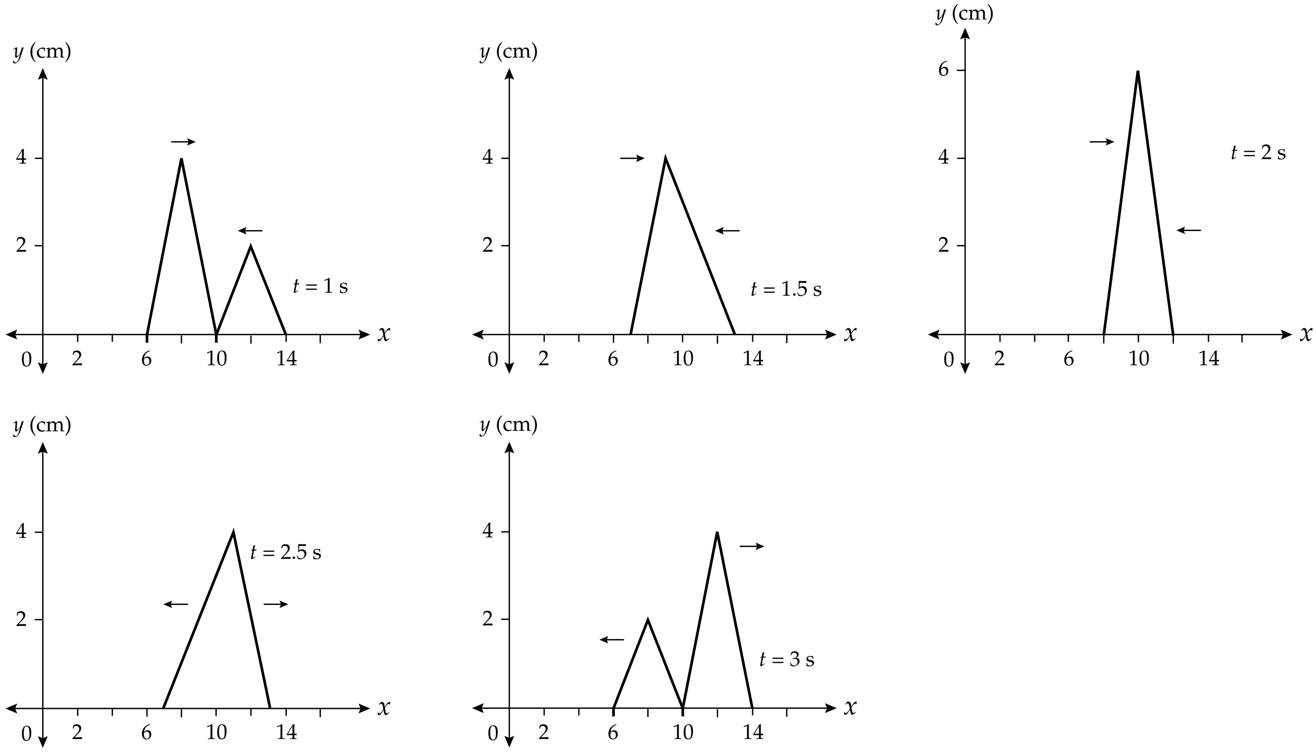
Chapter 16 Solutions

16.1 Replace x by $x - vt = x - 4.5t$

to get $\boxed{y = \dfrac{6}{[(x - 4.5t)^2 + 3]}}$

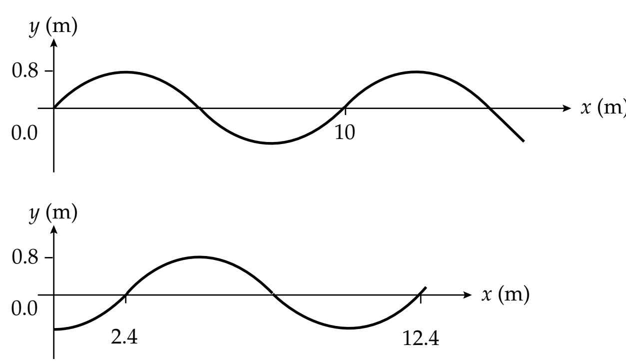
16.2



16.3 $5.00e^{-(x+5t)^2}$ is of the form $f(x + vt)$

so it describes a wave moving to the $\boxed{\text{left}}$ at $v = \boxed{5.00 \text{ m/s}}$

16.4



16.5 (a) The $\boxed{\text{longitudinal}}$ wave travels a shorter distance and is moving faster, so it will arrive at point B first.

(b) The wave that travels through the Earth must travel a distance of $2R\sin 30.0° = 2(6.37\times10^6\text{ m})\sin 30.0° = 6.37\times10^6\text{ m}$ at a speed of 7800 m/s.

Therefore, it takes $\dfrac{6.37\times10^6\text{ m}}{7800\text{ m/s}} = 817\text{ s}$

The wave that travels along the Earth's surface must travel a distance of

$$S = R\theta = R\left(\frac{\pi}{3}\text{ rad}\right) = 6.67\times10^6\text{ m at a speed of }4500\text{ m/s}$$

Therefore, it takes $\dfrac{6.67\times10^6}{4500} = 1482\text{ s}$

The time difference is $\boxed{665\text{ s}} = 11.1\text{ min.}$

***16.6** The distance the waves have traveled is

$$d = (7.80\text{ km/s})t = (4.50\text{ km/s})(t + 17.3\text{ s})$$

where t is the travel time for the faster wave.

Then, $(7.80 - 4.50)(\text{km/s})t = (4.50\text{ km/s})(17.3\text{ s})$

or $t = \dfrac{(4.50\text{ km/s})(17.3\text{ s})}{(7.80-4.50)(\text{km/s})} = 23.6\text{ s}$, and

the distance is $d = (7.80\text{ km/s})(23.6\text{ s}) = \boxed{184\text{ km}}$

16.7 (a) $\phi_1 = (20.0\text{ rad/cm})(5.00\text{ cm}) - (32.0\text{ rad/s})(2.00\text{ s}) = 36.0\text{ rad}$

$\phi_1 = (25.0\text{ rad/cm})(5.00\text{ cm}) - (40.0\text{ rad/s})(2.00\text{ s}) = 45.0\text{ rad}$

$\Delta\phi = 9.00\text{ radians} = 516° = \boxed{156°}$

(b) $\Delta\phi = \left|20.0x - 32.0t - [25.0x - 40.0t]\right| = \left|-5.00x + 8.00t\right|$

At $t = 2.00$ s, the requirement is

$$\Delta\phi = \left|-5.00x + 8.00\,(2.00)\right| = (2n+1)\pi \text{ for any integer } n.$$

For $x < 3.20$, $-5.00x + 16.0$ is positive, so we have

$$-5.00x + 16.0 = (2n+1)\pi, \text{ or}$$

$$x = 3.20 - \frac{(2n+1)\pi}{5.00}$$

The smallest positive value of x occurs for $n = 2$ and is

$$x = 3.20 - \frac{(4+1)\pi}{5.00} = 3.20 - \pi = \boxed{0.0584\text{ cm}}$$

16.8 $y = y_1 + y_2 = 3.00 \cos(4.00x - 1.60t) + 4.00 \sin(5.00x - 2.00t)$ evaluated at the given x values.

(a) $x = 1.00$, $t = 1.00$

$y = 3.00 \cos(2.40 \text{ rad}) + 4.00 \sin(+3.00 \text{ rad}) = \boxed{-1.65}$

(b) $x = 1.00$, $t = 0.500$

$y = 3.00 \cos(+3.20 \text{ rad}) + 4.00 \sin(+4.00 \text{ rad}) = \boxed{-6.02}$

(c) $x = 0.500$, $t = 0$

$y = 3.00 \cos(+2.00 \text{ rad}) + 4.00 \sin(+2.50 \text{ rad}) = \boxed{1.15}$

16.9 (a) $y_1 = f(x - vt)$, so wave 1 travels in the $\boxed{+x \text{ direction}}$.

$y_2 = f(x + vt)$, so wave 2 travels in the $\boxed{-x \text{ direction}}$.

(b) To cancel, $y_1 + y_2 = 0$:

$$\frac{5}{(3x - 4t)^2 + 2} = \frac{+5}{(3x + 4t - 6)^2 + 2}$$

$$(3x - 4t)^2 = (3x + 4t - 6)^2$$

$$3x - 4t = \pm(3x + 4t - 6)$$

$+\text{root} \rightarrow 8t = 6 \rightarrow \boxed{t = 0.750 \text{ s}}$

(at $t = 0.750$ s, the waves cancel everywhere)

(c) $-\text{root} \rightarrow 6x = 6 \rightarrow \boxed{x = 1.00 \text{ m}}$ (at $x = 1.00$ m, the waves cancel always)

***16.10** The down and back distance is 4.00 m + 4.00 m = 8.00 m.

The speed is then $v = \frac{d_{\text{total}}}{t} = \frac{4(8.00 \text{ m})}{0.800 \text{ s}} = 40.0 \text{ m/s} = \sqrt{T/\mu}$

Now, $\mu = \frac{0.200 \text{ kg}}{4.00 \text{ m}} = 5.00 \times 10^{-2} \text{ kg/m}$, so

$T = \mu v^2 = (5.00 \times 10^{-2} \text{ kg/m})(40.0 \text{ m/s})^2 = \boxed{80.0 \text{ N}}$

16.11 The mass per unit length is: $\mu = \frac{0.0600 \text{ kg}}{5.00 \text{ m}} = 1.20 \times 10^{-2} \text{ kg/m}$

The required tension is: $T = \mu v^2 = (0.0120 \text{ kg/m})(50.0 \text{ m/s})^2 = \boxed{30.0 \text{ N}}$

16.12 $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{1350 \text{ kg} \cdot \text{m/s}^2}{5.00 \times 10^{-3} \text{ kg/m}}} = \boxed{520 \text{ m/s}}$

16.13 $T = Mg$ is the tension

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Mg}{(m/L)}} = \sqrt{\frac{MgL}{m}} = \frac{L}{t} \quad \text{is the wave speed}$$

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

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

***16.14** $v = \sqrt{\dfrac{T}{\mu}}$

$$T = \mu v^2 = \rho A v^2 = \rho \pi r^2 v^2$$

$$T = (8920 \text{ kg/m}^3)(\pi)(7.50 \times 10^{-4} \text{ m})^2 (200 \text{ m/s})^2$$

$$T = \boxed{631 \text{ N}}$$

16.15 Since μ is constant, $\mu = \dfrac{T_2}{v_2^2} = \dfrac{T_1}{v_1^2}$ and

$$T_2 = \left(\frac{v_2}{v_1}\right)^2 T_1 = \left(\frac{30.0 \text{ m/s}}{20.0 \text{ m/s}}\right)^2 (6.00 \text{ N}) = \boxed{13.5 \text{ N}}$$

Goal Solution

G: Since $v \propto \sqrt{F}$, the new tension must be about twice as much as the original to achieve a 50% increase in the wave speed.

O: The equation for the speed of a transverse wave on a string under tension can be used if we assume that the linear density of the string is constant. Then the ratio of the two wave speeds can be used to find the new tension.

A: The 2 wave speeds can be written as: $v_1 = \sqrt{\dfrac{F_1}{\mu}}$ and $v_2 = \sqrt{\dfrac{F_2}{\mu}}$

Dividing, $\dfrac{v_2}{v_1} = \sqrt{\dfrac{F_2}{F_1}}$

so $F_2 = \left(\dfrac{v_2}{v_1}\right)^2 F_1 = \left(\dfrac{30.0 \text{ m/s}}{20.0 \text{ m/s}}\right)^2 (6.00 \text{ N}) = 13.5 \text{ N}$

L: The new tension is slightly more than twice the original, so the result agrees with our initial prediction and is therefore reasonable.

16.16 The period of the pendulum is $T = 2\pi\sqrt{\frac{L}{g}}$

Let F represent the tension in the string (to avoid confusion with the period) when the pendulum is vertical and stationary. The speed of waves in the string is then:

$$v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{Mg}{(m/L)}} = \sqrt{\frac{MgL}{m}}$$

Since it might be difficult to measure L precisely, we eliminate $\sqrt{L} = \frac{T\sqrt{g}}{2\pi}$

so $$v = \sqrt{\frac{Mg}{m}}\frac{T\sqrt{g}}{2\pi} = \boxed{\frac{Tg}{2\pi}\sqrt{\frac{M}{m}}}$$

16.17 If the tension in the wire is T, the tensile stress is

$$\text{Stress} = T/A \quad \text{so} \quad T = A(\text{stress})$$

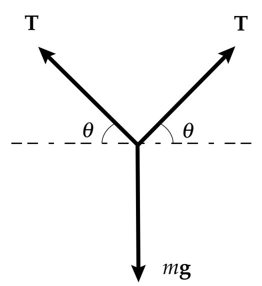
The speed of transverse waves in the wire is

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{A(\text{Stress})}{m/L}} = \sqrt{\frac{\text{Stress}}{m/AL}} = \sqrt{\frac{\text{Stress}}{m/(\text{Volume})}} = \sqrt{\frac{\text{Stress}}{\rho}}$$

where ρ is the density. The maximum velocity occurs when the stress is a maximum:

$$v_{\text{max}} = \sqrt{\frac{2.70 \times 10^9 \text{ Pa}}{7860 \text{ kg/m}^3}} = \boxed{586 \text{ m/s}}$$

16.18 From the free-body diagram,



$$mg = 2T\sin\theta$$

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

The angle θ is found from

$$\cos\theta = \frac{3L/8}{L/2} = \frac{3}{4}$$

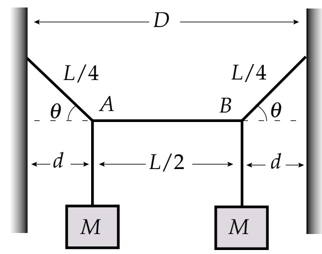
$$\therefore \theta = 41.4°$$

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

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

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

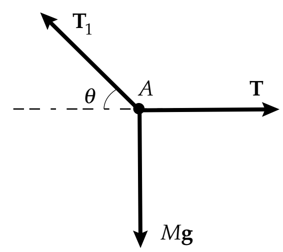
16.19 First, observe from the geometry shown in the figure that $2d + \frac{L}{2} = D$, or



$$d = \frac{D}{2} - \frac{L}{4} = 1.00\text{ m} - 0.750\text{ m} = 0.250\text{ m}$$

Thus, $\cos\theta = \frac{0.250\text{ m}}{0.750\text{ m}} = \frac{1}{3}$, and $\theta = 70.5°$

Now, consider a free body diagram of point A:



$\Sigma F_x = 0$ becomes $T = T_1 \cos\theta$, and

$\Sigma F_y = 0$ becomes $Mg = T_1 \sin\theta$

Dividing the second of these equations by the first gives:

$$\frac{Mg}{T} = \tan\theta \quad \text{or} \quad T = \frac{19.6\text{ N}}{\tan 70.5°} = 6.94\text{ N}$$

The linear density of the string is: $\mu = \frac{m}{L} = \frac{0.0100\text{ kg}}{3.00\text{ m}} = 3.33 \times 10^{-3}\text{ kg/m}$

so the speed of transverse waves in the string between points A and B is:

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{6.94\text{ N}}{3.33 \times 10^{-3}\text{ kg/m}}} = 45.6\text{ m/s}$$

The time for the pulse to travel 1.50 m from A to B is:

$$t = \frac{1.50\text{ m}}{45.6\text{ m/s}} = 0.0329\text{ s} = \boxed{32.9\text{ ms}}$$

16.20 Refer to the diagrams given in the solution for Problem 19 above. From the free-body diagram of point A:

$$\Sigma F_y = 0 \Rightarrow T_1 \sin\theta = Mg \quad \text{and} \quad \Sigma F_x = 0 \Rightarrow T_1 \cos\theta = T$$

Combining these equations to eliminate T_1 gives the tension in the string connecting points A and B as: $T = \frac{Mg}{\tan\theta}$

The speed of transverse waves in this segment of string is then

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Mg/\tan\theta}{m/L}} = \sqrt{\frac{MgL}{m\tan\theta}}$$

and the time for a pulse to travel from A to B is

$$t = \frac{L/2}{v} = \sqrt{\frac{mL\tan\theta}{4Mg}}$$

To evaluate tan θ, refer to the geometry shown in the first diagram:

$$\tan\theta = \frac{\sqrt{(L/4)^2 - d^2}}{d} = \sqrt{\left(\frac{L}{4d}\right)^2 - 1}$$

Also, $2d = D - L/2$, which gives $4d = 2D - L$

Thus, $\tan\theta = \sqrt{\left(\frac{L}{2D - L}\right)^2 - 1}$

The travel time for the pulse going from A to B is then

$$\boxed{t = \sqrt{\frac{mL\tan\theta}{4Mg}} \text{ where } \tan\theta = \sqrt{\left(\frac{L}{2D-L}\right)^2 - 1}}$$

16.21 The total time is the sum of the two times.

In each wire $t = \frac{L}{v} = L\sqrt{\frac{\mu}{T}}$

where $\mu = \rho A = \frac{\pi\rho d^2}{4}$

Thus, $t = L\left(\frac{\pi\rho d^2}{4T}\right)^{1/2}$

For copper, $t = (20.0)\left[\frac{(\pi)(8920)(1.00 \times 10^{-3})^2}{(4)(150)}\right]^{1/2} = 0.137 \text{ s}$

For steel, $t = (30.0)\left[\frac{(\pi)(7860)(1.00 \times 10^{-3})^2}{(4)(150)}\right]^{1/2} = 0.192 \text{ s}$

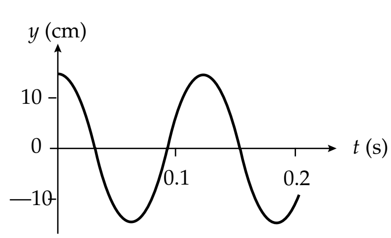
The total time is $0.137 + 0.192 = \boxed{0.329 \text{ s}}$

***16.22** (a) If the end is fixed, there is inversion of the pulse upon reflection. Thus, when they meet, they cancel and the amplitude is $\boxed{\text{zero}}$.

(b) If the end is free, there is no inversion on reflection. When they meet, the amplitude is $2A = 2(0.150 \text{ m}) = \boxed{0.300 \text{ m}}$.

16.23 (a) See figure at right.

(b) $T = \frac{2\pi}{\omega} = \frac{2\pi}{50.3} = \boxed{0.125 \text{ s}}$



16.24 Using data from the observations, we have $\lambda = 1.20$ m and $f = \frac{8.00}{12.0\text{ s}}$. Therefore,

$$v = \lambda f = (1.20\text{ m})\left(\frac{8.00}{12.0\text{ s}}\right) = \boxed{0.800\text{ m/s}}$$

16.25 $f = \frac{40.0\text{ vibrations}}{30.0\text{ s}} = \frac{4}{3}\text{ Hz}$

$$v = \frac{425\text{ cm}}{10.0\text{ s}} = 42.5\text{ cm/s}$$

$$\lambda = \frac{v}{f} = \frac{42.5\text{ cm/s}}{\left(\frac{4}{3}\text{ Hz}\right)} = 31.9\text{ cm} = \boxed{0.319\text{ m}}$$

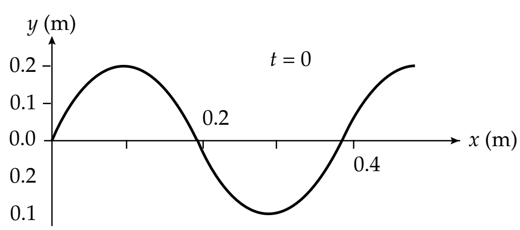
***16.26** At time t, the phase of $y = (15.0\text{ cm})\cos(0.157x - 50.3t)$ at coordinate x is $\phi = (0.157\text{ rad/cm})x - (50.3\text{ rad/s})t$. Since $60.0° = \frac{\pi}{3}$ rad, the requirement for point B is that $\phi_B = \phi_A \pm \frac{\pi}{3}$ rad, or (since $x_A = 0$),

$$(0.157\text{ rad/cm})x_B - (50.3\text{ rad/s})t = 0 - (50.3\text{ rad/s})t \pm \frac{\pi}{3}\text{ rad}$$

This reduces to $x_B = \frac{\pm\pi\text{ rad}}{3(0.157\text{ rad/cm})} = \boxed{\pm 6.67\text{ cm}}$

16.27 $v = f\lambda = (4.00\text{ Hz})(60.0\text{ cm}) = 240\text{ cm/s} = \boxed{2.40\text{ m/s}}$

16.28 (a)



(b) $k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.350\text{ m}} = \boxed{18.0\text{ rad/m}}$

$$T = \frac{1}{f} = \frac{1}{12.0/\text{s}} = \boxed{0.0833\text{ s}}$$

$$\omega = 2\pi f = 2\pi\, 12.0/\text{s} = \boxed{75.4\text{ rad/s}}$$

$$|v| = f\lambda = (12.0/\text{s})(0.350\text{ m}) = \boxed{4.20\text{ m/s}}$$

(c) $y = A\sin(kx + \omega t + \phi)$ specializes to

$y = 0.200\text{ m}\sin(18.0\,x/\text{m} + 75.4\,t/\text{s} + \phi)$

at $x = 0$, $t = 0$ we require

$$-3.00\times10^{-2}\text{ m} = 0.200\text{ m}\sin(+\phi)$$

$$\phi = -8.63° = -0.151\text{ rad}$$

so $y(x, t) = \boxed{(0.200\text{ m})\sin(18.0\,x/\text{m} + 75.4\,t/\text{s} - 0.151\text{ rad})}$

16.29 $y = 0.250\sin(0.300x - 40.0t)$ m

Compare this with the general expression $y = A\sin(kx - \omega t)$

(a) $A = \boxed{0.250\text{ m}}$ (b) $\omega = \boxed{40.0\text{ rad/s}}$ (c) $k = \boxed{0.300\text{ rad/m}}$

(d) $\lambda = \dfrac{2\pi}{k} = \dfrac{2\pi}{0.300\text{ rad/m}} = \boxed{20.9\text{ m}}$

(e) $v = f\lambda = \left(\dfrac{\omega}{2\pi}\right)\lambda = \left(\dfrac{40.0\text{ rad/s}}{2\pi}\right)(20.9\text{ m}) = \boxed{133\text{ m/s}}$

(f) The wave moves to the right, $\boxed{\text{in }+x\text{ direction}}$.

16.30 $y = (0.120\text{ m})\sin\left(\dfrac{\pi}{8}x + 4\pi t\right)$

(a) $v = \dfrac{dy}{dt} = (0.120)(4\pi)\cos\left(\dfrac{\pi}{8}x + 4\pi t\right)$

$v(0.200\text{ s}, 1.60\text{ m}) = \boxed{-1.51\text{ m/s}}$

$a = \dfrac{dv}{dt} = (-0.120\text{ m})(4\pi)^2\sin\left(\dfrac{\pi}{8}x + 4\pi t\right)$

$a = (0.200\text{ s}, 1.60\text{ m}) = \boxed{0}$

(b) $k = \dfrac{\pi}{8} = \dfrac{2\pi}{\lambda}$ $\lambda = \boxed{16.0\text{ m}}$

$\omega = 4\pi = \dfrac{2\pi}{T}$ $T = \boxed{0.500\text{ s}}$

$v = \dfrac{\lambda}{T} = \dfrac{16.0\text{ m}}{0.500\text{ s}} = \boxed{32.0\text{ m/s}}$

16.31 (a) $A = y_{\max} = 8.00\text{ cm} = 0.0800\text{ m}$: $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{(0.0800\text{ m})} = 7.85\text{ m}^{-1}$

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

Therefore,

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

or $\boxed{y = (0.0800)\sin(7.85x + 6\pi t)\text{m}}$ [where $y(0, t) = 0$]

(b) In general,

$$y = 0.0800\sin(7.85x + 6\pi t + \phi)$$

Assuming $y(x, 0) = 0$ at $x = 0.100$ m, then we require that

$$0 = 0.0800\sin(0.785 + \phi)$$

or $\phi = -0.785$

Therefore,

$$\boxed{y = 0.0800\sin(7.85x + 6\pi t - 0.785)\text{ m}}$$

16.32 (a) Let us write the wave function as $y(x, t) = A\sin(kx + \omega t + \phi)$

$$y(0, 0) = A\sin\phi = 0.0200\text{ m}$$

$$\left.\frac{dy}{dt}\right|_{0,0} = A\omega\cos\phi = -2.00\text{ m/s}$$

Also, $\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{0.0250\text{ s}} = 80.0\,\pi/\text{s}$

$$A^2 = x_i^2 + (v_i/\omega)^2 = (0.0200\text{ m})^2 + \left(\frac{2.00\text{ m/s}}{80.0\pi/\text{s}}\right)^2$$

$$A = \boxed{0.0215\text{ m}}$$

(b) $\dfrac{A\sin\phi}{A\cos\phi} = \dfrac{0.0200}{-2/80.0\pi} = -2.51 = \tan\phi$

Your calculator's answer $\tan^{-1}(-2.51) = -1.19$ rad has a negative sine and positive cosine, just the reverse of what is required. You must look beyond your calculator to find

$$\phi = \pi - 1.19\text{ rad} = \boxed{1.95\text{ rad}}$$

(c) $v_{y,\max} = A\omega = 0.0215 \text{ m } (80.0\pi/\text{s}) = \boxed{5.41 \text{ m/s}}$

(d) $\lambda = v_x T = (30.0 \text{ m/s})(0.0250 \text{ s}) = 0.750 \text{ m}$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.750 \text{ m}} = 8.38/\text{m}$$

$\omega = 80.0\pi/\text{s}$

$$\boxed{y(x, t) = (0.0215 \text{ m}) \sin(8.38x \text{ rad/m} + 80.0\pi t \text{ rad/s} + 1.95 \text{ rad})}$$

16.33 (a) $f = \dfrac{v}{\lambda} = \dfrac{(1.00 \text{ m/s})}{2.00 \text{ m}} = \boxed{0.500 \text{ Hz}}$

$\omega = 2\pi f = 2\pi(0.500/\text{s}) = \boxed{3.14 \text{ rad/s}}$

(b) $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{2.00 \text{ m}} = \boxed{3.14 \text{ rad/m}}$

(c) $y = A \sin(kx - \omega t + \phi)$ becomes

$y = \boxed{(0.100 \text{ m}) \sin(3.14\, x/\text{m} - 3.14\, t/\text{s} + 0)}$

(d) For $x = 0$ the wave function requires

$$\boxed{y = (0.100 \text{ m}) \sin(-3.14\, t/\text{s})}$$

(e) $\boxed{y = (0.100 \text{ m}) \sin(4.71 \text{ rad} - 3.14\, t/\text{s})}$

(f) $v_y = \dfrac{\partial y}{\partial t} = 0.100 \text{ m } (-3.14/\text{s}) \cos(3.14\, x/\text{m} - 3.14\, t/\text{s})$

The cosine varies between +1 and –1, so

$$v_y \le \boxed{0.314 \text{ m/s}}$$

16.34 $y = (0.150 \text{ m}) \sin(3.10x - 9.30t)$ SI units

$$v = \frac{\omega}{k} = \frac{9.30}{3.10} = 3.00 \text{ m/s}$$

$s = vt = \boxed{30.0 \text{ m in positive } x\text{-direction}}$

16.35 $y = (0.0200 \text{ m}) \sin(2.11x - 3.62t)$ SI units

$A = \boxed{2.00 \text{ cm}}$ $\quad k = 2.11 \text{ rad/m}$

$$\lambda = \frac{2\pi}{k} = \boxed{2.98 \text{ m}}$$

$\omega = 3.62 \text{ rad/s}$

$$f = \frac{\omega}{2\pi} = \boxed{0.576 \text{ Hz}}$$

$$v = f\lambda = \frac{\omega}{2\pi}\frac{2\pi}{k} = \frac{\omega}{k} = \frac{3.62}{2.11} = \boxed{1.72 \text{ m/s}}$$

16.36 (a) $\omega = 2\pi f = 2\pi(500) = 3140 \text{ rad/s}$, $k = \omega/v = (3140)/(196) = 16.0 \text{ rad/m}$

$$\boxed{y = (2.00 \times 10^{-4} \text{ m}) \sin(16.0x - 3140t)}$$

(b) $v = 196 \text{ m/s} = \sqrt{\dfrac{T}{4.10 \times 10^{-3} \text{ kg/m}}}$

$T = \boxed{158 \text{ N}}$

16.37 (a) at $x = 2.00$ m, $y = \boxed{(0.100 \text{ m}) \sin(1.00 \text{ rad} - 20.0t)}$

(b) $y = (0.100 \text{ m}) \sin(0.500x - 20.0t) = A \sin(kx - \omega t)$

so $\omega = 20.0 \text{ rad/s}$ and $f = \dfrac{\omega}{2\pi} = \boxed{3.18 \text{ Hz}}$

16.38 $f = \dfrac{v}{\lambda} = \dfrac{30.0}{0.500} = 60.0 \text{ Hz}$ $\quad \omega = 2\pi f = 120\pi \text{ rad/s}$

$$\wp = \frac{1}{2}\mu\omega^2 A^2 v = \frac{1}{2}\left(\frac{0.180}{3.60}\right)(120\pi)^2(0.100)^2(30.0) = \boxed{1.07 \text{ kW}}$$

16.39 Suppose that no energy is absorbed or carried down into the water. Then a fixed amount of power is spread thinner farther away from the source, spread over the circumference $2\pi r$ of an expanding circle. The power-per-width across the wave front

$$\frac{\wp}{2\pi r}$$

is proportional to amplitude squared so amplitude is proportional to

$$\sqrt{\frac{\wp}{2\pi r}}$$

16.40 T = constant; $v = \sqrt{\frac{T}{\mu}}$; $\wp = \frac{1}{2}\,\mu\omega^2 A^2$

(a) If L is doubled, v remains constant and $\boxed{\wp \text{ is constant}}$.

(b) If A is doubled and ω is halved, $\wp \propto \omega^2 A^2$ $\boxed{\text{remains constant}}$.

(c) If λ and A are doubled, the product $\omega^2 A^2 \propto A^2/\lambda^2$ remains constant, so $\boxed{\wp \text{ remains constant}}$.

(d) If L and λ are halved, then $\omega^2 \propto 1/\lambda^2$ is quadrupled, so $\boxed{\wp \text{ is quadrupled}}$. (Changing L doesn't affect $\wp$).

16.41 $A = 5.00 \times 10^{-2}$ m $\quad \mu = 4.00 \times 10^{-2}$ kg/m $\quad \wp = 300$ W $\quad T = 100$ N

Therefore,

$$v = \sqrt{\frac{T}{\mu}} = 50.0 \text{ m/s}$$

$$\wp = \frac{1}{2}\,\mu\omega^2 A^2 v$$

$$\omega^2 = \frac{2\wp}{\mu A^2 v} = \frac{2(300)}{(4.00 \times 10^{-2})(5.00 \times 10^{-2})^2(50.0)}$$

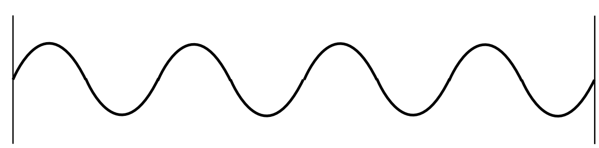
$$\omega = 346 \text{ rad/s}$$

$$f = \frac{\omega}{2\pi} = \boxed{55.1 \text{ Hz}}$$

***16.42** $\mu = 30.0$ g/m $= 30.0 \times 10^{-3}$ kg/m $\quad \lambda = 1.50$ m

$f = 50.0$ Hz $\quad \omega = 2\pi f = 314\ \text{s}^{-1}$

$2A = 0.150$ m $\quad A = 7.50 \times 10^{-2}$ m



(a) $y = A \sin\left(\frac{2\pi}{\lambda}x - \omega\, t\right)$

$$\boxed{y = (7.50 \times 10^{-2} \text{ m}) \sin(4.19x - 314t)}$$

(b) $\wp = \frac{1}{2}\,\mu\omega^2 A^2 v = \frac{1}{2}(30.0 \times 10^{-3})(314)^2(7.50 \times 10^{-2})^2\left(\frac{314}{4.19}\right)$ W

$$\boxed{\wp = 625 \text{ W}}$$

16.43 (a) $v = f\lambda = \frac{\omega}{2\pi}\frac{2\pi}{k} = \frac{\omega}{k} = \frac{50.0}{0.800}\text{ m/s} = \boxed{62.5\text{ m/s}}$

(b) $\lambda = \frac{2\pi}{k} = \frac{2\pi}{0.800}\text{ m} = \boxed{7.85\text{ m}}$

(c) $f = \frac{50.0}{2\pi} = \boxed{7.96\text{ Hz}}$

(d) $\wp = \frac{1}{2}\mu\omega^2A^2v = \frac{1}{2}(12.0\times10^{-3})(50.0)^2(0.150)^2(62.5)\text{ W} = \boxed{21.1\text{ W}}$

16.44 Originally,

$$\wp_o = \frac{1}{2}\mu\omega^2A^2v$$

$$\wp_o = \frac{1}{2}\mu\omega^2A^2\sqrt{\frac{T}{\mu}}$$

$$\wp_o = \frac{1}{2}\omega^2A^2\sqrt{T\mu}$$

The doubled string will have doubled mass-per-length. Presuming that we hold tension constant, it can carry power larger by $\sqrt{2}$ times.

$$\boxed{\sqrt{2}\,\wp_o} = \frac{1}{2}\omega^2A^2\sqrt{T\,2\mu}$$

***16.45** (a) $A = (7.00 + 3.00)4.00$ yields $\boxed{A = 40.0}$

(b) In order for two vectors to be equal, they must have the same magnitude and the same direction in three-dimensional space. All of their components must be equal. Thus, $7.00\mathbf{i} + 0\mathbf{j} + 3.00\mathbf{k} = A\mathbf{i} + B\mathbf{j} + C\mathbf{k}$ requires $\boxed{A = 7.00,\ B = 0,\text{ and } C = 3.00}$.

(c) In order for two functions to be identically equal, they must be equal for every value of every variable. They must have the same graphs. In $A + B\cos(Cx + Dt + E) = 0 + 7.00\text{ mm}\cos(3.00x + 4.00t + 2.00)$, the equality of average values requires that $\boxed{A = 0}$. The equality of maximum values requires $\boxed{B = 7.00\text{ mm}}$. The equality for the wavelength or periodicity as a function of x requires $\boxed{C = 3.00\text{ rad/m}}$. The equality of period requires $\boxed{D = 4.00\text{ rad/s}}$, and the equality of zero-crossings requires $\boxed{E = 2.00\text{ rad}}$.

16.46 Equation 16.26, with $v = \sqrt{T/\mu}$ is

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

If $y = e^{b(x - vt)}$,

then $\frac{\partial y}{\partial t} = -bve^{b(x-vt)}$ and $\frac{\partial y}{\partial x} = be^{b(x-vt)}$

$$\frac{\partial^2 y}{\partial t^2} = b^2 v^2 e^{b(x-vt)} \quad \text{and} \quad \frac{\partial^2 y}{\partial x^2} = b^2 e^{b(x-vt)}$$

Therefore, $\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2}$, and $e^{b(x-vt)}$ is a solution.

16.47 From Equation 16.25, $\left(\frac{\mu}{T}\right)\frac{\partial^2 y}{\partial t^2} = \frac{\partial^2 y}{\partial x^2}$

To verify that $y = \ln[b(x - vt)]$ is a solution, find the first and second derivatives of y with respect to x and t and substitute into Equation 16.25:

$$\frac{\partial y}{\partial t} = [b(x - vt)]^{-1}(-bv); \frac{\partial^2 y}{\partial t^2} = -\frac{v^2}{(x - vt)^2}$$

$$\frac{\partial y}{\partial x} = [b(x - vt)]^{-1}(b); \frac{\partial^2 y}{\partial t^2} = -\frac{1}{(x - vt)^2}$$

Substituting into Equation 16.25 we have $\frac{\mu}{T}\left[-\frac{v^2}{(x - vt)^2}\right] = -\frac{1}{(x - vt)^2}$

But $v^2 = \frac{T}{\mu}$, therefore the given function is a solution.

16.48 (a) From $y = x^2 + v^2 t^2$,

evaluate $\frac{\partial y}{\partial x} = 2x$ $\quad \frac{\partial^2 y}{\partial x^2} = 2$

$\frac{\partial y}{\partial t} = v^2 2t$ $\quad \frac{\partial^2 y}{\partial t^2} = 2v^2$

Does $\frac{\partial^2 y}{\partial t} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$?

By substitution: $2 = \frac{1}{v^2} 2v^2$ and this is true, so the wave function does satisfy the wave equation.

(b) Note $\frac{1}{2}(x+vt)^2 + \frac{1}{2}(x-vt)^2$

$$= \frac{1}{2}x^2 + xvt + \frac{1}{2}v^2t^2 + \frac{1}{2}x^2 - xvt + \frac{1}{2}v^2t^2$$

$$= x^2 + v^2t^2 \text{ as required}$$

So $\boxed{f(x+vt) = \frac{1}{2}(x+vt)^2}$ and $\boxed{g(x-vt) = \frac{1}{2}(x-vt)^2}$

(c) $y = \sin x \cos vt$ makes

$$\frac{\partial y}{\partial x} = \cos x \cos vt \qquad \frac{\partial^2 y}{\partial x^2} = -\sin x \cos vt$$

$$\frac{\partial y}{\partial t} = -v \sin x \sin vt \qquad \frac{\partial^2 y}{\partial t^2} = -v^2 \sin x \cos vt$$

Then $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$

becomes $-\sin x \cos vt = \frac{-1}{v^2} v^2 \sin x \cos vt$ which is true as required.

Note $\sin(x+vt) = \sin x \cos vt + \cos x \sin vt$

$\sin(x-vt) = \sin x \cos vt - \cos x \sin vt$

So $\sin x \cos vt = f(x+vt) + g(x-vt)$ with

$\boxed{f(x+vt) = \frac{1}{2}\sin(x+vt)}$ and $\boxed{g(x-vt) = \frac{1}{2}\sin(x-vt)}$

***16.49** Assume a typical distance between adjacent people ~1 m. Then the wave speed is

$$v = \frac{x}{t} \sim \frac{1\text{ m}}{0.1\text{ s}} \sim 10\text{ m/s}$$

Model the stadium as a circle with a radius of order 100 m. Then, the time for one circuit around the stadium is

$$T = \frac{2\pi r}{v} \sim \frac{2\pi(10^2\text{ m})}{10\text{ m/s}} = 63\text{ s}\ \boxed{\sim 1\text{ min}}$$

16.50 Compare the given wave function $y = 4.00 \sin(2.00x - 3.00t)$ cm to the general form $y = A\sin(kx - \omega t)$ to find

(a) amplitude $A = 4.00 \text{ cm} = \boxed{0.0400 \text{ m}}$

(b) $k = \dfrac{2\pi}{\lambda} = 2.00 \text{ cm}^{-1}$ and $\lambda = \pi \text{ cm} = \boxed{0.0314 \text{ m}}$

(c) $\omega = 2\pi f = 3.00 \text{ s}^{-1}$ and $f = \boxed{0.477 \text{ Hz}}$

(d) $T = \dfrac{1}{f} = \boxed{2.09 \text{ s}}$

(e) The minus sign indicates that the wave is traveling in the $\boxed{\text{positive } x\text{-direction}}$.

16.51 (a) Let $u = 10\pi t - 3\pi x + \dfrac{\pi}{4}$

$$\frac{du}{dt} = 10\pi - 3\pi\frac{dx}{dt} = 0$$

$$\frac{dx}{dt} = \frac{10}{3} = \boxed{3.33 \text{ m/s}}$$

The velocity is in the $\boxed{\text{positive } x\text{-direction}}$.

(b) $y(0.100, 0) = (0.350 \text{ m})\sin\left(-0.300\pi + \dfrac{\pi}{4}\right) = -0.0548 \text{ m} = \boxed{-5.48 \text{ cm}}$

(c) $k = \dfrac{2\pi}{\lambda} = 3\pi$

$\lambda = \boxed{0.667 \text{ m}}$

$\omega = 2\pi f = 10\pi$

$f = \boxed{5.00 \text{ Hz}}$

(d) $v_y = \dfrac{\partial y}{\partial t} = (0.350)(10\pi)\cos\left(10\pi t - 3\pi x + \dfrac{\pi}{4}\right)$

$v_{y,\,\max} = (10\pi)(0.350) = \boxed{11.0 \text{ m/s}}$

***16.52** The equation $v = \lambda f$ is a special case of

speed = (cycle length)(repetition rate)

Thus, $v = \left(19.0 \times 10^{-3} \dfrac{\text{m}}{\text{frame}}\right)\left(24.0 \dfrac{\text{frames}}{\text{s}}\right) = \boxed{0.456 \text{ m/s}}$

16.53 Assuming the incline to be frictionless and taking the positive x-direction to be up the incline:

$$\Sigma F_x = T - Mg \sin\theta = 0$$

or the tension in the string is $T = Mg \sin\theta$

The speed of transverse waves in the string is then

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Mg \sin\theta}{m/L}} = \sqrt{\frac{MgL \sin\theta}{m}}$$

and the time for a pulse to travel the length of the string is

$$t = \frac{L}{v} = L\sqrt{\frac{m}{MgL \sin\theta}} = \boxed{\sqrt{\frac{mL}{Mg \sin\theta}}}$$

16.54 (a) $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{80.0 \text{ N}}{(5.00 \times 10^{-3} \text{ kg}/2.00 \text{ m})}} = \boxed{179 \text{ m/s}}$

(b) From Equation 16.21, $\wp = \dfrac{1}{2} \mu v \omega^2 A^2$ and $\omega = 2\pi\left(\dfrac{v}{\lambda}\right)$

$$\wp = \frac{1}{2} \mu v A^2 \left(\frac{2\pi v}{\lambda}\right)^2 = \frac{2\pi^2 \mu A^2 v^3}{\lambda^2}$$

$$\wp = \frac{2\pi^2 (5.00 \times 10^{-3} \text{ kg}/2.00 \text{ m})(0.0400 \text{ m})^2 (179 \text{ m/s})^3}{(0.160 \text{ m})^2}$$

$$\wp = 1.77 \times 10^4 \text{ W} = \boxed{17.7 \text{ kW}}$$

16.55 Energy is conserved as the block moves down distance x:

$$(K + U_g + U_s)_{\text{top}} + \Delta E = (K + U_g + U_s)_{\text{bottom}}$$

$$0 + Mgx + 0 + 0 = 0 + 0 + \frac{1}{2} kx^2$$

$$x = \frac{2Mg}{k}$$

(a) $T = kx = 2Mg = 2(2.00 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{39.2 \text{ N}}$

(b) $L = L_0 + x = L_0 + \dfrac{2Mg}{k}$

$$L = 0.500\text{ m} + \frac{39.2\text{ N}}{100\text{ N/m}} = \boxed{0.892\text{ m}}$$

(c) $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{TL}{m}}$

$$v = \sqrt{\frac{39.2\text{ N} \times 0.892\text{ m}}{5.00 \times 10^{-3}\text{ kg}}}$$

$$v = \boxed{83.6\text{ m/s}}$$

16.56 $Mgx = \dfrac{1}{2}kx^2$

(a) $T = kx = \boxed{2Mg}$

(b) $L = L_0 + x = \boxed{L_0 + \dfrac{2Mg}{k}}$

(c) $v = \sqrt{\dfrac{T}{\mu}} = \sqrt{\dfrac{TL}{m}} = \boxed{\sqrt{\dfrac{2Mg}{m}\left(L_0 + \dfrac{2Mg}{k}\right)}}$

16.57 $v = \sqrt{\dfrac{T}{\mu}}$ and in this case $T = mg$; therefore, $m = \dfrac{\mu v^2}{g}$

From Equation 16.13, $v = \omega/k$ so that

$$m = \frac{\mu}{g}\left(\frac{\omega}{k}\right)^2 = \frac{0.250\text{ kg/m}}{9.80\text{ m/s}^2}\left[\frac{18\pi\text{ s}^{-1}}{0.750\pi\text{ m}^{-1}}\right]^2 = \boxed{14.7\text{ kg}}$$

16.58 (a) $\mu = \dfrac{dm}{dL} = \rho A\dfrac{dx}{dx} = \rho A$

$$v = \sqrt{T/\mu} = \sqrt{T/\rho A} = \sqrt{T/[\rho(ax+b)]}$$

$$= \sqrt{T/[\rho(10^{-3}x + 10^{-2})\text{cm}^2]}$$

With all SI units, $\boxed{v = \sqrt{T/[\rho(10^{-3}x + 10^{-2})10^{-4}]}\text{ m/s}}$

(b) $v\big|_{x=0} = \sqrt{24.0/[(2700)(0 + 10^{-2})(10^{-4})]} = \boxed{94.3\text{ m/s}}$

$v\big|_{x=10.0} = \sqrt{24.0/[(2700)(10^{-2} + 10^{-2})(10^{-4})]} = \boxed{66.7\text{ m/s}}$

16.59 $v = \sqrt{\dfrac{T}{\mu}}$ where $T = \mu x g$, the weight of a length x, of rope.

Therefore, $v = \sqrt{gx}$

But $v = \dfrac{dx}{dt}$ so that

$$dt = \frac{dx}{\sqrt{gx}}$$

and $t = \displaystyle\int_0^L \frac{dx}{\sqrt{gx}} = \boxed{2\sqrt{\frac{L}{g}}}$

16.60 At distance x from the bottom, the tension is $T = (mxg/L) + Mg$, so the wave speed is:

$$v = \sqrt{T/\mu} = \sqrt{TL/m} = \sqrt{xg + (MgL/m)} = \frac{dx}{dt}$$

Then

(a) $t = \displaystyle\int_0^t dt = \int_0^L [xg + (MgL/m)]^{-1/2}\, dx$

$$t = \frac{1}{g}\left.\frac{[xg + (MgL/m)]^{1/2}}{\frac{1}{2}}\right|_{x=0}^{x=L}$$

$$t = \frac{2}{g}\left[(Lg + MgL/m)^{1/2} - (MgL/m)^{1/2}\right]$$

$$\boxed{t = 2\sqrt{\frac{L}{g}}\left(\frac{\sqrt{m+M} - \sqrt{M}}{\sqrt{m}}\right)}$$

(b) When $M = 0$, $t = 2\sqrt{\dfrac{L}{g}}\left(\dfrac{\sqrt{m} - 0}{\sqrt{m}}\right) = \boxed{2\sqrt{\dfrac{L}{g}}}$ as in Problem 59.

(c) As $m \to 0$ we expand

$$\sqrt{m+M} = \sqrt{M}\,(1+m/M)^{1/2} = \sqrt{M}\left(1 + \frac{1}{2}m/M - \frac{1}{8}m^2/M^2 + \ldots\right)$$

to obtain

$$t = 2\sqrt{\frac{L}{g}}\left(\frac{\sqrt{M} + \frac{1}{2}m/\sqrt{M} - \frac{1}{8}m^2/M^{3/2} + \ldots - \sqrt{M}}{\sqrt{m}}\right)$$

$$t \approx 2\sqrt{\frac{L}{g}}\left(\frac{1}{2}\sqrt{\frac{m}{M}}\right) = \boxed{\sqrt{\frac{mL}{Mg}}}$$

16.61 (a) The speed in the lower half of a rope of length L is the same function of distance (from the bottom end) as the speed along the entire length of a rope of length $(L/2)$.

Thus, the time required $= 2\sqrt{\frac{L'}{g}}$ with $L' = \frac{L}{2}$

and the time required $= 2\sqrt{\frac{L}{2g}} = \boxed{0.707\left(2\sqrt{\frac{L}{g}}\right)}$

It takes the pulse more that 70% of the total time to cover 50% of the distance.

(b) By the same reasoning applied in part (a), the distance climbed in τ is given by

$$d = \frac{g\tau^2}{4}$$

For $\tau = \frac{t}{2} = \sqrt{\frac{L}{g}}$, we find the *distance climbed* $= \boxed{\frac{L}{4}}$

In half the total trip time, the pulse has climbed $\frac{1}{4}$ of the total length.

Goal Solution

G: The wave pulse travels faster as it goes up the rope because the tension higher in the rope is greater (to support the weight of the rope below it). Therefore it should take more than half the total time t for the wave to travel halfway up the rope. Likewise, the pulse should travel less than halfway up the rope in time $t/2$.

O: By using the time relationship given in the problem and making suitable substitutions, we can find the required time and distance.

A: (a) From the equation given, the time for a pulse to travel any distance, d, up from the bottom of a rope is $t_d = 2\sqrt{\frac{d}{g}}$.

So the time for a pulse to travel a distance $L/2$ from the bottom is

$$t_{L/2} = 2\sqrt{\frac{L}{2g}} = 0.707\left(2\sqrt{\frac{L}{g}}\right)$$

(b) Likewise, the distance a pulse travels from the bottom of a rope in a time t_d is $d = \frac{gt_d^2}{4}$.

So the distance traveled by a pulse after a time $t_d = \sqrt{L/g}$ is

$$d = \frac{g(L/g)}{4} = \frac{L}{4}$$

L: As expected, it takes the pulse more than 70% of the total time to cover 50% of the distance. In half the total trip time, the pulse has climbed only 1/4 of the total length.

16.62 (a) $v = \frac{\omega}{k} = \frac{15.0}{3.00} = \boxed{5.00 \text{ m/s in positive } x\text{-direction}}$

(b) $v = \frac{15.0}{3.00} = \boxed{5.00 \text{ m/s in negative } x\text{-direction}}$

(c) $v = \frac{15.0}{2.00} = \boxed{7.50 \text{ m/s in negative } x\text{-direction}}$

(d) $v = \frac{12.0}{1/2} = \boxed{24.0 \text{ m/s in positive } x\text{-direction}}$

16.63 Young's modulus for the wire may be written as $Y = \frac{T/A}{\Delta L/L}$, where T is the tension maintained in the wire and ΔL is the elongation produced by this tension. Also, the mass density of the wire may be expressed as $\rho = \frac{\mu}{A}$.

The speed of transverse waves in the wire is then

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T/A}{\mu/A}} = \sqrt{\frac{Y(\Delta L/L)}{\rho}}$$

and the strain in the wire is $\frac{\Delta L}{L} = \frac{\rho v^2}{Y}$

If the wire is aluminum and $v = 100$ m/s, the strain is

$$\frac{\Delta L}{L} = \frac{(2.70 \times 10^3 \text{ kg/m}^3)(100 \text{ m/s})^2}{7.00 \times 10^{10} \text{ N/m}^2} = \boxed{3.86 \times 10^{-4}}$$

16.64 (a) For an increment of spring length dx and mass dm, $F = ma$ becomes

$$k\,dx = a\,dm, \quad \text{or} \quad \frac{k}{(dm/dx)} = a$$

But $\dfrac{dm}{dx} = \mu$ so $a = \dfrac{k}{\mu}$

Also, $a = \dfrac{dv}{dt} = \dfrac{v}{t}$ when $v_i = 0$. But $L = vt$, so $a = \dfrac{v^2}{L}$.

Equating the two expressions for a, we have $\dfrac{k}{\mu} = \dfrac{v^2}{L}$ or

$$\boxed{v = \sqrt{\frac{kL}{\mu}}}$$

(b) Using the expression from part (a)

$$v = \sqrt{\frac{kL}{\mu}} = \sqrt{\frac{kL^2}{m}} = \sqrt{\frac{(100\text{ N/m})(2.00\text{ m})^2}{0.400\text{ kg}}} = \boxed{31.6\text{ m/s}}$$

16.65 (a) $v = (T/\mu)^{1/2} = (2T_0/\mu_o)^{1/2} = \boxed{v_0\sqrt{2}}$ where $v_0 \equiv (T_0/\mu_0)^{1/2}$

$$v' = (T/\mu')^{1/2} = (2T_0/3\mu_0)^{1/2} = \boxed{v_0\sqrt{2/3}}$$

(b) $t_{\text{left}} = \dfrac{L/2}{v} = \dfrac{L}{2v_0\sqrt{2}} = \dfrac{t_0}{2\sqrt{2}} = 0.354t_0$ where $t_0 \equiv \dfrac{L}{v_0}$

$$t_{\text{right}} = \frac{L/2}{v'} = \frac{L}{2v_0\sqrt{2/3}} = \frac{t_0}{2\sqrt{2/3}} = 0.612t_0$$

$$t_{\text{left}} + t_{\text{right}} = \boxed{0.966t_0}$$

16.66 (a) $\wp(x) = \dfrac{1}{2}\mu\omega^2A^2v = \dfrac{1}{2}\mu\omega^2A_0^2\,e^{-2bx}\left(\dfrac{\omega}{k}\right) = \boxed{\dfrac{\mu\omega^2}{2k}A_0^2\,e^{-2bx}}$

(b) $\wp(0) = \boxed{\dfrac{\mu\omega^2}{2k}A_0^2}$

(c) $\dfrac{\wp(x)}{\wp(0)} = \boxed{e^{-2bx}}$

16.67 $v = \dfrac{4450\text{ km}}{9.50\text{ h}} = 468\text{ km/h} = \boxed{130\text{ m/s}}$

$$\bar{d} = \frac{v^2}{g} = \frac{(130\ \text{m/s})^2}{(9.80\ \text{m/s}^2)} = \boxed{1730\ \text{m}}$$