{0.700}\right)$

$= 163\ N$

(b) 3 segs $\Rightarrow f_3 = 3f_1 = 660\ Hz$

23. A violin string has a length of 0.350 m and is tuned to concert G, with $f_G = 392$ Hz. Where must the violinist place her finger to play concert A, with $f_A = 440$ Hz? If this position is to remain correct to half the width of a finger (that is, to within 0.600 cm), what is the maximum allowable percentage change in the string tension?

(a) $f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$, so $\frac{f_1}{f_2} = \frac{L_2}{L_1}$

$\therefore \quad \frac{392}{440} = \frac{L_2}{L_1} = 0.89 = \frac{L_2}{0.350}, \quad L_2 = 0.312\,m$

$\therefore$ Place finger at 0.312 m from bridge or $0.35 - 0.312 = 0.038$ m from end.

(b) $\frac{\sqrt{T_1}}{L_1} = \frac{\sqrt{T_2}}{L_2}$

$\therefore \frac{\sqrt{xT}}{L + 0.006} = \frac{\sqrt{T}}{L}, \quad \sqrt{x} = \frac{L + 0.006}{L}$

$= \frac{0.356}{0.350} = 1.017$

$\frac{\sqrt{xT}}{L - 0.006} = \frac{\sqrt{T}}{L}, \quad \sqrt{x} = \frac{L - 0.006}{L}$

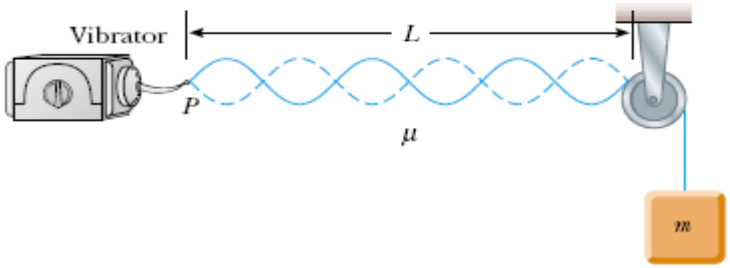
$= \frac{0.350 - 0.006}{0.350}$

$= \frac{344}{350} = 0.983$

$\therefore$ 0.017 = 1.7% each way,

so total variation in T = 3.4%

25. In the arrangement shown in Figure P18.21, an object can be hung from a string (with linear mass density $\mu = 0.002\,00$ kg/m) that passes over a light pulley. The string is connected to a vibrator (of constant frequency f), and the length of the string between point P and the pulley is $L = 2.00$ m. When the mass m of the object is either 16.0 kg or 25.0 kg, standing waves are observed; however, no standing waves are observed with any mass between these values. (a) What is the frequency of the vibrator? (*Note:* The greater the tension in the string, the smaller the number of nodes in the standing wave.) (b) What is the largest object mass for which standing waves could be observed?



(a) $f = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$ $\therefore f_{16} = \frac{n_{16}}{2L}\sqrt{\frac{16g}{\mu}} = 4n_{16}\frac{\sqrt{g}}{2L\sqrt{\mu}}$

$f_{25} = \frac{n_{25}}{2L}\sqrt{\frac{25g}{\mu}} = 5n_{25}\frac{\sqrt{g}}{2L\sqrt{\mu}}$

Note that $n_{25} + 1 = n_{16}$, since no standing waves between 16 kg and 25 kg means they are adjacent fundamental frequencies.

$\therefore \frac{f_{16}}{f_{25}} = \frac{4(n_{25}+1)}{5n_{25}}$

But $f_{16} = f_{25}$ since each is produced by the vibrator.

$\therefore 5 = 4n_{25} + 4$, $n_{25} = 4$. $\therefore n_{11} = 5$

$\therefore f = \frac{n_{25}}{22}\sqrt{\frac{T_{25}}{\mu}} = \frac{4}{2(2)}\sqrt{\frac{25g}{0.002}} = 5\sqrt{9.8(500)}$

$= 350$ Hz

(b) $n = 1$. $350 = \frac{1}{2(2)}\sqrt{\frac{mg}{0.002}}$

$\therefore \frac{350^2(4)^2}{(500)(9.8)} = m = 400$ kg

28. Standing-wave vibrations are set up in a crystal goblet with four nodes and four antinodes equally spaced around the 20.0-cm circumference of its rim. If transverse waves move around the glass at 900 m/s, an opera singer would have to produce a high harmonic with what frequency to shatter the glass with a resonant vibration?

4 nodes, so spaced equally at $\frac{20.0\text{ cm}}{4} = 5.0$

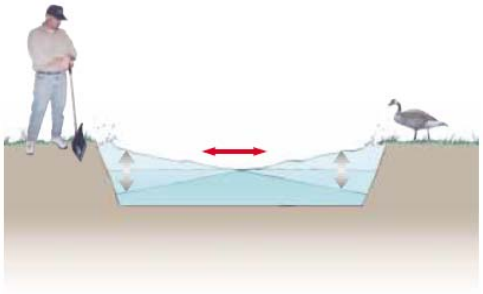
Nodes are $\lambda/2$ apart, so $\lambda/2 = 5.0$ cm, so

$\lambda = 10.0$ cm $= 0.100$ m

$\therefore f = v/\lambda = \frac{900\text{ m/sec}}{0.100\text{ m}} = 9000$ Hz $= 9$ KHz

(stereos transmit at 20 Hz - 20 KHz)

29. An earthquake can produce a *seiche* in a lake, in which the water sloshes back and forth from end to end with remarkably large amplitude and long period. Consider a seiche produced in a rectangular farm pond, as in the cross-sectional view of Figure P18.33. (The figure is not drawn to scale.) Suppose that the pond is 9.15 m long and of uniform width and depth. You measure that a pulse produced at one end reaches the other end in 2.50 s. (a) What is the wave speed? (b) To produce the seiche, several people stand on the bank at one end and paddle together with snow shovels, moving them in simple harmonic motion. What should be the frequency of this motion?



(a) $\frac{9.15\ m}{2.50\ sec} = 3.66\ m/sec$

(b) Need $\lambda_n = \frac{2L}{n}$, so for $n=1$, $\lambda_1 = 2L = 18.3\ m$ $\therefore v = \lambda f$, $f = \frac{(3.66)}{18.3} = \underline{0.200\ Hz}$

$\therefore n(0.200)$, where $n = 1, 2, 3, \ldots$, will produce a standing wave. Other frequencies will not.

31. Calculate the length of a pipe that has a fundamental frequency of 240 Hz if the pipe is (a) closed at one end and (b) open at both ends.

(a) For closed at one end, $\lambda_1 = 4L$, so

$f_1 = \frac{v}{\lambda_1} = \frac{343\ m/sec}{4L} = 240\ Hz$, $L = \underline{0.357\ m}$

(6) Open at both ends $\Rightarrow \lambda_1 = 2L$

$\therefore f_1 = \frac{v}{2L}$, $L = \frac{343}{2(240)} = \underline{0.715\ m}$

37. A shower stall measures 86.0 cm × 86.0 cm × 210 cm. If you were singing in this shower, which frequencies would sound the richest (because of resonance)? Assume that the stall acts as a pipe closed at both ends, with nodes at opposite sides. Assume that the voices of various singers range from 130 Hz to 2 000 Hz. Let the speed of sound in the hot shower stall be 355 m/s.

Closed at both ends $\Rightarrow \lambda_1 = 2L = 420\ cm$

$\therefore f_1 = \frac{355}{4.20} = 84.5\ Hz$ Using height

$\therefore f_n = n(84.5)$, $n = 1 \ldots 23$

Using width, $\lambda_1 = 2L = 172\ cm$

$\therefore f_1 = \frac{355}{1.72} = 206.4\ Hz$

$\therefore f_n = n(206.4)$, $n = 1 \ldots 9$

38. When an open metal pipe is cut into two pieces, the lowest resonance frequency for the air column in one piece is 256 Hz and that for the other is 440 Hz. (a) What resonant frequency would have been produced by the original length of pipe? (b) How long was the original pipe?

(a) Open at both ends: $\lambda_1 = 2L$

$$\therefore f_1 = \frac{v}{\lambda_1} = \frac{343}{2L} = 256$$

$$\therefore L = \frac{343}{2(256)} = 0.670 \text{ m}$$

$$f_1 = \frac{343}{2L} = 440$$

$$\therefore L = \frac{343}{2(440)} = 0.390 \text{ m}$$

$$\therefore \text{Total length} = 1.060 \text{ m}$$

$$\therefore f = \frac{343}{2(1.060)} = \underline{162 \text{ Hz}}$$

(b) As in (a), $\underline{1.06 \text{ m}}$

40. As shown in Figure P18.42, water is pumped into a tall vertical cylinder at a volume flow rate R. The radius of the cylinder is r, and at the open top of the cylinder a tuning fork is vibrating with a frequency f. As the water rises, how much time elapses between successive resonances?

Air column open at one end, so $f_1 = \frac{V}{4L}$

and $f_n = n f_1$, $n = 1, 3, 5, \ldots$

$\therefore \lambda_1 = \frac{V}{f_1} = 4L_1 \qquad L_1 = \frac{V}{4f} = \frac{\lambda}{4}$

$\lambda_3 = \frac{V}{f_3} = \frac{V}{3f_1} = \frac{4}{3} L_3$

$\lambda_5 = \frac{V}{f_5} = \frac{V}{5f_1} = \frac{4}{5} L_5$

Here, $f_1 = f_3 = f_5$, i.e., f is 1st harmonic at L_1, it is 3rd harmonic for L_3, etc. $\therefore L_1 = \frac{\lambda}{4}$, $L_3 = \frac{3}{4}\lambda$, $L_5 = \frac{5}{4}\lambda$

$\therefore \Delta L$ is always $\frac{\lambda}{2}$

Volume of cylinder $= \pi r^2 X$, X = height

Flow rate $= \frac{\pi r^2 X}{\text{sec}} = R$, so $X/\text{sec} = \frac{R}{\pi r^2}$

so rising at $\frac{R}{\pi r^2}$ m/sec

$\therefore$ Distance L is covered in $\frac{L}{X}$ secs, or

$$\frac{L}{\frac{R}{\pi r^2}} = \frac{\pi r^2 L}{R} \text{ secs}$$

$\therefore$ a distance of $\frac{\lambda}{2}$ is covered in

$\frac{\pi r^2}{R}\left(\frac{\lambda}{2}\right)$ secs.

Now, $\lambda = \frac{V}{f}$, so $\frac{\pi r^2}{R}\left(\frac{\lambda}{2}\right) = \frac{\pi r^2 V}{2Rf}$

$\therefore$ Time between resonances $= \underline{\underline{\frac{\pi r^2 V}{2Rf}}}$

43 An air column in a glass tube is open at one end and closed at the other by a movable piston. The air in the tube is warmed above room temperature, and a 384-Hz tuning fork is held at the open end. Resonance is heard when the piston is 22.8 cm from the open end and again when it is 68.3 cm from the open end. (a) What speed of sound is implied by these data? (b) How far from the open end will the piston be when the next resonance is heard?

Open at one end, closed at other means

$f = \frac{n V}{4L}$, $n = 1, 3, 5, \ldots$

Assume $n=1$ is 22.8, $n=3$ is 68.3

(a) $384 = \frac{(1)\,V}{4(0.228)}$, $V = \underline{\underline{350}}$ m/sec

$384 = \frac{(3)\,V}{4(0.683)}$, $V = \underline{\underline{350}}$ m/sec

(b) f_5 : $384 = \frac{5(350)}{4L}$, $L = 1.14\ m$

49. In certain ranges of a piano keyboard, more than one string is tuned to the same note to provide extra loudness. For example, the note at 110 Hz has two strings at this frequency. If one string slips from its normal tension of 600 N to 540 N, what beat frequency is heard when the hammer strikes the two strings simultaneously?

$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$, assume L and μ are same.

$\therefore \frac{f_1}{f_2} = \sqrt{\frac{T_1}{T_2}}$, $\frac{f}{110} = \sqrt{\frac{540}{600}} = \sqrt{.9}$,

$\therefore f = 110\sqrt{0.9} =$

$\therefore |110 - 110\sqrt{0.9}| = 5.64\ Hz$

50. While attempting to tune the note C at 523 Hz, a piano tuner hears 2 beats/s between a reference oscillator and the string. (a) What are the possible frequencies of the string? (b) When she tightens the string slightly, she hears 3 beats/s. What is the frequency of the string now? (c) By what percentage should the piano tuner now change the tension in the string to bring it into tune?

(a) $|f - 523| = 2$, $\therefore f = 525$ or $521\ Hz$

(b) Tightening ↑'s freq., so it must have

originally been 525 Hz; if it were 521, tightening would have ↓'d beats.

∴ Now $f = 3 + 523 = \underline{526\ \text{Hz}}$

(c) $\frac{f_1}{f_2} = \sqrt{\frac{T_1}{T_2}}$, $\frac{T_1}{T_2} = \frac{f_1^2}{f_2^2} = \left(\frac{526}{523}\right)^2 = 1.0115$

∴ $1.0115\,x = 1.0$, $x = 0.9886$, $1 - x = 0.0114$

∴ Decrease tension by $\underline{1.14\%}$

51. A student holds a tuning fork oscillating at 256 Hz. He walks toward a wall at a constant speed of 1.33 m/s. (a) What beat frequency does he observe between the tuning fork and its echo? (b) How fast must he walk away from the wall to observe a beat frequency of 5.00 Hz?

(a) Effectively, student hears 256 Hz from fork (as it moves with him), and he hears reflected wave as if he is moving toward the source, which is also moving toward him (it's reflected from wall).

∴ $f' = \left(\frac{v + v_0}{v - v_s}\right) f = \left(\frac{343 + 1.33}{343 - 1.33}\right) 256 = 258$

$\therefore 258 - 256 = 2$ Hz

(b) Walking away from wall at r,

$$f' = \left(\frac{343 - r}{343 + r}\right)(256), \quad f' = 256 - 5 = 251 \text{ Hz}$$

$$\therefore \frac{251}{256} = \frac{343 - r}{343 + r}, \quad 251(343) + 251r = 256(343) - 256r$$

$$\therefore 507r = 343(256 - 251)$$

$$r = \frac{343(5)}{507} = \underline{\underline{3.38}} \text{ m/sec}$$