Q16.9 Each element of the rope must support the weight of the rope below it. The tension increases with height. (It increases linearly, if the rope does not stretch.) Then the wave speed $v = \sqrt{\dfrac{T}{\mu}}$ increases with height.

Q16.16 Let $\Delta t = t_s - t_p$ represent the difference in arrival times of the two waves at a station at distance $d = v_s t_s = v_p t_p$ from the hypocenter. Then $d = \Delta t \left(\dfrac{1}{v_s} - \dfrac{1}{v_p} \right)^{-1}$. Knowing the distance from the first station places the hypocenter on a sphere around it. A measurement from a second station limits it to another sphere, which intersects with the first in a circle. Data from a third non-collinear station will generally limit the possibilities to a point.

P16.15 (a) $A = y_{\text{max}} = 8.00 \text{ cm} = 0.080\,0 \text{ m}$ $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{(0.800 \text{ m})} = 7.85 \text{ m}^{-1}$

$\omega = 2\pi f = 2\pi(3.00) = 6.00\pi \text{ rad/s}$

Therefore, $y = A \sin(kx + \omega t)$

Or (where $y(0, t) = 0$ at $t = 0$) $\boxed{y = (0.080\,0) \sin(7.85x + 6\pi t) \text{ m}}$

(b)   In general, $y = 0.080\,0 \sin(7.85x + 6\pi t + \phi)$

Assuming $y(x, 0) = 0$ at $x = 0.100 \text{ m}$

then we require that $0 = 0.080\,0 \sin(0.785 + \phi)$

or $\phi = -0.785$

Therefore, $\boxed{y = 0.080\,0 \sin(7.85x + 6\pi t - 0.785) \text{ m}}$

P16.25 $T = Mg$ is the tension; $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{Mg}{\frac{m}{L}}} = \sqrt{\dfrac{MgL}{m}} = \dfrac{L}{t}$ is the wave speed.

Then, $\dfrac{MgL}{m} = \dfrac{L^2}{t^2}$

and $g = \dfrac{Lm}{Mt^2} = \dfrac{1.60 \text{ m} \left(4.00 \times 10^{-3} \text{ kg} \right)}{3.00 \text{ kg} \left(3.61 \times 10^{-3} \text{ s} \right)^2} = \boxed{1.64 \text{ m/s}^2}$

P16.30   From the free-body diagram $mg = 2T \sin\theta$

$T = \dfrac{mg}{2 \sin\theta}$

The angle θ is found from $\cos\theta = \dfrac{\frac{3L}{8}}{\frac{L}{2}} = \dfrac{3}{4}$

$\therefore \theta = 41.4°$

FIG. P16.30

(a) $v = \sqrt{\dfrac{T}{\mu}}$ $v = \sqrt{\dfrac{mg}{2\mu \sin 41.4°}} = \left(\sqrt{\dfrac{9.80 \text{ m/s}^2}{2 \left(8.00 \times 10^{-3} \text{ kg/m} \right) \sin 41.4°}} \right) \sqrt{m}$

or $v = \boxed{\left(30.4 \dfrac{\text{m/s}}{\sqrt{\text{kg}}} \right) \sqrt{m}}$

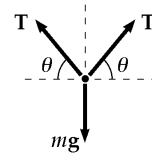(b) $v = 60.0 = 30.4\sqrt{m}$ and $\boxed{m = 3.89 \text{ kg}}$

P16.52   Assuming the incline to be frictionless and taking the positive x-direction to be up the incline:

$\sum F_x = T - Mg \sin\theta = 0$ or the tension in the string is $T = Mg \sin\theta$

The speed of transverse waves in the string is then $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{Mg \sin\theta}{\frac{m}{L}}} = \sqrt{\dfrac{MgL \sin\theta}{m}}$

The time interval for a pulse to travel the string's length is $\Delta t = \dfrac{L}{v} = L \sqrt{\dfrac{m}{MgL \sin\theta}} = \boxed{\sqrt{\dfrac{mL}{Mg \sin\theta}}}$

P16.4 (a) the P wave; (b) 665 s

P16.6 0.800 m/s

P16.8 2.40 m/s

P16.10 0.300 m in the positive x-direction

P16.12 ± 6.67 cm

P16.14 (b) 0.125 s; in agreement with the example

P16.16 (b) 18.0/m ; 83.3 m s; 75.4 rad/s; 4.20 m/s;

(c) $(0.2\,\text{m})\sin(18x+75.4t-0.151)$

P16.18 (a) 0.021 5 m ; (b) 1.95 rad; (c) 5.41 m/s;

(d) $y(x,t)=(0.021\,5\,\text{m})\sin(8.38x+80.0\pi t+1.95)$

P16.20 (a) see the solution; (b) 3.18 Hz

P16.22 30.0 N

P16.24 (a) $y=(0.2\,\text{mm})\sin(16x-3\,140t)$; (b) 158 N

P16.26 631 N

P16.28 $v=\dfrac{Tg}{2\pi}\sqrt{\dfrac{M}{m}}$

P16.30 (a) $v=\left(30.4\,\dfrac{\text{m}}{\text{s}\cdot\sqrt{\text{kg}}}\right)\sqrt{m}$; (b) 3.89 kg

P16.32 $\sqrt{\dfrac{mL\tan\theta}{4Mg}}$

P16.34 1.07 kW

P16.36 (a), (b), (c) P is constant; (d) P is quadrupled

P16.38 (a) $y=(0.075\,0)\sin(4.19x-314t)$; (b) 625 W

P16.40 (a) 15.1 W ; (b) 3.02 J

P16.42 The amplitude increases by 5.00 times

P16.46 (b) $\dfrac{1}{2}(x+vt)^2+\dfrac{1}{2}(x-vt)^2$;

(c) $\dfrac{1}{2}\sin(x+vt)+\dfrac{1}{2}\sin(x-vt)$

P16.48 (a) 0.040 0 m ; (b) 0.031 4 m ; (c) 0.477 Hz;

(d) 2.09 s; (e) positive x-direction

P16.50 (a) 21.0 m s; (b) 1.68 m

P16.52 $\Delta t=\sqrt{\dfrac{mL}{Mg\sin\theta}}$

P16.54 (a) $2Mg$; (b) $L_0+\dfrac{2Mg}{k}$;

(c) $\sqrt{\dfrac{2Mg}{m}\left(L_0+\dfrac{2Mg}{k}\right)}$

P16.56 14.7 kg

P16.58 (a) $v=\sqrt{\dfrac{T}{\rho\left(10^{-7}x+10^{-6}\right)}}$ in SI units;

(b) 94.3 m/s; 66.7 m/s

P16.62 (a) $5.00\hat{\mathbf{i}}$ m/s; (b) $-5.00\hat{\mathbf{i}}$ m/s;

(c) $-7.50\hat{\mathbf{i}}$ m/s; (d) $24.0\hat{\mathbf{i}}$ m/s

P16.64 (a) μv_0^2; (b) v_0;

(c) One travels 2 rev and the other does not move around the loop.

P16.66 (a) $v=\left(\dfrac{2T_0}{\mu_0}\right)^{1/2}=v_0\sqrt{2}$; $v'=\left(\dfrac{2T_0}{3\mu_0}\right)^{1/2}=v_0\sqrt{\dfrac{2}{3}}$; (b)

$0.966\Delta t_0$

Q17.10 A microwave pulse is reflected from a moving object. The waves that are reflected back are Doppler shifted in frequency according to the speed of the target. The receiver in the radar gun detects the reflected wave and compares its frequency to that of the emitted pulse. Using the frequency shift, the speed can be calculated to high precision. Be forewarned: this technique works if you are either traveling toward or away from your local law enforcement agent!

*P17.5 Let x_1 represent the cowboy's distance from the nearer canyon wall and x_2 his distance from the farther cliff. The sound for the first echo travels distance $2x_1$. For the second, $2x_2$. For the third, $2x_1+2x_2$. For the fourth echo, $2x_1+2x_2+2x_1$. Then $\dfrac{2x_2-2x_1}{340\ \text{m/s}}=1.92$ s and $\dfrac{2x_1+2x_2-2x_2}{340\ \text{m/s}}=1.47$ s. Thus $x_1=\dfrac{1}{2}\,340$ m/s 1.47 s $=250$ m

and $\dfrac{2x_2}{340\ \text{m/s}}=1.92$ s $+1.47$ s; $x_2=576$ m .

(a) So $x_1+x_2=\boxed{826\ \text{m}}$

(b) $\dfrac{2x_1+2x_2+2x_1-(2x_1+2x_2)}{340\ \text{m/s}}=\boxed{1.47\ \text{s}}$

P17.38 (a) $\omega=2\pi f=2\pi\left(\dfrac{115/\text{m in}}{60.0\ \text{s/m in}}\right)=12.0$ rad/s

$v_{\text{m ax}}=\omega A=(12.0\ \text{rad/s})(1.80\times10^{-3}\ \text{m})=\boxed{0.021\,7\ \text{m/s}}$

(b) The heart wall is a moving observer.

$f'=f\left(\dfrac{v+v_O}{v}\right)=(2\,000\,000\ \text{Hz})\left(\dfrac{1\,500+0.021\,7}{1\,500}\right)=\boxed{2\,000\,028.9\ \text{Hz}}$

(c)   Now the heart wall is a moving source.

$$f'' = f'\left(\frac{v}{v - v_S}\right) = (2\,000\,029\ \text{H z})\left(\frac{1\,500}{1\,500 - 0.021\,7}\right) = \boxed{2\,000\,057.8\ \text{H z}}$$

P17.42   (a) $v = (331\ \text{m /s}) + 0.6\dfrac{\text{m}}{\text{s} \cdot °\text{C}}(-10°\text{C}) = \boxed{325\ \text{m /s}}$

(b)   Approaching the bell, the athlete hears a frequency of $f' = f\left(\dfrac{v + v_O}{v}\right)$

After passing the bell, she hears a lower frequency of $f'' = f\left(\dfrac{v + (-v_O)}{v}\right)$

The ratio is $\dfrac{f''}{f'} = \dfrac{v - v_O}{v + v_O} = \dfrac{5}{6}$

which gives $6v - 6v_o = 5v + 5v_o$ or $v_O = \dfrac{v}{11} = \dfrac{325\ \text{m /s}}{11} = \boxed{29.5\ \text{m /s}}$

P17.58   (a) $f' = \dfrac{fv}{v - u}$ $f'' = \dfrac{fv}{v - (-u)}$ $f' - f'' = fv\left(\dfrac{1}{v - u} - \dfrac{1}{v + u}\right)$

$$\Delta f = \frac{fv(v + u - v + u)}{v^2 - u^2} = \frac{2uvf}{v^2\left(1 - (u^2/v^2)\right)} = \boxed{\frac{2(u/v)}{1 - (u^2/v^2)}f}$$

(b)   130 km /h = 36.1 m /s $\therefore \Delta f = \dfrac{2(36.1)(400)}{340\left[1 - (36.1)^2/340^2\right]} = \boxed{85.9\ \text{H z}}$

P17.69   (a)   If the source and the observer are moving away from each other, we have: $\theta_S - \theta_0 = 180°$, and since $\cos 180° = -1$, we get Equation 17.12 with negative values for both v_o and v_S.

(b)   If $v_O = 0$ m /s then $f' = \dfrac{v}{v - v_S \cos\theta_S}f$

Also, when the train is 40.0 m from the intersection, and the car is 30.0 m from the intersection,

$$\cos\theta_S = \frac{4}{5}$$

so $f' = \dfrac{343\ \text{m /s}}{343\ \text{m /s} - 0.800(25.0\ \text{m /s})}(500\ \text{H z})$

or $f' = \boxed{531\ \text{H z}}$.

Note that as the train approaches, passes, and departs from the intersection, θ_S varies from 0° to 180° and the frequency heard by the observer varies from:

$$f'_{max} = \frac{v}{v - v_S \cos 0°}f = \frac{343\ \text{m /s}}{343\ \text{m /s} - 25.0\ \text{m /s}}(500\ \text{H z}) = 539\ \text{H z}$$

$$f'_{min} = \frac{v}{v - v_S \cos 180°}f = \frac{343\ \text{m /s}}{343\ \text{m /s} + 25.0\ \text{m /s}}(500\ \text{H z}) = 466\ \text{H z}$$

P17.2   1.43 km /s

P17.4   (a) 27.2 s; (b) longer than 25.7 s, because the air is cooler

P17.6   (a) 153 m /s; (b) 614 m

P17.8   (a) 4.16 m; (b) 0.455 μs; (c) 0.157 mm

P17.10 1.55×10^{-10} m

P17.12   (a) 1.27 Pa; (b) 170 H z; (c) 2.00 m; (d) 340 m /s

P17.14 $s = 22.5\ \text{nm}\ \cos\left(62.8x - 2.16 \times 10^4 t\right)$

P17.16   (a) 4.63 mm; (b) 14.5 m /s; (c) 4.73×10^9 W /m^2

P17.18   (a) 5.00×10^{-17} W ; (b) 5.00×10^{-5} W

P17.20   (a) 1.00×10^{-5} W /m^2; (b) 90.7 m Pa

P17.22 (a) $I_2 = \left(\dfrac{f'}{f}\right)^2 I_1$; (b) $I_2 = I_1$

P17.24 21.2 W

P17.26 (a) 4.51 times larger in water than in air and 18.0 times larger in iron;
(b) 5.60 times larger in water than in iron and 331 times larger in air;
(c) 59.1 times larger in water than in air and 331 times larger in iron;
(d) 0.331 m; 1.49 m; 5.95 m; 10.9 nm; 184 pm; 32.9 pm; 29.2 mPa; 1.73 Pa; 9.67 Pa

P17.30 10.0 m; 100 m

P17.32 86.6 m

P17.34 (a) 1.76 kJ; (b) 108 dB

Q18.2 The energy has not disappeared, but is still carried by the wave pulses. Each particle of the string still has kinetic energy. This is similar to the motion of a simple pendulum. The pendulum does not stop at its equilibrium position during oscillation—likewise the particles of the string do not stop at the equilibrium position of the string when these two waves superimpose.

P18.10 Suppose the man's ears are at the same level as the lower speaker. Sound from the upper speaker is delayed by traveling the extra distance $\Delta r = \sqrt{L^2 + d^2} - L$.

He hears a minimum when $\Delta r = (2n-1)\left(\dfrac{\lambda}{2}\right)$ with $n = 1, 2, 3, \ldots$

Then, $\sqrt{L^2 + d^2} - L = \left(n - \dfrac{1}{2}\right)\left(\dfrac{v}{f}\right)$

$\sqrt{L^2 + d^2} = \left(n - \dfrac{1}{2}\right)\left(\dfrac{v}{f}\right) + L$

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

$d^2 - \left(n - \dfrac{1}{2}\right)^2 \left(\dfrac{v}{f}\right)^2 = 2\left(n - \dfrac{1}{2}\right)\left(\dfrac{v}{f}\right)L$ \hfill (1)

Equation 1 gives the distances from the lower speaker at which the man will hear a minimum. The path difference Δr starts from nearly zero when the man is very far away and increases to d when $L = 0$.

(a) The number of minima he hears is the greatest integer value for which $L \geq 0$. This is the same as the greatest integer solution to $d \geq \left(n - \dfrac{1}{2}\right)\left(\dfrac{v}{f}\right)$, or

$$\boxed{\text{number of minima heard} = n_{\max} = \text{greatest integer} \leq d\left(\dfrac{f}{v}\right) + \dfrac{1}{2}.}$$

(b) From equation 1, the distances at which minima occur are given by

$$\boxed{L_n = \dfrac{d^2 - (n - 1/2)^2 (v/f)^2}{2(n - 1/2)(v/f)} \quad \text{where } n = 1, 2, \ldots, n_{\max}.}$$

P18.28 $\lambda_G = 2(0.350 \text{ m}) = \dfrac{v}{f_G}$; $\lambda_A = 2L_A = \dfrac{v}{f_A}$

$L_G - L_A = L_G - \left(\dfrac{f_G}{f_A}\right)L_G = L_G\left(1 - \dfrac{f_G}{f_A}\right) = (0.350 \text{ m})\left(1 - \dfrac{392}{440}\right) = 0.038 \, 2 \text{ m}$

Thus, $L_A = L_G - 0.038 \, 2 \text{ m} = 0.350 \text{ m} - 0.038 \, 2 \text{ m} = 0.312 \text{ m}$,

or the finger should be placed $\boxed{31.2 \text{ cm from the bridge}}$.

$L_A = \dfrac{v}{2f_A} = \dfrac{1}{2f_A}\sqrt{\dfrac{T}{\mu}}$; $dL_A = \dfrac{dT}{4f_A\sqrt{T\mu}}$; $\dfrac{dL_A}{L_A} = \dfrac{1}{2}\dfrac{dT}{T}$

$$\frac{dT}{T} = 2\frac{dL_A}{L_A} = 2\frac{0.600 \text{ cm}}{(35.0 - 3.82) \text{ cm}} = \boxed{3.84\%}$$

P18.34   The wave speed is $v = \sqrt{gd} = \sqrt{(9.80 \text{ m/s}^2)(36.1 \text{ m})} = 18.8 \text{ m/s}$

The bay has one end open and one closed. Its simplest resonance is with a node of horizontal velocity, which is also an antinode of vertical displacement, at the head of the bay and an antinode of velocity, which is a node of displacement, at the mouth. The vibration of the water in the bay is like that in one half of the pond shown in Figure P18.33.

Then, $d_{NA} = 210 \times 10^3 \text{ m} = \dfrac{\lambda}{4}$

and $\lambda = 840 \times 10^3 \text{ m}$

Therefore, the period is $T = \dfrac{1}{f} = \dfrac{\lambda}{v} = \dfrac{840 \times 10^3 \text{ m}}{18.8 \text{ m/s}} = 4.47 \times 10^4 \text{ s} = \boxed{12 \text{ h } 24 \text{ min}}$

$\boxed{\text{This agrees precisely with the period of the lunar excitation}}$, so we identify the extra-high tides as amplified by resonance.

P18.40   The air in the auditory canal, about 3 cm long, can vibrate with a node at the closed end and antinode at the open end,

with $d_{N \text{ to } A} = 3 \text{ cm} = \dfrac{\lambda}{4}$

so $\lambda = 0.12 \text{ m}$

and $f = \dfrac{v}{\lambda} = \dfrac{343 \text{ m/s}}{0.12 \text{ m}} \approx \boxed{3 \text{ kHz}}$

$\boxed{\begin{array}{l} \text{A small-amplitude external excitation at this frequency can, over time, feed energy} \\ \text{into a larger-amplitude resonance vibration of the air in the canal, making it audible.} \end{array}}$

P18.51 $f \propto v \propto \sqrt{T}$ $f_{new} = 110\sqrt{\dfrac{540}{600}} = 104.4 \text{ Hz}$

$\Delta f = \boxed{5.64 \text{ beats/s}}$

P18.4   5.66 cm

P18.6   0.500 s

P18.8   (a) 3.33 rad; (b) 283 Hz

P18.10   (a) The number is the greatest
integer $\leq d\left(\dfrac{f}{v}\right) + \dfrac{1}{2}$;

(b) $L_n = \dfrac{d^2 - (n-1/2)^2 (v/f)^2}{2(n-1/2)(v/f)}$ where

$n = 1, 2, \ldots, n_{max}$

P18.12   (a) $\Delta x = \dfrac{\lambda}{2}$;

(b) along the hyperbola $9x^2 - 16y^2 = 144$

P18.14   (a) $(2n+1)\pi$ m for $n = 0, 1, 2, 3, \ldots$;

(b) 0.029 4 m

P18.20   15.7 Hz

P18.22   (a) 257 Hz; (b) 6

P18.24   (a) 495 Hz; (b) 990 Hz

P18.26   19.976 kHz

P18.28   3.84%

P18.30   291 Hz

P18.32   0.352 Hz

P18.38   0.656 m; 1.64 m

P18.40   3 kHz; see the solution

P18.42 $\Delta t = \dfrac{\pi r^2 v}{2Rf}$

P18.44 $L = 0.252 \text{ m}, 0.504 \text{ m}, 0.757 \text{ m}, \ldots, n(0.252) \text{ m}$
for $n = 1, 2, 3, \ldots$

P18.46   0.502 m; 0.837 m

P18.48   (a) 0.195 m; (b) 841 m

P18.50   1.16 m

P18.52   (a) 521 Hz or 525 Hz; (b) 526 Hz;
(c) reduce by 1.14%

P18.54   4-foot and $2\dfrac{2}{3}$-foot; $2\dfrac{2}{3}$ and 2-foot; and all
three together

P18.58   (a) and (b) 3.99 beats/s

P18.60   4.85 m

P18.62   31.1 N

P18.64   (a) $\dfrac{1}{2}Mg$; (b) $3h$; (c) $\dfrac{m}{3h}$; (d) $\sqrt{\dfrac{3Mgh}{2m}}$;

(e) $\sqrt{\dfrac{3Mg}{8mh}}$; (f) $\sqrt{\dfrac{2mh}{3Mg}}$; (g) h ;

(h) $(2.00 \times 10^{-2})\sqrt{\dfrac{3Mg}{8mh}}$

P18.66   (a) 45.0 Hz or 55.0 Hz; (b) 162 N or 242 N

P18.70   262 kHz