Lecture 48

(Ch.14: 7-13)

Topic Summary

- **The Doppler Effect**

$$f_O = f_S\left(\frac{v+v_O}{v-v_S}\right)$$

- **Interference of Sound Waves**

$$r_2 - r_1 = n\lambda \quad n = 0,\ 1, 2, \ldots$$

$$r_2 - r_1 = \left(n+\frac{1}{2}\right)\lambda \quad n = 0,\ 1, 2, \ldots$$

79. A block with a speaker bolted to it is connected to a spring having spring constant $k = 20.0$ N/m, as shown in Figure P14.79. The total mass of the block and speaker is 5.00 kg, and the amplitude of the unit's motion is 0.500 m. If the speaker emits sound waves of frequency 440. Hz, determine the

a. lowest and

b. highest frequencies heard by the person to the right of the speaker.

14.79 The maximum speed of the oscillating block and speaker is

$$v_{max} = A\omega = A\sqrt{\frac{k}{m}} = (0.500\text{ m})\sqrt{\frac{20.0\text{ N/m}}{5.00\text{ kg}}} = 1.00\text{ m/s}$$

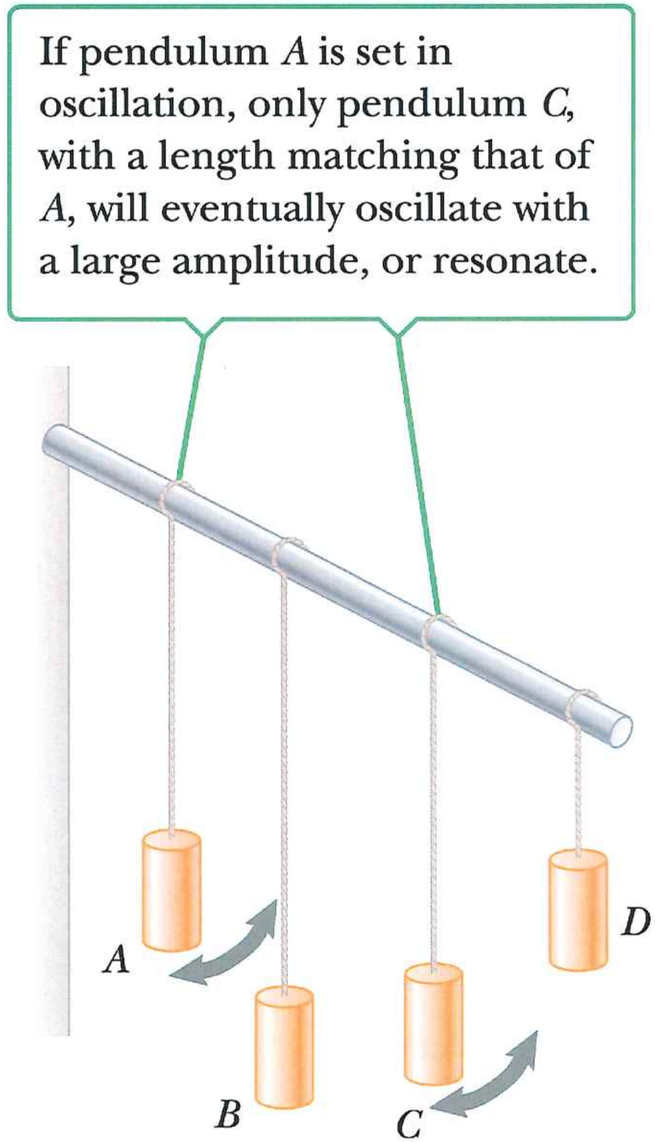
(a) When the speaker moves *away from* the stationary observer, the source velocity is $v_S = -v_{max}$ and the minimum frequency heard is

$$(f_O)_{min} = f_S\left(\frac{v}{v + v_{max}}\right) = (440\text{ Hz})\left(\frac{343\text{ m/s}}{343\text{ m/s} + 1.00\text{ m/s}}\right) = \boxed{439\text{ Hz}}$$

(b) When the speaker (sound source) moves *toward* the stationary observer, then $v_S = +v_{max}$ and the maximum frequency heard is

$$(f_O)_{max} = f_S\left(\frac{v}{v - v_{max}}\right) = (440\text{ Hz})\left(\frac{343\text{ m/s}}{343\text{ m/s} - 1.00\text{ m/s}}\right) = \boxed{441\text{ Hz}}$$

Forced Vibrations and Resonance



53. A car's 30.0-kg front tire is suspended by a spring with spring constant $k = 1.00 \times 10^5$ N/m. At what speed is the car moving if washboard bumps on the road every 0.750 m drive the tire into a resonant oscillation?

14.53 The spring's natural oscillation frequency is

$$\omega = \sqrt{k/m} = \sqrt{(1.00 \times 10^5 \text{ N/m})/(30.0 \text{ kg})} = 57.5 \text{ rad/s}$$ which

corresponds to a period of $T = 2\pi/\omega = 0.109$ s. To drive the tire into resonance, it should hit a bump (spaced $d = 0.750$ m) once per period.

The car's minimum speed is then $v = d/T = (0.750 \text{ m})/(0.109 \text{ s}) =$

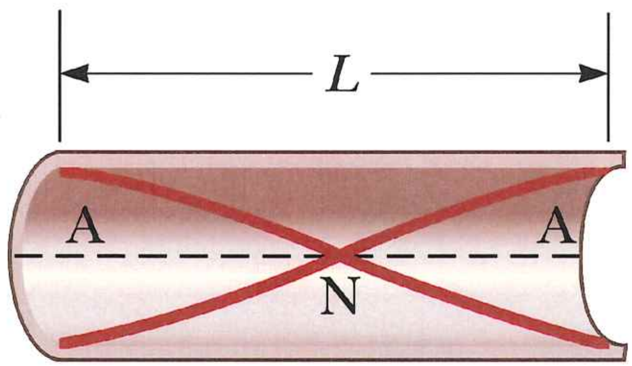
$\boxed{6.88 \text{ m/s}}$ (approximately 15.4 mph).

Standing Waves in Air Columns

A pipe open at both ends.

$$L = 2\left(\frac{\lambda_1}{4}\right) = \frac{\lambda_1}{2}$$

First harmonic



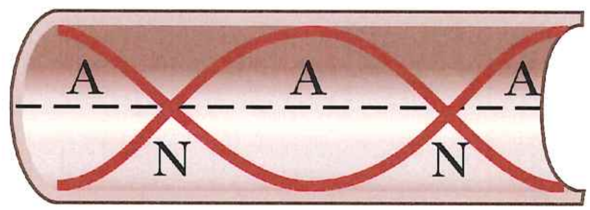
$$\lambda_1 = 2L$$

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$$

$$f = \frac{v}{\lambda_1} = \frac{v}{2L}$$

Standing Waves in Air Columns

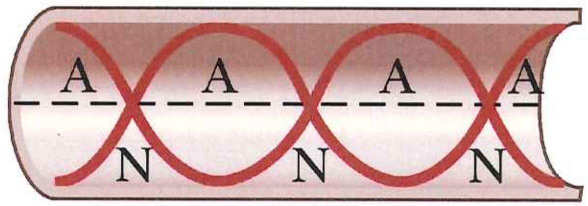
Second harmonic



$$\lambda_2 = L$$

$$f_2 = \frac{v}{L} = 2f_1$$

Third harmonic



$$\lambda_3 = \frac{2}{3}L$$

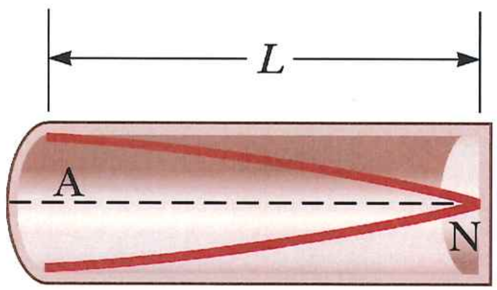
$$f_3 = \frac{3v}{2L} = 3f_1$$

$$f_n = n\frac{v}{2L} = nf_1$$

$$n = 1,\ 2,\ 3,\ldots$$

Standing Waves in Air Columns

A pipe closed at one end.

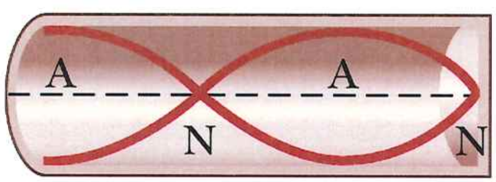


First harmonic

$$\lambda_1 = 4L$$

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$$

$$L = \frac{\lambda_1}{4} \rightarrow \lambda_1 = 4L$$



Third harmonic

$$\lambda_3 = \frac{4}{3}L$$

$$f_3 = \frac{3v}{4L} = 3f_1$$

$$L = 3\left(\frac{\lambda_3}{4}\right) \rightarrow \lambda_3 = \frac{4L}{3}$$

$$f_n = n\frac{v}{4L} = nf_1 \quad n = 1,\ 3,\ 5,\ \ldots$$

54. A pipe has a length of 0.750 m and is open at both ends.

a. Calculate the two lowest harmonics of the pipe.

b. Calculate the two lowest harmonics after one end of the pipe is closed.

14.54 **(a)** The harmonic frequencies of a pipe open at both ends are given by

$$f_n = nf_1 = n\frac{v}{2L} \qquad n = 1,2,3,\ \ldots$$

where v =343 m/s is the sound speed and L = 0.750 m is the pipe's length. Substitute values to find

$$f_1 = (1)\frac{v}{2L} = \frac{343\ \text{m/s}}{2(0.750\ \text{m})} = \boxed{229\ \text{Hz}}$$

$$f_2 = 2f_1 = \boxed{457\ \text{Hz}}$$

(b) The harmonic frequencies of a pipe closed at one end are given by

$$f_n = nf_1 = n\frac{v}{4L} \qquad n = 1,3,5,\ \ldots$$

Substitute values to find

$$f_1 = (1)\frac{v}{4L} = \frac{343\ \text{m/s}}{4(0.750\ \text{m})} = \boxed{114\ \text{Hz}}$$

$$f_3 = 3f_1 = \boxed{343\ \text{Hz}}$$

59. T A pipe open at both ends has a fundamental frequency of 3.00×10^2 Hz when the temperature is 0°C.

a. What is the length of the pipe?

Answer

b. What is the fundamental frequency at a temperature of 30.0°C?

14.59 **(a)** The fundamental wavelength of the pipe open at both ends is $\lambda_1 = 2L = v/f_1$. Since the speed of sound is 331 m/s at 0°C, the length of the pipe is

$$L = \frac{v}{2f_1} = \frac{331\text{ m/s}}{2(300\text{ Hz})} = \boxed{0.552\text{ m}}$$

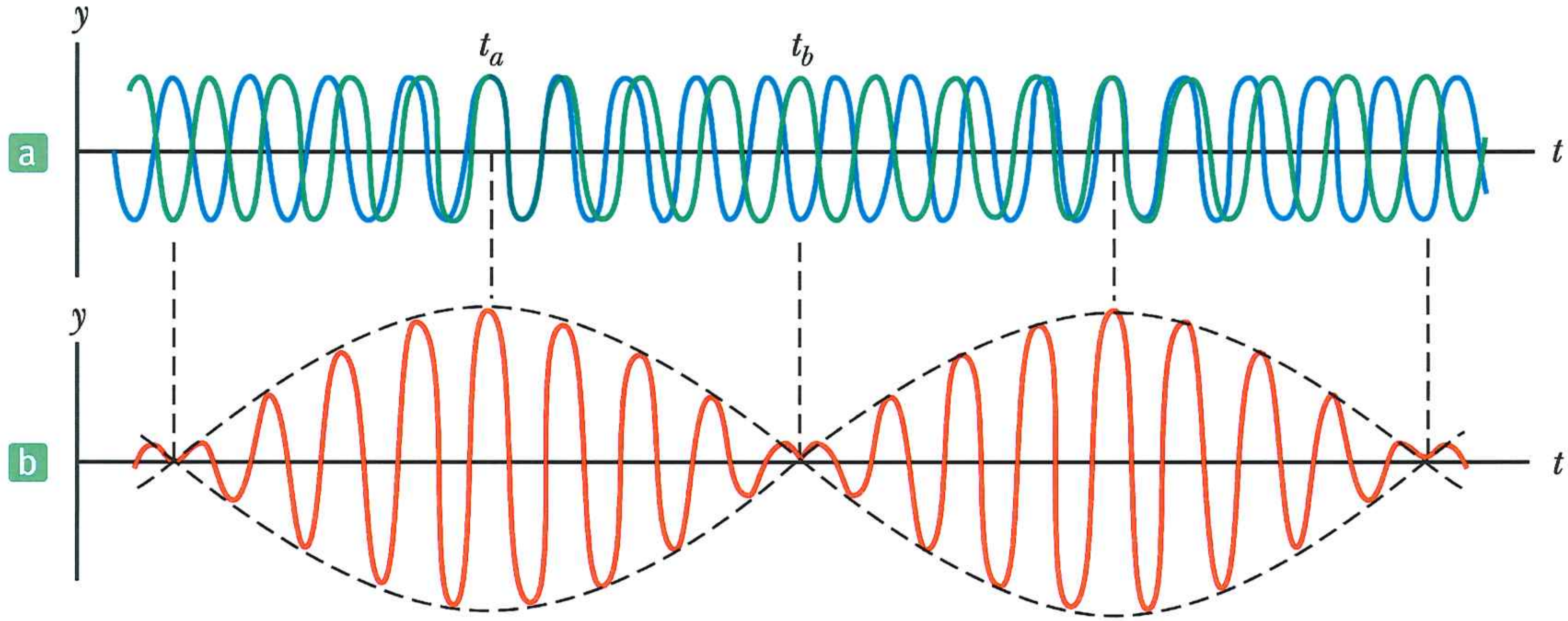
(b) At $T = 30°\text{C} = 303$ K,

$$v = (331\text{ m/s})\sqrt{\frac{T_K}{273}} = (331\text{ m/s})\sqrt{\frac{303}{273}} = 349\text{ m/s}$$

and

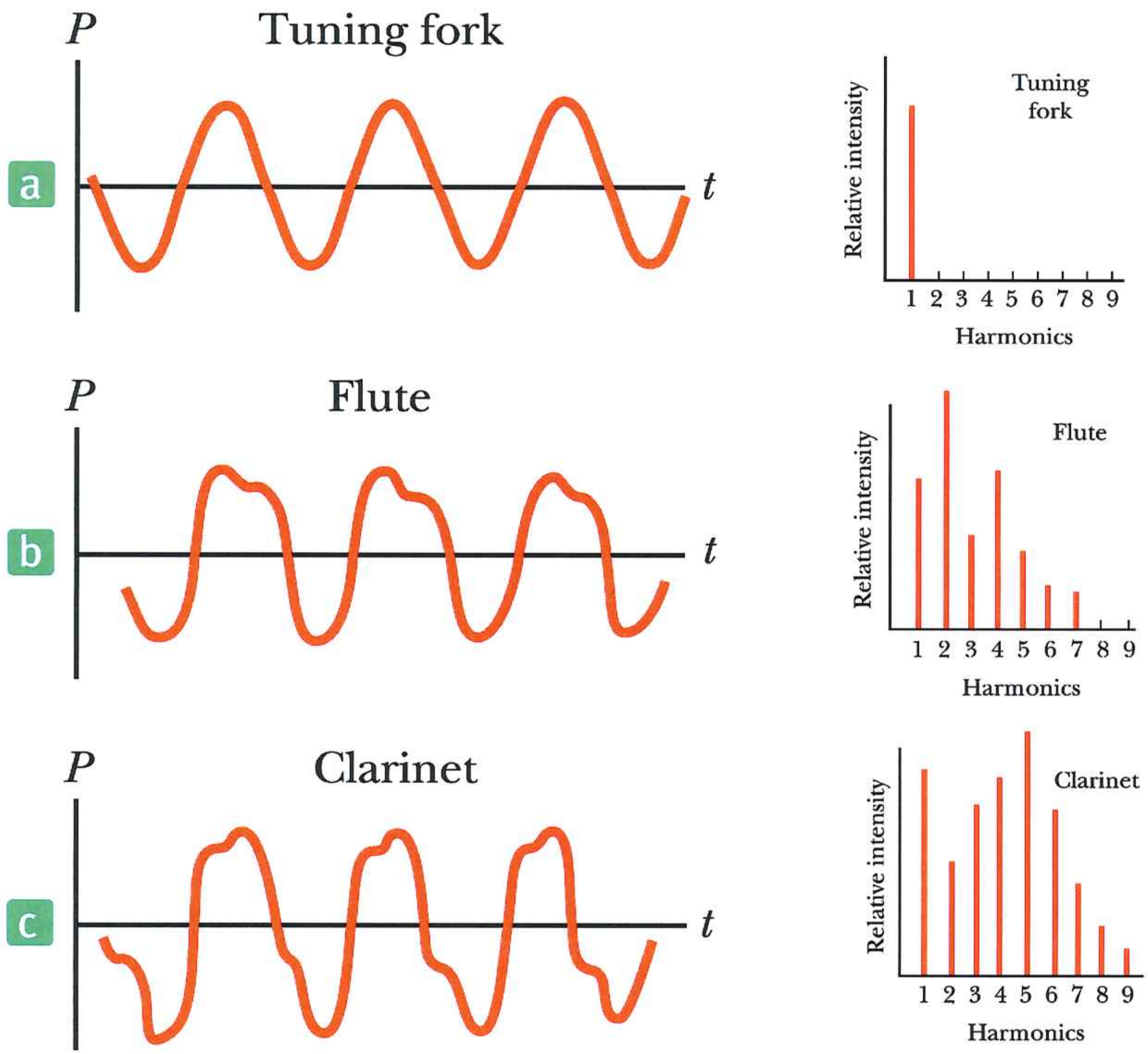
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L} = \frac{349\text{ m/s}}{2(0.552\text{ m})} = \boxed{316\text{ Hz}}$$

Beats



$$f_b = |f_2 - f_1|$$

Quality of Sound



61. A guitarist sounds a tuner at 196 Hz while his guitar sounds a frequency of 199 Hz. Find the beat frequency.

14.61 The beat frequency is $f_b = |f_2 - f_1| = |196\text{ Hz} - 199\text{ Hz}| = \boxed{3\text{ Hz}}$.

63. 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 1.10×10^2 Hz has two strings at this frequency. If one string slips from its normal tension of 6.00×10^2 N to 5.40×10^2 N, what beat frequency is heard when the hammer strikes the two strings simultaneously?

14.63 In a string fixed at both ends, the length of the string is equal to a half-wavelength of the fundamental resonance frequency, so $\lambda_1 = 2L$. The fundamental frequency may then be written as

$$f_1 = \frac{v}{\lambda_1} = \frac{1}{2L}\sqrt{\frac{F}{\mu}} = \sqrt{\frac{F}{4L^2\mu}}$$

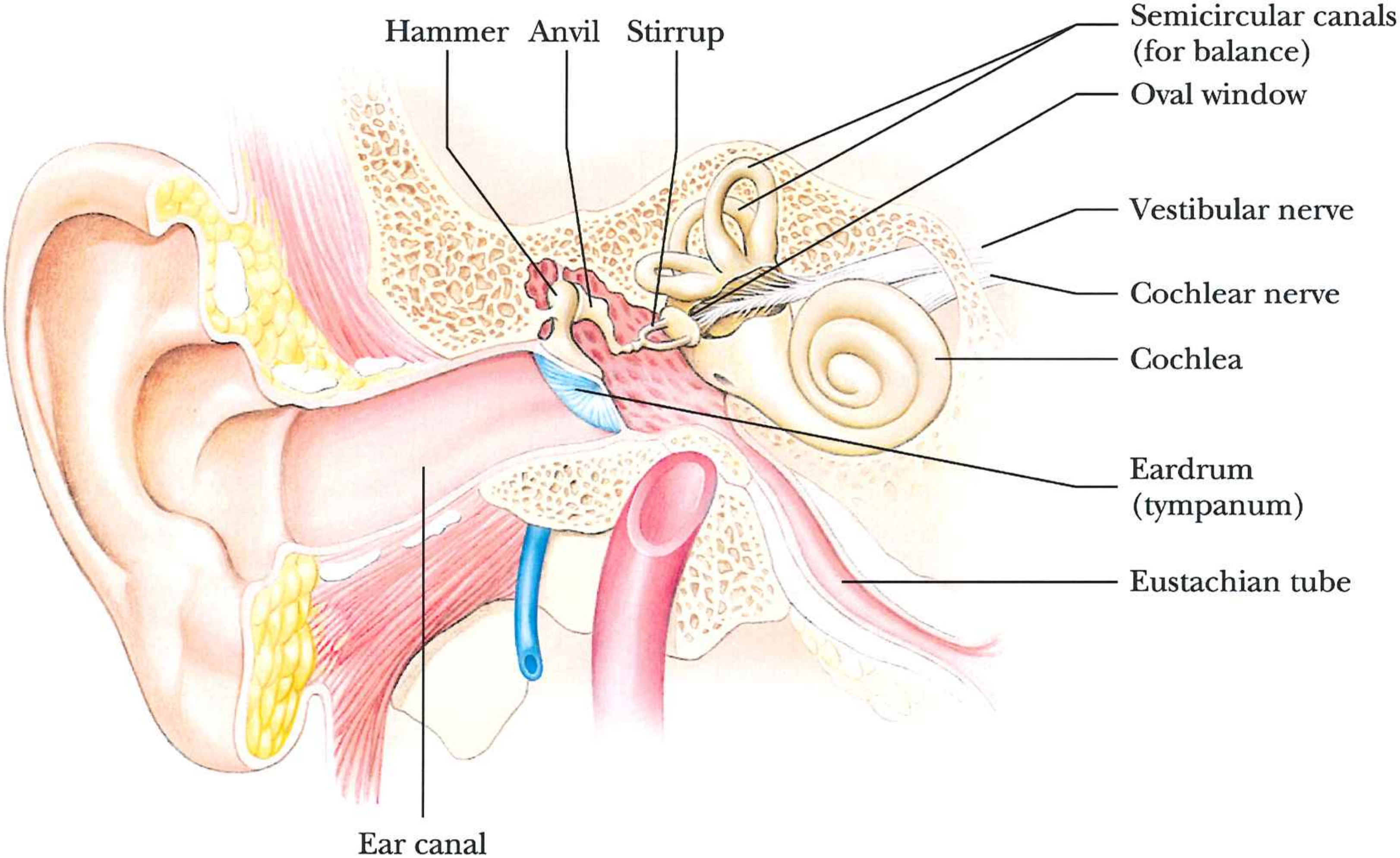
If a second identical string with tension $F' < F$ is struck, the fundamental frequency of vibration would be

$$f_1' = \sqrt{\frac{F'}{4L^2\mu}} = \sqrt{\left(\frac{F}{4L^2\mu}\right)\frac{F'}{F}} = f_1\sqrt{\frac{F'}{F}}$$

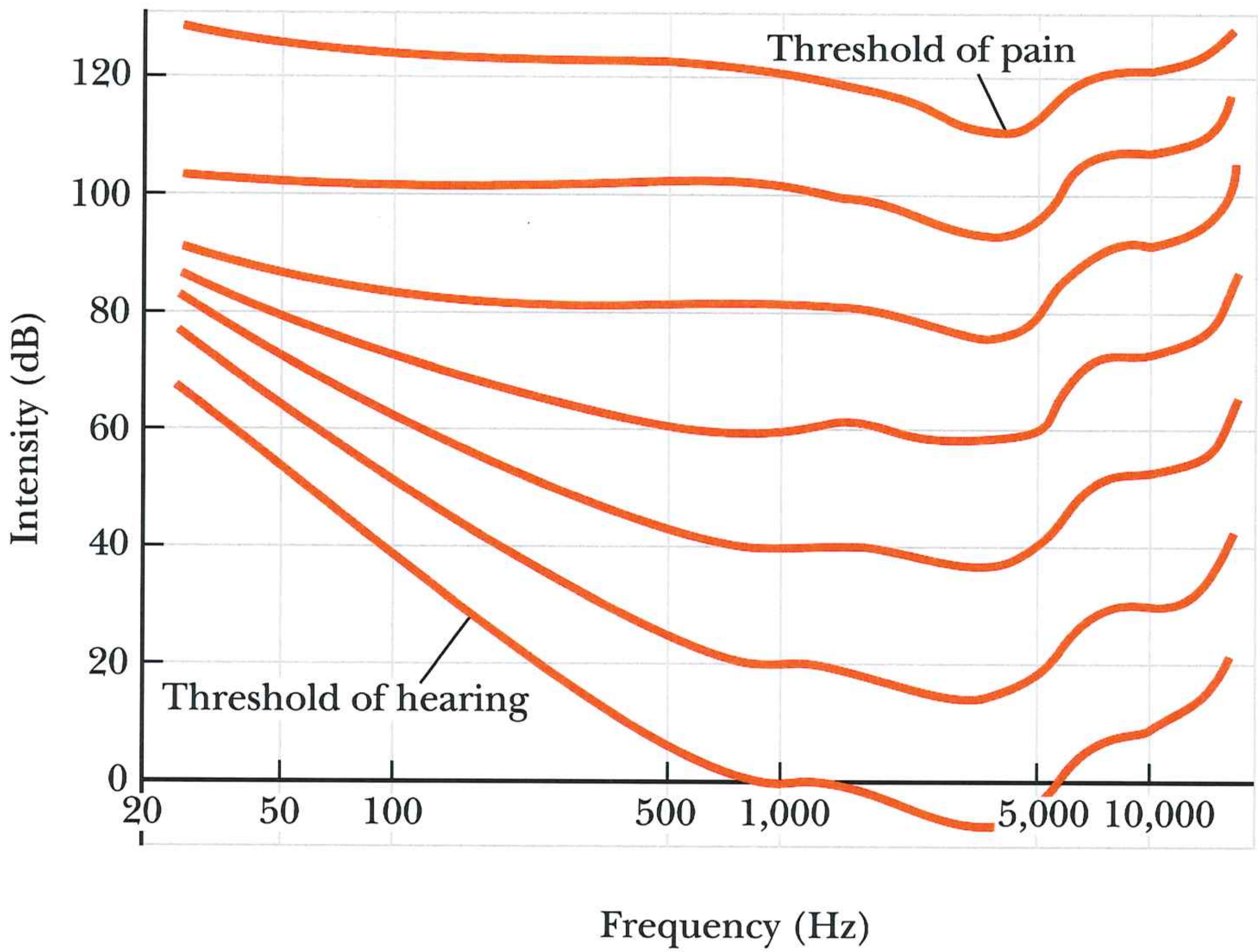
When the two strings are sounded together, the beat frequency heard will be

$$f_{\text{beat}} = f_1 - f_1' = f_1\left(1 - \sqrt{\frac{F'}{F}}\right) = (1.10\times10^2\ \text{Hz})\left(1 - \sqrt{\frac{5.40\times10^2\ \text{N}}{6.00\times10^2\ \text{N}}}\right) = \boxed{5.64\ \text{beats/s}}$$

The Ear


Hammer
Anvil
Stirrup
Semicircular canals
(for balance)
Oval window
Vestibular nerve
Cochlear nerve
Cochlea
Eardrum
(tympanum)
Eustachian tube
Ear canal

The Ear


Threshold of pain
Threshold of hearing
Intensity (dB)
0
20
40
60
80
100
120
20
50
100
500
1,000
5,000
10,000
Frequency (Hz)

68. BIO If a human ear canal can be thought of as resembling an organ pipe, closed at one end, that resonates at a fundamental frequency of 3.0×10^3 Hz, what is the length of the canal? Use a normal body temperature of $37.0°C$ for your determination of the speed of sound in the canal.

14.68 The extra sensitivity of the ear at 3 000 Hz appears as downward dimples on the curves in Figure 14.30 of the textbook.

At $T = 37°C = 310$ K the speed of sound in air is

$$v = (331 \text{ m/s})\sqrt{\frac{T_K}{273}} = (331 \text{ m/s})\sqrt{\frac{310}{273}} = 353 \text{ m/s}$$

Thus, the wavelength of 3 000 Hz sound is

$$\lambda = \frac{v}{f} = \frac{353 \text{ m/s}}{3\ 000 \text{ Hz}} = 0.118 \text{ m}$$

For the fundamental resonant mode in a pipe closed at one end, the length required is

$$L = \frac{\lambda}{4} = \frac{0.118 \text{ m}}{4} = 0.029\ 5 \text{ m} = \boxed{2.95 \text{ cm}}$$

81. By proper excitation, it is possible to produce both longitudinal and transverse waves in a long metal rod. In a particular case, the rod is 1.50 m long and 0.200 cm in radius and has a mass of 50.9 g. Young's modulus for the material is 6.80×10^{10} Pa. Determine the required tension in the rod so that the ratio of the speed of longitudinal waves to the speed of transverse waves is 8.

14.81 The speeds of the two types of waves in the rod are

$$v_{\text{long}} = \sqrt{\frac{Y}{\rho}} = \sqrt{\frac{Y}{m/V}} = \sqrt{\frac{Y(A \cdot L)}{m}} \text{ and } v_{\text{trans}} = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{F \cdot L}{m}}$$

Thus, if $v_{\text{long}} = 8v_{\text{trans}}$, we have $\frac{Y(A \cdot L)}{m} = 64\left(\frac{F \cdot L}{m}\right)$, or the required tension is

$$F = \frac{Y \cdot A}{64} = \frac{\left(6.80 \times 10^{10} \text{ N/m}^2\right)\left[\pi\left(0.200 \times 10^{-2} \text{ m}\right)^2\right]}{64} = \boxed{1.34 \times 10^4 \text{ N}}$$