# Chapter 14

# Waves and Sound

## Answers to Even-numbered Conceptual Questions

**2.** Waves passing through a field of grain are longitudinal waves – the motion of each stalk of grain is in the same direction as the motion of the wave itself.

**4.** This wave is longitudinal, since each cat moves in the same direction as the wave.

**6.** Referring to Equation 14-2, we see that to double the speed, the tension in the string must be increased by a factor of 4.

**8.** The thick string has more mass per length than the thin string. Therefore, if the wave speed is the same, the tension in the thick string must be greater than the tension in the thin string.

**10.** **(a)** When the string is displaced (stretched) by its greatest amount, its potential energy is a maximum, just as in the case of a spring. **(b)** At zero displacement, the string is like a spring at its equilibrium position. Therefore, the potential energy of the string is a minimum.

**12.** **(a)** This wave travels in the negative $x$ direction, because $Bx + Ct$ = (constant) implies $x$ = (constant)/$B$ – $(C/B)t$. **(b)** The constant $A$ is the amplitude of the wave. **(c)** The speed of this wave, as can be seen from part (a), is $C/B$. **(d)** To be specific, let's find the times when the wave has zero displacement at $x = 0$. In this case, we have $y = A \sin(Ct)$, which is equal to zero at the times $t = 0, \pm\pi/C, \pm 2\pi/C, \pm 3\pi/C, \ldots$. Other values of $x$ can be considered similarly.

**14.** If the speed of sound depended on frequency, the sound in the first row – where the travel time is so small – would not be affected significantly. Farther back from the stage, however, sounds with different frequencies would arrive at different times – the bass would be "out of sync" with the treble.

**16.** As was shown in Example 14-5 for the case of sound, there is a direct relationship between the speed of an object and the Doppler frequency it experiences. This effect applies to radar waves as well, providing a one-to-one correspondence between the observed frequency and the speed of the car.

**18.** As can be seen in Figure 14-18, the speed of the observer must be equal to the speed of sound.

**20.** The sliding part of a trombone varies the length of the vibrating air column that produces the trombone's sound. By adjusting this length, the player controls the resonant frequencies of the instrument. This, in turn, varies the frequency of sound produced by the trombone.

**22.** The thicker string is used to produce the low-frequency notes. This follows because the frequency of the fundamental depends directly on the speed of waves on the string. Therefore, for a given tension, a string with a greater mass per length has a smaller wave speed and hence a lower frequency.

**24.** The sound produced after taking a sip is lower in frequency. This is because the vibrating column of air is now longer, which means that the wavelength of the sound is longer as well. Since the speed of sound is the same, it follows that the frequency is reduced.

**26.** You have just observed a series of beats between your wipers and the wipers of the other car.

**28.** You hear no beats because the difference in frequency between these notes is too great to produce detectable beats.

## Solutions to Problems

**1. (a)** The wavelength is the horizontal crest-to-crest distance, or twice the horizontal crest-to-trough distance:

$$\lambda = 2(23\text{ cm}) = \boxed{46\text{ cm}}$$

**(b)** The amplitude is the vertical crest-to-midline distance, or half the vertical crest-to-trough distance:

$$A = \frac{1}{2}(17\text{ cm}) = \boxed{8.5\text{ cm}}$$

**2.** $v = \lambda f = (34\text{ m})(14\text{ Hz}) = \boxed{4.8\times10^2\text{ m/s}}$

**3.** $$f = \frac{v_1}{\lambda_1} = \frac{2.0\ \frac{\text{m}}{\text{s}}}{1.5\text{ m}} = 1.333\text{ Hz}$$

$$\lambda_2 = \frac{v_2}{f} = \frac{1.6\ \frac{\text{m}}{\text{s}}}{1.333\text{ Hz}} = \boxed{1.2\text{ m}}$$

**4.** $$f = \frac{v}{\lambda} = \frac{\left(750\times10^3\ \frac{\text{m}}{\text{h}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)}{310\times10^3\text{ m}} = \boxed{6.7\times10^{-4}\text{ Hz}}$$

**5. (a)** $d_\text{w} = vt = \lambda ft = (27\times10^{-2}\text{ m})(5.5\text{ Hz})(0.50\text{ s}) = \boxed{0.74\text{ m}}$

**(b)** $d_\text{k} = (4A)\left(\frac{t}{T}\right) = 4Aft = 4(14\times10^{-2}\text{ m})(5.5\text{ Hz})(0.50\text{ s}) = \boxed{1.5\text{ m}}$

**(c)** The distance traveled by a wave peak is independent of the amplitude, so the answer in part (a) is unchanged. The distance traveled by the knot varies directly with the amplitude, so the answer in part (b) is halved.

**6.** $$v = \sqrt{\frac{g\lambda}{2\pi}} = \sqrt{\frac{\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(4.5\text{ m})}{2\pi}} = \boxed{2.67\text{ m/s}}$$

$$f = \frac{v}{\lambda} = \frac{2.651\ \frac{\text{m}}{\text{s}}}{4.5\text{ m}} = \boxed{0.59\text{ Hz}}$$

**7.** $v=\sqrt{gd}=\sqrt{\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(2.6\times10^{-2}\ \text{m})}=\boxed{0.51\ \text{m/s}}$

$f=\frac{v}{\lambda}=\frac{0.505\ \frac{\text{m}}{\text{s}}}{0.0075\ \text{m}}=\boxed{67\ \text{Hz}}$

**8.** $v=\sqrt{\frac{F}{\mu}}$, so $v\propto\sqrt{F}$ and to double the speed one must $\boxed{\text{quadruple the tension force}}$.

**9.** $t=\frac{d}{v}=d\sqrt{\frac{\mu}{F}}=d\sqrt{\frac{\frac{m}{d}}{F}}=\sqrt{\frac{md}{F}}=\sqrt{\frac{(0.032\ \text{kg})(9.5\ \text{m})}{8.6\ \text{N}}}=\boxed{0.19\ \text{s}}$

**10.** **(a)** $t\propto\frac{1}{\sqrt{F}}$, so with increased tension the wave takes $\boxed{\text{less time}}$.

**(b)** $t=\sqrt{\frac{md}{F}}$

For 9.0 N, $t=\sqrt{\frac{(0.032\ \text{kg})(9.5\ \text{m})}{9.0\ \text{N}}}=\boxed{0.18\ \text{s}}$

For 10.0 N, $t=\sqrt{\frac{(0.032\ \text{kg})(9.5\ \text{m})}{10.0\ \text{N}}}=\boxed{0.17\ \text{s}}$

**11.** $v=\sqrt{\frac{F}{\mu}}$

$F=\mu v^2=\frac{m}{L}\left(\frac{L}{t}\right)^2=\frac{mL}{t^2}$

**(a)** $F=\frac{(0.085\ \text{kg})(7.3\ \text{m})}{(0.94\ \text{s})^2}=\boxed{0.70\ \text{N}}$

**(b)** $F\propto m$ for a given $v$ and $L$. So increased mass means $\boxed{\text{increased}}$ tension.

**(c)** $F=\frac{(100.0\ \text{kg})(7.3\ \text{m})}{(0.94\ \text{s})^2}=\boxed{0.83\ \text{N}}$

**12.** $v=\sqrt{\frac{F}{\mu}}$, and a doubled diameter means a quadrupled cross-sectional area, thus a quadrupled mass per length, $\mu$.

$$\frac{v_\text{A}}{v_\text{B}}=\sqrt{\frac{F_\text{A}\mu_\text{B}}{\mu_\text{A}F_\text{B}}}$$
$$=\sqrt{4.0\frac{F_\text{A}}{F_\text{B}}}$$
$$=\sqrt{4.0\left(\frac{410\ \text{N}}{820\ \text{N}}\right)}$$
$$=\boxed{1.4}$$

**13.**

| quantity | dimension |
|---|---|
| speed $v$ | $\frac{[\mathrm{L}]}{[\mathrm{T}]}$ |
| tension $T$ | $\frac{[\mathrm{M}][\mathrm{L}]}{[\mathrm{T}^2]}$ |
| radius $R$ | $[\mathrm{L}]$ |
| mass per volume $\rho$ | $\frac{[\mathrm{M}]}{[\mathrm{L}^3]}$ |

Since speed has dimension [T] in the denominator, and only tension contains dimension [T], we conclude that $v \propto \sqrt{T}$

Since speed does not have dimension [M], but $T$ does, it is necessary to include mass per volume in the denominator.

$$v \propto \sqrt{\frac{T}{\rho}}$$

So far this has the dimensions

$$\sqrt{\frac{\frac{[\mathrm{M}][\mathrm{L}]}{[\mathrm{T}^2]}}{\frac{[\mathrm{M}]}{[\mathrm{L}^3]}}} \propto \sqrt{\frac{[\mathrm{L}^4]}{[\mathrm{T}^2]}}$$

From this we see that a factor of dimension $[\mathrm{L}^2]$ must be in the denominator. So $\boxed{v \propto \sqrt{\frac{T}{R^2\rho}}}$ which has dimension $\sqrt{\frac{[\mathrm{L}^2]}{[\mathrm{T}^2]}} = \frac{[\mathrm{L}]}{[\mathrm{T}]}$.

**14.** $y = A\cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$.

Here,

$$y = (0.11\text{ m})\cos\left(\frac{2\pi}{2.5\text{ m}}x - \frac{2\pi}{1.2\text{ s}}t\right) = \boxed{(0.11\text{ m})\cos\left(\frac{2\pi}{2.5\text{ m}}x - \frac{\pi}{0.60\text{ s}}t\right)}$$

**15.** $y = A\cos\left(\frac{2\pi}{\lambda}x + \frac{2\pi}{T}t\right)$.

The "+" sign is because the wave propagates to the left. Here $T = \frac{1}{f} = \frac{\lambda}{v} = \frac{2.8\text{ m}}{13.3\ \frac{\text{m}}{\text{s}}} = 0.2105\text{ s}$

and $y = (0.12\text{ m})\cos\left(\frac{2\pi}{2.8\text{ m}}x + \frac{2\pi}{0.2105\text{ s}}t\right) = \boxed{(0.12\text{ m})\cos\left(\frac{\pi}{1.4\text{ m}}x + \frac{\pi}{0.11\text{ s}}t\right)}$

**16.** The form is $y = A\cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$.

**(a)** $A = \boxed{15\text{ cm}}$

**(b)** $\dfrac{\pi}{5.0\text{ cm}}=\dfrac{2\pi}{\lambda}$, so $\lambda=\boxed{10\text{ cm}}$

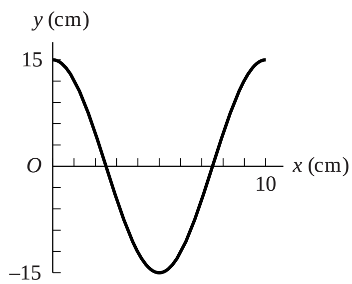
**(c)** $\dfrac{\pi}{12\text{ s}}=\dfrac{2\pi}{T}$, so $T=\boxed{24\text{ s}}$

**(d)** $v=\lambda f=\dfrac{\lambda}{T}=\dfrac{10\text{ cm}}{24\text{ s}}=\boxed{0.42\text{ cm/s}}$

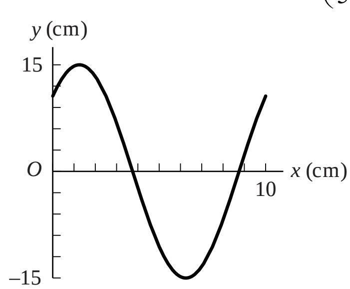
**(e)** $\boxed{\text{To the right}}$, because the *t*-term has the opposite sign of the *x*-term.

**17.** $y=(15\text{ cm})\cos\left(\dfrac{\pi}{5.0\text{ cm}}x-\dfrac{\pi}{12\text{ s}}t\right)$, with *x*, *y* in centimeters and *t* in seconds.

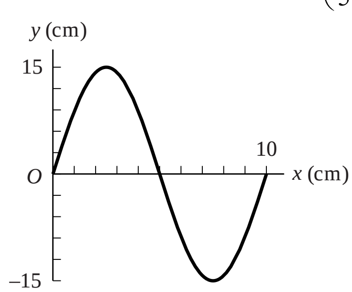
**(a)** For $t=0$, $y=(15\text{ cm})\cos\left(\dfrac{\pi}{5.0\text{ cm}}x\right)$:




**(b)** For $t=3.0$ s, $y=(15\text{ cm})\cos\left(\dfrac{\pi}{5.0\text{ cm}}x-\dfrac{\pi}{4.0}\right)$:




**(c)** For $t=6.0$ s, $y=(15\text{ cm})\cos\left(\dfrac{\pi}{5.0\text{ cm}}x-\dfrac{\pi}{2.0}\right)$:




**(d)** The time is one quarter-period, or $\boxed{6.0\text{ s}}$.

**18. (a)** Waves $\boxed{y_A \text{ and } y_C}$, because $x$ and $t$ have opposite signs.

**(b)** Waves $\boxed{y_B \text{ and } y_D}$, because $x$ and $t$ have the same sign.

**(c)** Wave $\boxed{y_C}$, which has the largest magnitude coefficient for $t$.

**(d)** Wave $\boxed{y_A}$, which has the smallest magnitude coefficient for $x$.

**(e)** Wave $\boxed{y_C}$, for which the magnitude of the $t$-coefficient divided by the $x$-coefficient is greatest $\left(\text{thereby maximizing } \dfrac{1/T}{1/\lambda} = \lambda f = v\right)$.

**19.** $d = \dfrac{1}{2}vt = \dfrac{1}{2}\left(343 \ \dfrac{\text{m}}{\text{s}}\right)(2.1 \text{ s}) = \boxed{360 \text{ m}}$

**20. (a)** $t = 2\dfrac{d}{v} = 2\left(\dfrac{75 \text{ m}}{1530 \ \frac{\text{m}}{\text{s}}}\right) = \boxed{0.098 \text{ s}}$

**(b)** $\lambda = \dfrac{v}{f} = \dfrac{1530 \text{ m/s}}{55 \text{ kHz}} = 28 \times 10^{-3} \text{ m} = \boxed{28 \text{ mm}}$

**21.** Low A: $f = (440 \text{ Hz})\left(\dfrac{1}{2}\right)^4 = \boxed{27.5 \text{ Hz}}$

$\lambda = \dfrac{v}{f} = \dfrac{343 \ \frac{\text{m}}{\text{s}}}{2.75 \text{ Hz}} = \boxed{12.5 \text{ m}}$

High C: $f = (262 \text{ Hz})(2)^4 = \boxed{4.19 \text{ kHz}}$

$\lambda = \dfrac{v}{f} = \dfrac{343 \ \frac{\text{m}}{\text{s}}}{4.192 \times 10^3 \text{ Hz}} = \boxed{8.18 \text{ cm}}$

**22. (a)** $\lambda = \dfrac{v}{f} = \dfrac{343 \ \frac{\text{m}}{\text{s}}}{420 \text{ Hz}} = \boxed{0.817 \text{ m}}$

**(b)** It $\boxed{\text{decreases}}$, because $\lambda$ varies inversely as $f$.

**(c)** $\lambda = \dfrac{343 \ \frac{\text{m}}{\text{s}}}{450 \text{ Hz}} = \boxed{0.762 \text{ m}}$

**23. (a)** total time = fall time + sound travel time

$$y = y_0 + v_0 t_f + \frac{1}{2} a t_f^2$$

$$0 = d + 0 + \frac{1}{2}\left(-9.81 \frac{\text{m}}{\text{s}^2}\right) t_f^2$$

$$t_f = \sqrt{\frac{d}{4.905 \frac{\text{m}}{\text{s}^2}}}$$

$$v_s t_s = d$$

$$t_s = \frac{d}{343 \frac{\text{m}}{\text{s}}}$$

$$t_s + t_f = 1.5 \text{ s}$$

$$0 = \left(\frac{1}{343 \frac{\text{m}}{\text{s}}}\right) d + \frac{1}{\sqrt{4.905 \frac{\text{m}}{\text{s}^2}}} \sqrt{d} - 1.5 \text{ s}$$

By the quadratic formula, with $\sqrt{d}$ as the variable,

$$\sqrt{d} = (3.2537 \text{ m})^{1/2}$$

$$d = \boxed{11 \text{ m}}$$

**(b)** Less, because although the sound travel time would double, the fall time would less than double.

**24.** fall time = total time – sound travel time

$$t_s = \frac{d}{v} = \frac{8.8 \text{ m}}{343 \frac{\text{m}}{\text{s}}} = 0.0257 \text{ s}$$

$$t_f = 1.2 \text{ s} - 0.0257 \text{ s} = 1.1743 \text{ s}$$

$$y = y_0 + v_0 t_f + \frac{1}{2} a t_f^2$$

$$v_0 = \frac{y - y_0}{t_f} - \frac{1}{2} a t_f$$

$$= \frac{-8.8 \text{ m}}{1.1743 \text{ s}} - \frac{1}{2}\left(-9.81 \frac{\text{m}}{\text{s}^2}\right)(1.1743 \text{ s})$$

$$= -1.7 \text{ m/s}$$

speed = $\boxed{1.7 \text{ m/s}}$

**25.** $\beta = 10 \text{ Log}\left(\frac{I}{I_0}\right)$

$$I = I_0 10^{\beta/10}$$

$$= \left(10^{-12} \frac{\text{W}}{\text{m}^2}\right)(10^{90.0/10})$$

$$= \boxed{1.00 \text{ mW/m}^2}$$

**26.** **(a)** Since $I=\dfrac{P}{A}$ and $A$ is increased by a factor of 9 when distance is tripled, $I$ is decreased by $\boxed{\text{a factor of 9}}$.

**(b)** Since $\beta = 10\text{ Log}\left(\dfrac{I}{I_0}\right)$ and $I$ is decreasing by a factor of 9, $\beta$ is decreased by $10\text{ Log}\left(\dfrac{1}{9}\right)=\boxed{-9.54}$.

**27.** $\Delta\beta=\beta_2-\beta_1=10\log\left(\dfrac{I_2}{I_0}\right)-10\log\left(\dfrac{I_1}{I_0}\right)=10\left\{\log\left(\dfrac{I_2}{I_0}\right)-\log\left(\dfrac{I_1}{I_0}\right)\right\}$

$$\Delta\beta=10\log\left[\frac{\left(\frac{I_2}{I_0}\right)}{\left(\frac{I_1}{I_0}\right)}\right]=10\log\left(\frac{I_2}{I_1}\right)$$

$$2.5\text{ dB}=10\log\left(\frac{I_2}{I_1}\right)=10\log\left(\frac{I_2}{380\text{ W/m}^2}\right)$$

$$0.25=\log\left(\frac{I_2}{380\text{ W/m}^2}\right)$$

$$10^{0.25}=\frac{I_2}{380\text{ W/m}^2}$$

$$I_2=(380\text{ W/m}^2)(10^{0.25})=\boxed{680\text{ W/m}^2}$$

**28.** $I_2=\left(\dfrac{r_1}{r_2}\right)^2 I_1$

$$r_2=r_1\sqrt{\frac{I_1}{I_2}}$$

$$=(1.00\text{ m})\sqrt{\frac{2.80\times10^{-6}\ \frac{\text{W}}{\text{m}^2}}{10^{-12}\ \frac{\text{W}}{\text{m}^2}}}$$

$$=\boxed{1.67\text{ km}}$$

**29.** $I_2=\left(\dfrac{r_1}{r_2}\right)^2 I_1$

**(a)** $I_2=\left(\dfrac{2.0\text{ m}}{12\text{ m}}\right)^2 I_1$

$$10\text{ Log}\left(\frac{I_2}{I_0}\right)=10\text{ Log}\left[\left(\frac{2.0\text{ m}}{12\text{ m}}\right)^2\left(\frac{I_1}{I_0}\right)\right]$$

$$=10\text{ Log}\left(\frac{I_1}{I_0}\right)+10\text{ Log}\left[\left(\frac{2.0\text{ m}}{12\text{ m}}\right)^2\right]$$

$$=120+(-15.6)$$

$$=\boxed{104\text{ dB}}$$

**(b)** $10\text{ Log}\left(\frac{I_2}{I_0}\right) = 10\text{ Log}\left(\frac{I_1}{I_0}\right) + 10\text{ Log}\left[\left(\frac{2.0\text{ m}}{21\text{ m}}\right)^2\right] = 120 + (-20.4) = \boxed{99.6\text{ dB}}$

**(c)** At maximum distance, $I_2 = I_0$ and $10\text{ Log}\left(\frac{I_2}{I_0}\right) = 0.$

$$10\text{ Log}\left[\left(\frac{2.0\text{ m}}{r_2}\right)^2\right] = -120$$

$$\left(\frac{2.0\text{ m}}{r_2}\right)^2 = 10^{-12}$$

$$r_2 = \frac{2.0\text{ m}}{10^{-6}} = \boxed{2.0\times10^6\text{ m}}$$

This is a theoretical limit that could be realized in an ideal case. In a more realistic scenario, ambient noise, as well as energy losses when the sound waves are reflected or absorbed by surfaces, would prevent us from hearing the sound 2000 km away. Sometimes, the real-world factors we ignore make a huge difference.

**30.** A 10 dB increase in intensity level is a 10-fold increase in power. It would take $\boxed{\text{10 callers}}$.

**31. (a)** Twenty violins represent a 10-fold increase from one violin, followed by a 2-fold increase, or an increase of 10.0 dB + 3.0 dB = 13.0 dB. So one violin has an intensity of 82.5 dB – 13.0 dB = $\boxed{\text{69.5 dB}}$.

**(b)** Doubling the number of violins doubles the intensity, producing an intensity level increase of 3 dB. The intensity level will be 72.5 dB, which is much $\boxed{\text{less than}}$ 165 dB.

**32.** $P = IA$, where $A = \pi r^2 = \pi(4.0\times10^{-3}\text{ m})^2 = 5.0\times10^{-5}\text{ m}^2.$

**(a)** $P = \left(10^{-12}\ \frac{\text{W}}{\text{m}^2}\right)(5.0\times10^{-5}\text{ m}^2) = \boxed{5.0\times10^{-17}\text{ W}}$

**(b)** $P = \left(1\ \frac{\text{W}}{\text{m}^2}\right)(5.0\times10^{-5}\text{ m}^2) = \boxed{5.0\times10^{-5}\text{ W}}$

**33.** $I_\text{P} = \left(\frac{r_\text{B}}{r_\text{P}}\right)^2 I_\text{B}$

$$r_\text{P} = r_\text{B}\sqrt{\frac{I_\text{B}}{I_\text{P}}} = (10\text{ m})(\sqrt{2}) = 10\sqrt{2}\text{ m}$$

Now use the Pythagorean Theorem.

$$r_\text{BP} = \sqrt{(10\text{ m})^2 + (10\sqrt{2}\text{ m})^2} = \boxed{10\sqrt{3}\text{ m}}$$

**34.** Moving source:

$$f' = \left(\frac{v}{v-u}\right)f$$
$$v-u = \left(\frac{f}{f'}\right)v$$
$$u = \left(1-\frac{f}{f'}\right)v$$
$$= \left(1-\frac{450\text{ Hz}}{470\text{ hz}}\right)\left(343\ \frac{\text{m}}{\text{s}}\right)$$
$$= \boxed{15\text{ m/s}}$$

**35.** Moving source:

$$f' = \left(\frac{1}{1-\frac{u}{v}}\right)f = \left(\frac{1}{1-\frac{31.8\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}\right)(136\text{ Hz}) = \boxed{1.50\times10^2\text{ Hz}}$$

**36.** Moving observer (the passenger):

$$f' = (1+\tfrac{u}{v})f = \left(1+\frac{31.8\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}\right)(136\text{ Hz}) = \boxed{149\text{ Hz}}$$

**37.** **(a)** moving source:

$$f' = \left(\frac{1}{1-\frac{u}{v}}\right)f = \left(\frac{1}{1-\frac{3.60\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}\right)(35.0\text{ kHz}) = \boxed{35.4\text{ kHz}}$$

**(b)** Higher, because the bat is moving toward the moth.

**(c)** $$f' = \left(\frac{1}{1-\frac{4.50\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}\right)(35.0\text{ kHz}) = \boxed{35.5\text{ kHz}}$$

**38.** $$f' = \left(\frac{1+\frac{u_o}{v}}{1-\frac{u_s}{v}}\right)f = \left(\frac{1+\frac{13.0\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}{1-\frac{27.0\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}\right)(512\text{ Hz}) = \boxed{577\text{ Hz}}$$

**39.** $$f'' = \left(1 - \frac{u_o}{v}\right) f'$$
$$= \left(1 - \frac{u_o}{v}\right)\left(\frac{1}{1 - \frac{u_s}{v}}\right) f$$
$$= \left(\frac{1 - \frac{u_o}{v}}{1 - \frac{u_s}{v}}\right) f$$
$$= \left(\frac{1 - \frac{13.0 \text{ m/s}}{343 \text{ m/s}}}{1 - \frac{27.0 \text{ m/s}}{343 \text{ m/s}}}\right)(512 \text{ Hz})$$
$$= \boxed{535 \text{ Hz}}$$

**40.** First, find the truck's speed.
$$f_1' = \left(\frac{1}{1 - \frac{u}{v}}\right) f$$
$$f_2' = \left(\frac{1}{1 + \frac{u}{v}}\right) f$$
$$f_1'\left(1 - \frac{u}{v}\right) = f = f_2'\left(1 + \frac{u}{v}\right)$$
$$f_1'v - f_2'v = f_1'u + f_2'u$$
$$u = \left(\frac{f_1' - f_2'}{f_1' + f_2'}\right) v$$
$$= \left(\frac{460 \text{ Hz} - 410 \text{ Hz}}{460 \text{ Hz} + 410 \text{ Hz}}\right)\left(343 \frac{\text{m}}{\text{s}}\right)$$
$$= 19.7 \frac{\text{m}}{\text{s}}$$

Now,
$$\text{time} = \frac{5.0 \times 10^3 \text{ m}}{19.7 \frac{\text{m}}{\text{s}}} = 254 \text{ s} = \boxed{4.2 \text{ min}}$$

**41.** Moving observer:
$$f' = (1 + \tfrac{u}{v}) f$$
$$1.15 f = (1 + \tfrac{u}{v}) f$$
$$\frac{u}{v} = 0.15$$
$$u = 0.15v = 0.15(343 \text{ m/s})$$
$$= \boxed{51.5 \text{ m/s}}$$

**42. (a)** The pilot of the jet on the ground hears a greater Doppler shift, because Doppler effects are greater with a moving source.

**(b)** Moving observer:

$$f' = (1+\tfrac{u}{v})f = \left(1+\frac{9}{10}\right)(400.0\text{ Hz}) = \boxed{760.0\text{ Hz}}$$

**(c)** Moving source:

$$f' = \left(\frac{1}{1-\frac{u}{v}}\right)f = \left(\frac{1}{1-\frac{9}{10}}\right)(400.0\text{ Hz}) = \boxed{4.000\text{ kHz}}$$

**43. (a)** $$f' = \left(\frac{1+\frac{u_o}{v}}{1-\frac{u_s}{v}}\right)f = \left(\frac{1+\frac{8.5\ \frac{m}{s}}{343\ \frac{m}{s}}}{1-\frac{8.5\ \frac{m}{s}}{343\ \frac{m}{s}}}\right)(300.0\text{ Hz}) = \boxed{320\text{ Hz}}$$

**(b)** Bicyclist A speeding up. For equal changes in speed, moving-source effects are greater than moving-observer effects.

**44.**

$$f'' = \left(1+\frac{u_o}{v}\right)f'$$

$$= \left(1+\frac{u_o}{v}\right)\left(\frac{1}{1+\frac{u_s}{v}}\right)f$$

$$f''\left(1+\frac{u_s}{v}\right) = \left(1+\frac{u_o}{v}\right)f$$

$$u_o = \left[\frac{f''}{f}\left(1+\frac{u_s}{v}\right)-1\right]v$$

$$= \left[\frac{131\text{ Hz}}{125\text{ Hz}}\left(1+\frac{32\ \frac{m}{s}}{343\ \frac{m}{s}}\right)-1\right]\left(343\ \tfrac{m}{s}\right)$$

$$= \boxed{50\text{ m/s}}$$

**45.**

$$f' = \left(\frac{1-\frac{u}{v}}{1+\frac{u}{v}}\right)f \quad (u_o = u_s = u)$$

$$f'(v+u) = f(v-u)$$

$$u = \left(\frac{f-f'}{f+f'}\right)v$$

$$= \left(\frac{205\text{ Hz}-192\text{ Hz}}{205\text{ Hz}+192\text{ Hz}}\right)\left(343\ \frac{m}{s}\right)$$

$$= \boxed{11.2\text{ m/s}}$$

**46.**

$$f = \left(1+\tfrac{u}{v}\right)f_0$$

$$\frac{2}{3}f = \left(1-\tfrac{u}{v}\right)f_0$$

$$\frac{2}{3} = \frac{1-\frac{u}{v}}{1+\frac{u}{v}}$$

$$2v + 2u = 3v - 3u$$

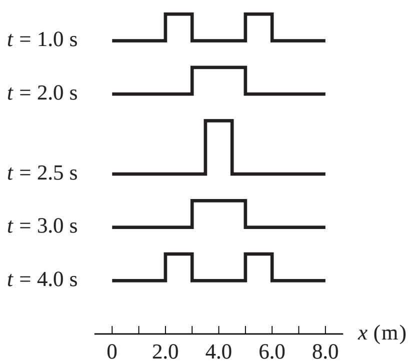
$$5u = v$$

$$u = \frac{1}{5}v$$

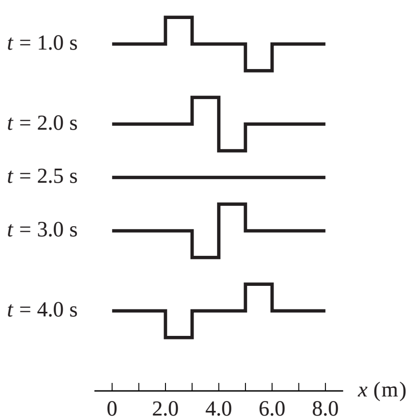
$$= \frac{1}{5}\left(343\ \frac{\text{m}}{\text{s}}\right)$$

$$= \boxed{68.6\ \text{m/s}}$$

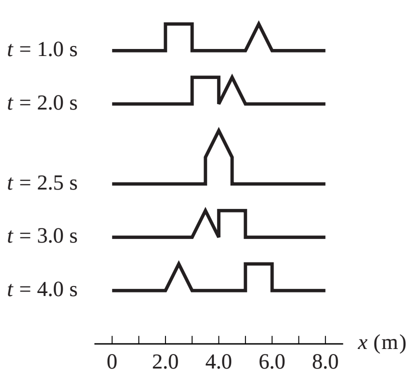
**47.**



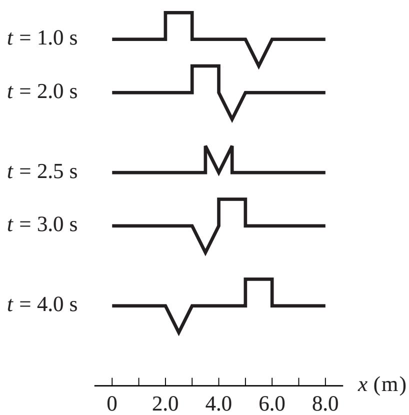

**48.**




**49.**



**50.**




**51.** By the Pythagorean Theorem, your distance from the other speaker is $\sqrt{(0.60\text{ m})^2+(1.0\text{ m})^2}=1.2\text{ m}$ and the difference in distances is 0.166 m. At the lowest constructive interference frequency, that difference is one wavelength, so that

$$f=\frac{v}{\lambda}=\frac{343\ \frac{\text{m}}{\text{s}}}{0.166\text{ m}}=\boxed{2.1\text{kHz}}.$$

**52. (a)** The smallest separation is

$$\frac{\lambda}{2}=\frac{v}{2f}=\frac{343\ \frac{\text{m}}{\text{s}}}{2(440\text{ Hz})}=\boxed{0.39\text{ m}}$$

**(b)** Higher frequency means shorter wavelength and $\boxed{\text{shorter minimum separation}}$.

**(c)** $$\frac{\lambda}{2}=\frac{343\ \frac{\text{m}}{\text{s}}}{2(500.0\text{ Hz})}=\boxed{0.343\text{ m}}$$

**53.** The difference in distances must be one half-wavelength or $\frac{\lambda}{2}=\frac{v}{2f}$ so that the observer must walk one quarter-wavelength.

$$\frac{\lambda}{4}=\frac{v}{4f}=\frac{343\ \frac{\text{m}}{\text{s}}}{4(256\text{ Hz})}=\boxed{0.335\text{ m}}$$

**54. (a)** Lower frequency means longer wavelength and $\boxed{\text{longer required walking distance}}$.

**(b)** $$\frac{\lambda}{4}=\frac{v}{4f}=\frac{343\ \frac{\text{m}}{\text{s}}}{4(240\text{ Hz})}=\boxed{0.36\text{ m}}$$

**55.** The difference in distances from the two speakers is one half-wavelength.

$$d_1 = \sqrt{(5.0\text{ m})^2 + \left(\frac{3.5}{2}\text{ m} + 0.84\text{ m}\right)^2} = 5.631\text{ m}$$

$$d_2 = \sqrt{(5.0\text{ m})^2 + \left(\frac{3.5}{2}\text{ m} - 0.84\text{ m}\right)^2} = 5.082\text{ m}$$

$$f = \frac{v}{\lambda} = \frac{v}{2(d_1 - d_2)} = \frac{343\ \frac{\text{m}}{\text{s}}}{2(5.631\text{ m} - 5.082\text{ m})} = \boxed{0.31\text{ kHz}}$$

**56.** A frequency of close to zero will approach complete destructive interference. The next frequency to produce destructive interference is the one that results in a one-wavelength difference in the distances from the two speakers:

$$f = \frac{v}{\lambda} = \frac{v}{d_2 - d_1} = \frac{343\ \frac{\text{m}}{\text{s}}}{2.33\text{ m}} = \boxed{147\text{ Hz}}$$

**57.** $f_1 = \frac{v}{2L} = \frac{343\ \frac{\text{m}}{\text{s}}}{2(3.5\text{ m})} = \boxed{49\text{ Hz}}$

**58.** $f_1 = \frac{v}{2L}$ and $v = \sqrt{\frac{F}{\mu}}$, so

$$f_1 = \frac{1}{2L}\sqrt{\frac{F}{\mu}} = \frac{1}{2(1.5\text{ m})}\sqrt{\frac{95\text{ N}}{\frac{2.1\times10^{-3}\text{ kg}}{1.5\text{ m}}}} = \boxed{87\text{ Hz}}$$

**59. (a)** $f_1 = \frac{v}{4L} = \frac{343\ \frac{\text{m}}{\text{s}}}{4(2.4\times10^{-2}\text{ m})} = \boxed{3.6\text{ kHz}}$; $\lambda_1 = 4L = 4(2.4\text{ cm}) = \boxed{9.6\text{ cm}}$

**(b)** frequency of second harmonic in pipe open at one end $= 3f_1$

$f = 3(3.57\text{ kHz}) = \boxed{11\text{ kHz}}$

$\lambda = \frac{343\text{ m/s}}{10.7\text{ kHz}} = 31\times10^{-3}\text{ m} = \boxed{3.2\text{ cm}}$

**(c)** $\boxed{\text{Greater}}$, because a shorter wavelength has a higher frequency.

**60. (a)** The number of antinodes equals the number of the harmonic: $\boxed{3}$.

**(b)** $\frac{1}{2}\lambda = \frac{1}{3}L$, so $\lambda = \frac{2}{3}L = \frac{2}{3}(62\text{ cm}) = \boxed{41\text{ cm}}$

**61.** $v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{22.1\text{ N}}{\frac{12.5\times10^{-3}\text{ kg}}{7.66\text{ m}}}} = 116.37\ \frac{\text{m}}{\text{s}}$

**(a)** $f_1 = \frac{v}{2L} = \frac{116.37\ \frac{\text{m}}{\text{s}}}{2(7.66\text{ m})} = \boxed{7.60\text{ Hz}}$

**(b)** $f_2 = \dfrac{2v}{2L} = \dfrac{116.37\ \frac{\text{m}}{\text{s}}}{7.66\ \text{m}} = \boxed{15.2\ \text{Hz}}$

**(c)** Increase, because increasing tension increases wave speed without changing wavelength.

**62. (a)** With a more massive rope, $\mu$ increases and $v$ decreases, resulting in decreasing the frequencies.

**(b)** $v = \sqrt{\dfrac{F}{\mu}} = \sqrt{\dfrac{22.1\ \text{N}}{\frac{15\times10^{-3}\ \text{kg}}{7.66\ \text{m}}}} = 106.23\ \dfrac{\text{m}}{\text{s}}$

$f_1 = \dfrac{v}{2L} = \dfrac{106.23\ \frac{\text{m}}{\text{s}}}{2(7.66\ \text{m})} = \boxed{6.93\ \text{Hz}}$

$f_2 = \dfrac{2v}{2L} = \dfrac{106.23\ \frac{\text{m}}{\text{s}}}{7.66\ \text{m}} = \boxed{13.9\ \text{Hz}}$

**63. (a)** The wave corresponds to $f_3 = 3f_1$.

$f_3 = \dfrac{3v}{4L} = \dfrac{3\left(343\ \frac{\text{m}}{\text{s}}\right)}{4(2.5\ \text{m})} = \boxed{0.10\ \text{kHz}}$

**(b)** $f_1 = \dfrac{v}{4L} = \dfrac{343\ \frac{\text{m}}{\text{s}}}{4(2.5\ \text{m})} = \boxed{34\ \text{Hz}}$

**64. (a)** The wave corresponds to $f_2 = 2f_1$, so $f_1 = \dfrac{1}{2}(232\ \text{Hz}) = \boxed{116\ \text{Hz}}$.

**(b)** $f_1 = \dfrac{v}{2L}$

$L = \dfrac{v}{2f_1}$

$= \dfrac{343\ \frac{\text{m}}{\text{s}}}{2(116\ \text{Hz})}$

$= \boxed{1.48\ \text{m}}$

**65. (a)** $f_n = nf_1 = 440\ \text{Hz}$

$f_{n+1} = (n+1)f_1 = 522\ \text{Hz}$

$f_1 = f_{n+1} - f_n = 522\ \text{Hz} - 440\ \text{Hz} = \boxed{82\ \text{Hz}}$

**(b)** $f_1 = \dfrac{v}{2L}$

$L = \dfrac{v}{2f_1}$

$= \dfrac{343\ \frac{\text{m}}{\text{s}}}{2(82\ \text{Hz})}$

$= \boxed{2.1\ \text{m}}$

**66.** $f_{\text{beat}} = |f_1 - f_2| = |292\text{ Hz} - 275\text{ Hz}| = \boxed{17\text{ Hz}}$

**67.** $f = f_c \pm f_{\text{beat}} = 261\text{ Hz} \pm 3\text{ Hz} = \boxed{264\text{ Hz or }258\text{ Hz}}$

**68.** $f_2 = f_1 + f_{\text{beat}} = 441\text{ Hz} + \dfrac{8.00\text{ beats}}{2.00\text{ s}} = \boxed{445\text{ Hz}}$

**69. (a)** $f_1 = \dfrac{v}{2L}$

Solve for the length of the shorter string.

$$L = \frac{v}{2f_1} = \frac{34.2\ \frac{\text{m}}{\text{s}}}{2(212\text{ Hz})} = 8.066\text{ cm}$$

So, the longer string has length $L' = 8.066\text{ cm} + 0.560\text{ cm} = 8.626\text{ cm}.$

$$\begin{aligned} f_{\text{beat}} &= |f_1 - f_1'| \\ &= \left|\frac{v}{2L} - \frac{v}{2L'}\right| \\ &= \frac{v}{2}\left|\frac{1}{L} - \frac{1}{L'}\right| \\ &= \left(\frac{34.2\ \frac{\text{m}}{\text{s}}}{2}\right)\left|\frac{1}{8.066\times10^{-2}\text{ m}} - \frac{1}{8.626\times10^{-2}\text{ m}}\right| \\ &= \boxed{13.8\text{ Hz}} \end{aligned}$$

**(b)** The beat frequency will $\boxed{\text{increase}}$.

**(c)** $f_{\text{beat}} = \left(\dfrac{34.2\ \frac{\text{m}}{\text{s}}}{2}\right)\left|\dfrac{1}{8.066\times10^{-2}\text{ m}} - \dfrac{1}{8.066\times10^{-2}\text{ m}+0.761\times10^{-2}\text{ m}}\right| = \boxed{18.3\text{ Hz}}$

**70. (a)** An increased beat frequency means a larger frequency difference. So, $\boxed{\text{the 320.0 Hz fork has the lower frequency.}}$

$f_{\text{beat}} = f_{\text{unknown}} - f_{\text{known}}$

**(b)** $\Delta f_{\text{beat}} = -\Delta f_{\text{known}}$

$$\begin{aligned} f_{\text{known},2} &= f_{\text{known},1} + \Delta f_{\text{known}} \\ &= f_{\text{known},1} - \Delta f_{\text{beat}} \\ &= 320.0\text{ Hz} - 3.0\text{ Hz} \\ &= \boxed{317.0\text{ Hz}} \end{aligned}$$

**(c)** $f_{\text{unknown}} = f_{\text{known},1} + f_{\text{beat},1} = 320.0\text{ Hz} + 4.50\text{ Hz} = \boxed{324.5\text{ Hz}}$

**71.** The second frequency is 4.0 Hz higher than the first, or 262 Hz. Since for strings of identical tension and linear density, $2f_1L_1 = v = 2f_2L_2,$ it follows that

$$L_2 = \frac{f_1}{f_2}L_1 = \left(\frac{258\text{ Hz}}{262\text{ Hz}}\right)(1.15\text{ m}) = \boxed{1.13\text{ m}}$$

**72.** Call the pipe open at both ends A and the pipe open at one end B.

$$f_{\text{beat2}} = f_{\text{beat3}}$$
$$|f_{A2} - f_{B3}| = |f_{A3} - f_{B5}|$$
$$\left|\frac{v}{L_A} - \frac{3v}{4L_B}\right| = \left|\frac{3v}{2L_A} - \frac{5v}{4L_B}\right|$$
$$\left|\frac{1}{L_A} - \frac{3}{4L_B}\right|^2 = \left|\frac{3}{2L_A} - \frac{5}{4L_B}\right|^2$$
$$\frac{1}{L_A{}^2} - \frac{6}{4L_A L_B} + \frac{9}{16L_B{}^2} = \frac{9}{4L_A{}^2} - \frac{15}{4L_A L_B} + \frac{25}{16L_B{}^2}$$
$$0 = \frac{5}{4L_A{}^2} - \frac{9}{4L_A L_B} + \frac{1}{L_B{}^2}$$
$$= \frac{5}{L_A{}^2} - \frac{9}{L_A L_B} + \frac{4}{L_B{}^2}$$

Use the quadratic formula to solve for $L_A$.

$$\frac{1}{L_A} = \frac{\frac{9}{L_B} \pm \sqrt{\frac{81}{L_B{}^2} - 4(5)\left(\frac{4}{L_B{}^2}\right)}}{2(5)}$$
$$= \frac{9}{10L_B} \pm \frac{1}{10}\sqrt{\frac{1}{L_B{}^2}}$$
$$= \frac{1}{L_B} \text{ or } \frac{5}{5L_B}$$
$$L_A = L_B \text{ or } \frac{5}{4}L_B$$
$$= \boxed{1.00 \text{ m or } 1.25 \text{ m}}$$

**73.** $d = vt = \left(343 \ \frac{\text{m}}{\text{s}}\right)(8.5 \text{ s}) = \boxed{2.9 \text{ km}}$

**74.** Closed pipe:

$$f_1 = \frac{v}{4L}$$
$$L = \frac{v}{4f_1} = \frac{343 \ \frac{\text{m}}{\text{s}}}{4(261.6 \text{ Hz})} = \boxed{0.328 \text{ m}}$$

Open pipe:

$$f_2 = 2\left(\frac{v}{2L}\right)$$
$$L = \frac{v}{f_2} = \frac{343 \ \frac{\text{m}}{\text{s}}}{261.6 \text{ Hz}} = \boxed{1.31 \text{ m}}$$

**75.** $f_n = \dfrac{nv}{2L}$

$$n = \frac{2f_nL}{v} = \frac{2(603\text{ Hz})(1.33\text{ m})}{402\ \frac{\text{m}}{\text{s}}} = \boxed{4}$$

**76.** A 20 dB reduction in hearing sensitivity implies the new threshold of hearing is 20 dB, rather than 0 dB.

$$20\text{ dB} = 10\log\frac{I}{I_0}$$

$$\frac{I}{I_0} = 10^{20/10} = 10^2$$

$$I = 10^2 I_0 = (10)(1.0\times10^{-12}\text{ W/m}^2) = \boxed{1.0\times10^{-10}\text{ W/m}^2}$$

**77.** mechanical energy $= mgh = (0.50\times10^{-3}\text{ kg})(9.81\text{ m/s}^2)(0.25\text{ m}) = 1.23\times10^{-3}\text{ J}$

$$\text{power of sound} = \frac{\text{energy}}{\text{time}} = \frac{1.23\times10^{-3}\text{ J}}{2.5\times10^{-3}\text{ s}} = 0.49\text{ W}$$

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{P}{4\pi I_0}} \quad \text{at threshold of hearing}$$

$$r = \sqrt{\frac{0.49\text{ W}}{(4\pi)(10^{-12}\text{ W/m}^2)}} = \boxed{2.0\times10^5\text{ m}}$$

This is a theoretical limit that could be realized in an ideal case. In a more realistic scenario, ambient noise, as well as energy losses when the sound waves are reflected or absorbed by surfaces, would prevent us from hearing the sound 200 km away. Sometimes, the real-world factors we ignore make a huge difference.

**78.** A reduction of 10 dB is a reduction in intensity by a factor of 10. Ninety machines must be turned off.

**79. (a)** The bottle is essentially an air column closed at one end. Since $f_1 = \dfrac{v}{4L}$, tripling $v$ triples $f_1$.

**(b)** $f = 3(206\text{ Hz}) = \boxed{618\text{ Hz}}$

**80.** $v = \sqrt{gd} = \sqrt{\left(9.81\ \dfrac{\text{m}}{\text{s}^2}\right)(4.3\times10^3\text{ m})} = \boxed{2.1\times10^2\text{ m/s}}$

**81.** The observer is between two approaching sound sources, moving at speeds $u_1$ (the faster train) and $u_2$ (the slower train).

$$f_{\text{beat}} = \left(\frac{1}{1-\frac{u_1}{v}}\right)f - \left(\frac{1}{1-\frac{u_2}{v}}\right)f$$

$$\frac{f_{\text{beat}}}{v} + \frac{f}{v-u_2} = \frac{f}{v-u_1}$$

$$u_1 = v - \frac{f}{\frac{f_{\text{beat}}}{v} + \frac{f}{v-u_2}}$$

$$= 343\ \frac{\text{m}}{\text{s}} - \frac{124\text{ Hz}}{\frac{4.4\text{ Hz}}{343\ \frac{\text{m}}{\text{s}}} + \frac{124\text{ Hz}}{343\ \frac{\text{m}}{\text{s}} - 22\ \frac{\text{m}}{\text{s}}}}$$

$$= \boxed{32\text{ m/s}}$$

**82. (a)** $f' = \left(\frac{1}{1-\frac{u}{v}}\right)f = \left(\frac{1}{1-\frac{24\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}}\right)(330\text{ Hz}) = \boxed{0.35\text{ kHz}}$

**(b)** Greater, because the echo makes Jim an observer moving toward a source producing a sound of the same frequency as Betsy hears.

**(c)** $f'' = (1+\frac{u}{v})f' = \left(1+\frac{24\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}\right)(355\text{ Hz}) = \boxed{0.38\text{ kHz}}$

**83.** The Doppler-shifted frequency from the moving ship is 165 Hz ± 3.0 Hz = 168 Hz or 162 Hz.
If the moving ship is approaching:

$$f' = \left(\frac{1}{1-\frac{u}{v}}\right)f$$

$$u = \left(1-\frac{f}{f'}\right)v$$

$$= \left(1-\frac{165\text{ Hz}}{168\text{ Hz}}\right)\left(343\ \frac{\text{m}}{\text{s}}\right)$$

$$= \boxed{6.13\text{ m/s}}$$

If the moving ship is receding:

$$f' = \left(\frac{1}{1+\frac{u}{v}}\right)f$$

$$u = \left(\frac{f}{f'}-1\right)v$$

$$= \left(\frac{165\text{ Hz}}{162\text{ Hz}}-1\right)\left(343\ \frac{\text{m}}{\text{s}}\right)$$

$$= \boxed{6.35\text{ m/s}}$$

**84.** $f_1 = \dfrac{v}{2L} = \dfrac{1}{2L}\sqrt{\dfrac{F}{\mu}}$

**(a)** $f_1$ increases by a factor of $\sqrt{4} = \boxed{2}$.

**(b)** $\mu$ increases by a factor of $3^2 = 9$, so $f_1$ decreases by a factor of $\sqrt{9} = \boxed{3}$.

**(c)** $\boxed{f_1 \text{ is doubled.}}$

**85. (a)** $\dfrac{L}{t} = v = \sqrt{\dfrac{F}{\mu}}$, $F = kL$, and $\mu = \dfrac{m}{L}$, so

$$\frac{L}{t} = \sqrt{\frac{kL}{\frac{m}{L}}}$$

$$t^2 = \frac{m}{k}$$

$$k = \frac{m}{t^2} = \frac{0.23\text{ kg}}{(0.75\text{ s})^2} = \boxed{0.41\text{ N/m}}$$

**(b)** $\boxed{\text{It will stay the same, because } t \text{ does not depend on } L \text{ here, only on } m \text{ and } k.}$

**(c)** $\boxed{0.75\text{ s}}$

**86. (a)** $I = 10^{\beta/10} I_0 = 10^{95.0/10}(10^{-12}\text{ W/m}^2) = 10^{-2.50}\text{ W/m}^2 = 0.00316\text{ W/m}^2$

Energy $= Pt = IAt = I(\pi d^2/4)t = (0.00316\text{ W/m}^2)[(\pi)(9.5\times10^{-3}\text{ m})^2/4](4\text{ h})\left(\dfrac{3600\text{ s}}{\text{h}}\right) = \boxed{0.0032\text{ J}}$

**(b)** $I = 10^{105/10}(10^{-12}\text{ W/m}^2) = 10^{-1.5}\text{ W/m}^2 = 0.0316\text{ W/m}^2$

Energy $= (0.0316\text{ W/m}^2)[(\pi)(9.5\times10^{-3}\text{ m})^2/4](1\text{ h})\left(\dfrac{3600\text{ s}}{\text{h}}\right) = \boxed{0.0081\text{ J}}$

**(c)** $\boxed{\text{Evidently not, since the two energy values are quite different.}}$

**87. (a)** $\boxed{\text{The length of a vibrating air column determines its resonant frequency.}}$

**(b)** $f = \dfrac{v}{2L} = \dfrac{343\text{ m/s}}{2(0.82\text{ m})} = \boxed{210\text{ Hz}}$

**(c)** $I = 10^{\beta/10} I_0 = 10^{95/10}(10^{-12}\text{ W/m}^2) = 3.16\times10^{-3}\text{ W/m}^2$

$1200I = 1200(3.16\times10^{-3}\text{ W/m}^2) = 3.79\text{ W/m}^2$

$$\beta = 10\log\left(\frac{I}{I_0}\right) = 10\log\left(\frac{3.79\text{ W/m}^2}{10^{-12}\text{ W/m}^2}\right) = \boxed{126\text{ dB}}$$

**88.** At $f_3$ the pipe contains three quarter-wavelengths and each quarter-wavelength is a distance between a node and an adjacent antinode. That distance is $\frac{1}{3}(2.5\text{ m}) = \boxed{0.83\text{ m}}$.

**89.** $f_n = \frac{nv}{2L} = \frac{n}{2L}\sqrt{\frac{F}{\mu}}$

The increased tension raises the frequency by a factor of $\sqrt{1.0200}$, so the beat frequency is $\sqrt{1.0200}\,f_n - f_n = \left(\sqrt{1.0200} - 1\right)(631\text{ Hz}) = \boxed{6.28\text{ Hz}}$.

**90.** **(a)** Wave speed depends on tension. Tension is highest at the top of the rope, so the wave speed increases as the wave moves up the rope.

**(b)** $v = \sqrt{\frac{F}{\mu}}$ and at height $y$, $F = (\mu y)g$. So $v = \sqrt{\frac{\mu y g}{\mu}} = \sqrt{yg}$.

**91.**

| Quantity | Units |
|---|---|
| $v$ | $\frac{[\text{L}]}{[\text{T}]}$ |
| $d$ | $[\text{L}]$ |
| $\rho$ | $\frac{[\text{M}]}{[\text{L}^3]}$ |
| $g$ | $\frac{[\text{L}]}{[\text{T}^2]}$ |

Since $\rho$ is the only quantity with mass units, $v$ cannot depend on it (there is no way for the mass units to cancel out). Also, $d$ and $g$ cannot add, since they have different units. So, suppose that for rational numbers $n$ and $m$, $v = g^n d^m$. In units, $\frac{[\text{L}]}{[\text{T}]} = \frac{[\text{L}^n]}{[\text{T}^{2n}]} \cdot [\text{L}^m]$. Thus $n + m = 1$ and $2n = 1$. From this it follows that $n = m = \frac{1}{2}$ and $\boxed{v = \sqrt{gd}}$.

**92.** $T = \frac{\lambda}{v} = \frac{\lambda}{\sqrt{\frac{g\lambda}{2\pi}}} = \boxed{\sqrt{\frac{2\pi\lambda}{g}}}$

**93.** **(a)** $f_1 = \left(1 + \frac{u}{v}\right)f = \left(1 + \frac{1.35\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}\right)(256\text{ Hz}) = \boxed{257\text{ Hz}}$

$f_2 = \left(1 - \frac{u}{v}\right)f = \left(1 - \frac{1.35\ \frac{\text{m}}{\text{s}}}{343\ \frac{\text{m}}{\text{s}}}\right)(256\text{ Hz}) = \boxed{255\text{ Hz}}$

**(b)** $f_{\text{beat}} = |f_1 - f_2| = 257\text{ Hz} - 255\text{ Hz} = \boxed{2\text{ Hz}}$

**(c)** To change the difference in distances by a full wavelength, the observer must walk half a wavelength, or

$$\frac{1}{2}\left(\frac{v}{f}\right)=\frac{1}{2}\left(\frac{343\ \frac{\text{m}}{\text{s}}}{256\ \text{Hz}}\right)=\boxed{0.670\ \text{m}}.$$

**(d)** The observer passes points of maximal constructive interference at a rate of

$$\frac{1.35\ \frac{\text{m}}{\text{s}}}{0.67\ \text{m}}=\boxed{2\ \text{Hz, which equals the beat frequency}}.$$