3.23
Since the velocity-time curve for the object is a straight line, its instantaneous acceleration at any given moment is equal to the average acceleration. So at $t = 4 \text{s}$

$$a = a_{av} = \frac{v_t - v_i}{t_t - t_i} = \frac{-15 \text{ m/s} - 30 \text{ m/s}}{6.0 \text{ s} - 0} = -7.5 \text{ m/s}^2,$$

where the negative sign indicates that the direction of $\ddot{\text{a}}$ is opposite to our choice of the positive direction for $\ddot{v}$.

3.24
The instantaneous speed is the time derivative of $x(t)$:

$$v(t) = \frac{dx(t)}{dt} = \frac{d}{dt} (B + Ct^3) = C \frac{dt^3}{dt} = C(3t^2) = 3Ct^2.$$

Now take the time derivative of $v(t)$ to find the acceleration $a(t)$:

$$a(t) = \frac{dv(t)}{dt} = \frac{d}{dt} (3Ct^2) = 3C \frac{dt^2}{dt} = 3C(2t) = 6Ct.$$

3.25
Since the speed as a function of time is given by $v(t) = 25.0 \text{ m/s} - (5.00 \text{ m/s}^2)t$, its value at $t = 0$ is

$$v(0) = [25.0 \text{ m/s} - (5.00 \text{ m/s}^2)t]_{t=0} = 25.0 \text{ m/s},$$

while its value at $t = 1.00 \text{ s}$ is

$$v(1.00 \text{ s}) = [25.0 \text{ m/s} - (5.00 \text{ m/s}^2)t]_{t=1.00 \text{ s}} = 25.0 \text{ m/s} - (5.00 \text{ m/s}^2)(1.00 \text{ s}) = 20.0 \text{ m/s}.$$

The acceleration of the car can be obtained as the time derivative of $v$:

$$a(t) = \frac{dv}{dt} = \frac{d}{dt} [25.0 \text{ m/s} - (5.00 \text{ m/s}^2)t] = -5.00 \text{ m/s}^2,$$

which is a time-independent constant.

3.26
The speed of the robot is the time derivative of the path length it travels:

$$v = \frac{dl}{dt} = \frac{d}{dt} (At^2 - Bt + C) = 2At - B.$$
3.30
From $t_i = 2.0\, \text{s}$ to $t_f = 7.0\, \text{s}$, all three cyclists change their speeds from $v_i = 1.0\, \text{m/s}$ to $v_f = 6.0\, \text{m/s}$. Thus they share the same average acceleration:

$$a_{av} = \frac{v_f - v_i}{t_f - t_i} = \frac{6.0\, \text{m/s} - 1.0\, \text{m/s}}{7.0\, \text{s} - 2.0\, \text{s}} = 1.0\, \text{m/s}^2.$$

Curve (1) corresponds to a varying acceleration, (2) corresponds to a constant acceleration ($a = a_{av} = 1.0\, \text{m/s}^2$), and (3) corresponds to a period of zero acceleration (from $2.0\, \text{s}$ to $4.0\, \text{s}$), followed by a larger, constant acceleration.

At $t = 2.0\, \text{s}$ all three cyclists have the same initial speed ($= 1.0\, \text{m/s}$). By $t = 4.6\, \text{s}$ the speed of cyclist (1) is the greatest, so (1) has the greatest speed change, and hence the greatest average acceleration, between $t = 2.0\, \text{s}$ and $t = 4.6\, \text{s}$.

The instantaneous acceleration is determined by the local slope of the velocity vs time curve. From Fig. P20 it is clear that curve (3) has the steepest local slope at $t = 4.6\, \text{s}$. Thus (3) has the greatest instantaneous acceleration.

3.31
From $t_i = 0\, \text{to} \, t_f = 3.0\, \text{s}$ the velocity of the car changes from $v_i = -20\, \text{m/s}$ to $v_f = 40\, \text{m/s}^2$. Thus from Eq. (3.2) the average acceleration for the time duration is

$$a_{av} = \frac{v_f - v_i}{t_f - t_i} = \frac{(40\, \text{m/s}^2) - (-20\, \text{m/s}^2)}{3.0\, \text{s} - 0.0\, \text{s}} = 20\, \text{m/s}^2.$$

[Alternatively, you may plot the $v$ vs $t$ from $t_i = 0\, \text{to} \, t_f = 3.0\, \text{s}$, and compute the slope of the resulting straight line (using rise over run) to obtain the average acceleration.]
At both $t = 0$ and $t = 3.0$ s the velocity of the car is not changing (as the local slope of the $v$ vs $t$ curve is zero). Thus the instantaneous acceleration at both times is zero.

3.32
According to the problem statement $a = 1\, \text{m/s}^2$ from $t = 0$ to $4$ s, $a = 0$ from $t = 4$ s to $5$ s, and then $a = -2\, \text{m/s}^2$ from $t = 5$ s to $7$ s. The corresponding $a$ vs $t$ diagram is shown below on the left. For the $v$ vs $t$ diagram, use $v = v_0 + a(t - t_0)$ to compute the speed as a function of time during each stage of constant acceleration. For example, the speed at $t = 4$ s is given by $v = 0 + (1\, \text{m/s}^2)(4) = 4\, \text{m/s}$. Draw a straight line connecting $v_0 = 0$, $t_0 = 0$ and $v = 4\, \text{m/s}$, $t = 4$ s to obtain the $v$ vs $t$ diagram for that time duration. The diagram from $t = 4.0$ s on can be obtained in a similar fashion. The complete $v$ vs $t$ diagram is shown below on the right.

3.33
(a) From Problem (3.14) we know that the speed of the boat at $t_3 = 7.0$ s is $v_3 = 22\, \text{m/s}$. From then on the boat decelerates at $a = -1.1\, \text{m/s}^2$. Thus at $t = 27$ s (i.e. 20 s into the deceleration) its speed becomes $v = v_3 + a(t - t_3) = 22\, \text{m/s} + (-1.1\, \text{m/s}^2)(20) = 0$, as indicated in the problem statement. Thus the net change in speed for the boat during its 27-s journey is zero, and so is its average acceleration.

(b) The boat is in constant deceleration with $a = -1.1\, \text{m/s}^2$ from $t_3 = 7.0$ s to $t = 27$ s. Thus $a = -1.1\, \text{m/s}^2$ at $t = 10$ s.

3.34
We want to know the acceleration of the rocket (R) with respect to the helicopter (H). Denoting the ground with subscript G, we have $\vec{a}_{RH} = \vec{a}_{RG} + \vec{a}_{GH} = \vec{a}_{RG} - \vec{a}_{HG}$. Choosing the positive $y$-direction to be upward, then $a_{RG} = (10\, \text{m/s}^2)\hat{j}$ and $a_{HG} = (-5.0\, \text{m/s}^2)\hat{j}$. Hence

$$a_{RH} = a_{RG} - a_{HG} = (10\, \text{m/s}^2)\hat{j} - (-5.0\, \text{m/s}^2)\hat{j} = (15\, \text{m/s}^2)\hat{j} = (15\, \text{m/s}^2)\text{-upward}.$$
Finally, between $t = 3.0\, \text{s}$ and $t = 5.0\, \text{s}$, the mouse again has a positive displacement of

$$ s_3 = s|_{t=5.0\, \text{s}} - s|_{t=3.0\, \text{s}} $$

$$ = [0.10t^3 - 0.60t^2 + 0.90t]_{t=5.0} - [0.10t^3 - 0.60t^2 + 0.90t]_{t=3.0} $$

$$ = +2.0\, \text{m}. $$

The total distance the mouse travels is then $|s_1| + |s_2| + |s_3| = 0.40\, \text{m} + 0.40\, \text{m} + 2.0\, \text{m} = 2.8\, \text{m}$.

**3.39**

Take the derivative of $v$ with respect to time to find the acceleration $a$:

$$ a = \frac{dv}{dt} = \left( \frac{dv}{ds} \right) \left( \frac{ds}{dt} \right) = \left( \frac{dv}{ds} \right) v $$

$$ = \left( \frac{d}{ds} \sqrt{k + 2gs} \right) \sqrt{k + 2gs} $$

$$ = \left( \frac{2g}{2\sqrt{k + 2gs}} \right) \sqrt{k + 2gs} $$

$$ = g = \text{constant}, $$

where we used $ds/dt = v$ and the Chain Rule. You can also start by squaring both sides of the expression for $v$: $v^2 = k + 2gs$, then take the derivative of both sides with respect to $t$:

$$ \frac{dv^2}{dt} = 2v \left( \frac{dv}{dt} \right) = \frac{d}{dt} (k + 2gs) = 2g \left( \frac{ds}{dt} \right) = 2gv, $$

and so $a = dv/dt = 2gv/2v = g$.

**3.40**

(a) For simplicity we temporarily suppress the units and ignore the significant figure notations in the expression for $l(t)$ to obtain $l(t) = 3t + 1/(t + 1)$. Take the time derivative of $l$ to find the corresponding speed:

$$ v(t) = \frac{dl}{dt} = \frac{d}{dt} \left( 3t + \frac{1}{t + 1} \right) = 3 - \frac{1}{(t + 1)^2} = 3.0\, \text{m/s} - \frac{1.0\, \text{m/s}}{[(1.0 \, \text{s}^{-1})t + 1.0]^2} $$

where in the last step we restored the units and expressed the constants in proper (two) significant figures. Plug in $t = 3.0\, \text{s}$ to find the speed to be $2.9\, \text{m/s}$.

(b) The scalar value of the tangential acceleration is the rate of change of the speed:

$$ a_t(t) = \frac{dv}{dt} = \frac{d}{dt} \left[ 3 - \frac{1}{(t + 1)^2} \right] = \frac{2}{(t + 1)^3} = \frac{2.0\, \text{m/s}^2}{[(1.0 \, \text{s}^{-1})t + 1.0]^3}. $$
Taking the derivative with respect to time once again, we get
\[ \frac{d^2x_A}{dt^2} + \frac{d^2x_B}{dt^2} + 2 \frac{d^2x_C}{dt^2} = 0. \]

Here \( \frac{d^2x_A}{dt^2} = a_A \), \( \frac{d^2x_B}{dt^2} = a_B \). Also, the velocity of the car satisfies \( v_C = -\frac{dx_C}{dt} \) as the car is being pulled to the left, so its acceleration is \( a_C = \frac{dv_C}{dt} = -\frac{d^2x_C}{dt^2} \). Thus
\[ \frac{d^2x_A}{dt^2} + \frac{d^2x_B}{dt^2} + 2 \frac{d^2x_C}{dt^2} = a_A + a_B - 2a_C = 0, \]
or \( a_A + a_B = 2a_C \).

### 3.45

Following the notations introduced in the problem statement, we find the length \( l_1 \) of the leftmost segment of the rope to be \( l_1 = y_A - L_1 \). Meanwhile, the lengths of the middle and rightmost segments of the rope are given by \( l_2 = y_A - L_2 \) and \( l_3 = y_B - L_2 \), respectively. The total length of the rope, \( l_{\text{total}} \), is then
\[ l_{\text{total}} = l_1 + l_2 + l_3 = (y_A - L_1) + (y_A - L_2) + (y_B - L_2) = 2y_A + y_B - L_1 - 2L_2, \]
which remains a constant, i.e.,
\[ \frac{dl_{\text{total}}}{dt} = \frac{d}{dt}(2y_A + y_B - L_1 - 2L_2) = 2 \frac{dy_A}{dt} + \frac{dy_B}{dt} = 0. \]

Taking the time derivative once again and noting that \( a_A = \frac{d^2y_A}{dt^2} \) and \( a_B = \frac{d^2y_B}{dt^2} \), we obtain
\[ 2 \frac{d^2y_A}{dt^2} + \frac{d^2y_B}{dt^2} = 2a_A + a_B = 0, \]
or \( a_A = -\frac{1}{2}a_B \). The significance of the minus sign here is that the direction of the acceleration for mass A is opposite to that for mass B. This is clear from Fig. P45. Indeed, if we pull mass B downward with a downward acceleration, mass A must move upward accordingly, with an upward acceleration.

### 3.46

The \( x \)-component of the acceleration \( \ddot{a} \) is the rate at which \( v_x \) changes with time, while \( v_x \) is the rate at which \( x(t) \) changes with time. Thus
\[ v_x = \frac{dx(t)}{dt} = \frac{d}{dt} \left[ (20 \text{ cm/s}^2) t^2 - (8.0 \text{ cm/s})t \right] = (20 \text{ cm/s}^2)(2t) - 8.0 \text{ cm/s}, \]
and
\[ a_x = \frac{dv_x}{dt} = \frac{d}{dt} \left[ (20 \text{ cm/s}^2)(2t) - 8.0 \text{ cm/s} \right] = 40 \text{ cm/s}^2. \]
3.61
Since the acceleration is assumed to be a constant, the average speed of the Corvette is given by \( v_{av} = \frac{1}{2}(v_0 + v) \), where \( v_0 = 0 \) and \( v = 26.8 \text{ m/s} \). So in \( t = 4.8 \text{ s} \) the distance it covers is
\[
s = v_{av} t = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(0 + 26.8 \text{ m/s})(4.8 \text{ s}) = 64 \text{ m}.
\]

3.62
Use Eq. (3.10): \( v^2 = v_0^2 + 2as \). In our case \( v_0 = 0, v = 340 \text{ cm/s} = 3.40 \text{ m/s} \), and \( s = 4 \text{ cm} = 0.04 \text{ m} \); so
\[
a = \frac{v^2 - v_0^2}{2s} = \frac{(3.40 \text{ m/s})^2 - 0}{2(0.04 \text{ m})} = 1 \times 10^2 \text{ m/s}^2.
\]

3.63
The constant-\( a \) equation which relates \( v_0, v, a \) and \( s \) in a one-dimensional motion is Eq. (3.10): \( v^2 = v_0^2 + 2as \). Here \( v_0 = 1.5 \text{ m/s}, a = 1.0 \text{ m/s}^2, \) and \( s = 10 \text{ m} \). Thus
\[
v = \sqrt{v_0^2 + 2as} = \sqrt{(1.5 \text{ m/s})^2 + 2(1.0 \text{ m/s}^2)(10 \text{ m})} = 4.7 \text{ m/s}.
\]

3.64
Use Eq. (3.10), \( v^2 = v_0^2 + 2as \). Here \( v_0 = 10.0 \text{ m/s}, a = 2.50 \text{ m/s}^2, \) and \( s = 100 \text{ m} \). So the final speed \( v_f \) of the car is given by
\[
v = \sqrt{v_0^2 + 2as} = \sqrt{(10.0 \text{ m/s})^2 + 2(2.50 \text{ m/s}^2)(100 \text{ m})} = 24.5 \text{ m/s}.
\]

3.65
As the cyclist enters the tunnel his initial speed is \( v_0 = 5.00 \text{ m/s} \). After he traverses a distance \( s = 25.0 \text{ m} \), his final speed \( v \) upon leaving the tunnel satisfies \( v^2 = v_0^2 + 2as \), where \( a = 0.20 \text{ m/s}^2 \) is his acceleration. So
\[
v = \sqrt{v_0^2 + 2as} = \sqrt{(5.00 \text{ m/s})^2 + 2(0.20 \text{ m/s}^2)(25.0 \text{ m})} = 5.9 \text{ m/s}.
\]

3.66
Suppose that, after Superman starts to apply a constant deceleration \( a \) to slow it down, the train continues to move forward by a distance \( s \) before coming to a complete stop. Just before
Now, \( s = s_1 + s_2 \). After plugging in the expressions for \( s_1 \) and \( s_2 \) obtained above, we get
\[
s = s_1 + s_2 = v_0 t_R - \frac{v_0^2}{2a}.
\]
Solve for \( t_R \):
\[
t_R = \frac{s}{v_0} + \frac{v_0}{2a} = \frac{23.3 \text{ m}}{16.7 \text{ m/s}} + \frac{16.7 \text{ m/s}}{2(-7 \text{ m/s}^2)} = 0.2 \text{ s}.
\]

3.74
Since the speeds for all parts of the vessel are the same, let us first focus on its bow, whose initial speed as it passes the edge of the pier is \( v_0 = 2.50 \text{ m/s} \). By the time the stern passes through the same point, the bow must have moved forward a distance \( s \) which is equal to the length of the vessel (\( = 315.5 \text{ m} \)). Thus for the bow of the ship, which is undergoing an acceleration of \( a \) (\( = 0.01 \text{ m/s}^2 \)), we may apply \( v^2 - v_0^2 = 2as \) to obtain \( v \), its speed the moment the stern of the ship passes through the edge of the pier:
\[
v = \sqrt{v_0^2 + 2as} = \sqrt{(2.50 \text{ m/s})^2 + 2(0.01 \text{ m/s}^2)(315.5 \text{ m})} = 4 \text{ m/s}.
\]
This is also the speed at which the stern is moving at the same moment.

3.75
First, use \( v^2 - v_0^2 = 2as \) to find the acceleration \( a \) of the swimmer as she slows down from \( v_0 = 2.2 \text{ m/s} \) to \( v = 0 \) over a distance of \( s = 10 \text{ m} \):
\[
a = \frac{v^2 - v_0^2}{2s} = \frac{0 - (2.2 \text{ m/s})^2}{2(10 \text{ m})} = -0.242 \text{ m/s}^2.
\]
Now, at this acceleration, she can cover a distance of \( s = v_0 t + \frac{1}{2} at^2 \) a time \( t \) after the onset of the acceleration. Therefore at the beginning of the 3rd second (i.e. the end of the 2nd second) her displacement is given by \( s_2 = v_0 t_2 + \frac{1}{2} at_2^2 \), where \( t_2 = 2.0 \text{ s} \); while at the end of the 3rd second it becomes \( s_3 = v_0 t_3 + \frac{1}{2} at_3^2 \), where \( t_3 = 3.0 \text{ s} \). Her net displacement during the third second is thus
\[
\Delta s = s_3 - s_2 = \left( v_0 t_3 + \frac{1}{2} at_3^2 \right) - \left( v_0 t_2 + \frac{1}{2} at_2^2 \right) = v_0 (t_3 - t_2) + \frac{1}{2} a(t_3^2 - t_2^2)
\]
\[
= (2.2 \text{ m/s})(3.0 \text{ s} - 2.0 \text{ s}) + \frac{1}{2}(-0.242 \text{ m/s}^2) [(3.0 \text{ s})^2 - (2.0 \text{ s})^2]
\]
\[
= 1.6 \text{ m}.
\]

3.76
To complete the 1.00-km journey in as little time as possible, the car must be accelerated at its top rate (\( a_1 = 4.00 \text{ m/s}^2 \)) to its top speed (\( v_{\text{max}} = 40.0 \text{ km/h} \)), remain at this speed for a period of time, then be decelerated as quickly as possible (at \( a_2 = -6.00 \text{ m/s}^2 \)) to a stop.
where the minus sign indicates that the bullet is decelerating.

3.70
Apply Eq. (3.10): \( v^2 = v_0^2 + 2as \). Here \( v_0 = 30.0 \text{ m/s} \) is the speed of the car before the collision, \( v = 0 \) is its speed after the collision, and \( s = 50.0 \text{ cm} = 0.500 \text{ m} \) is the distance traversed by the car during its deceleration. Solve for \( a \):

\[
a = \frac{v^2 - v_0^2}{2s} = \frac{0 - (30.0 \text{ m/s})^2}{2(0.500 \text{ m})} = -900 \text{ m/s}^2 ,
\]

where the minus sign corresponds to the fact that the car is slowing down.

3.71
In the final phase, the shuttle starts with an initial speed of \( v_0 = (682 \text{ km/h})(10^3 \text{ m/km}) \times (1 \text{ h/}3600 \text{ s}) = 189.44 \text{ m/s} \), and decelerates to a final speed \( v = (346 \text{ km/h})(10^3 \text{ m/km}) \times (1 \text{ h/}3600 \text{ s}) = 96.11 \text{ m/s} \) (upon landing) in \( \Delta t = 86.0 \text{ s} \). The average tangential acceleration \((a_t)_{av}\) must satisfy

\[
(a_t)_{av} = \frac{\text{change in speed}}{\text{time duration}} = \frac{v - v_0}{\Delta t} = \frac{96.11 \text{ m/s} - 189.44 \text{ m/s}}{86.0 \text{ s}} = -1.09 \text{ m/s}^2 ,
\]

where the minus sign indicates that the speed of the shuttle is decreasing.

3.72
Use Eq. (3.13) (for constant-\( a_t \)), \( v^2 = v_0^2 + 2a_t l \), where in this case \( v_0 = 0 \) is the cart’s initial speed, \( a_t = 4.5 \text{ m/s}^2 \) its tangential acceleration, and \( l = 30.0 \text{ m} \) the distance it travels along the ramp. Thus the final speed of the cart is

\[
v = \sqrt{v_0^2 + 2a_t l} = \sqrt{2(4.5 \text{ m/s}^2)(30.0 \text{ m})} = 16 \text{ m/s} .
\]

Note that, as long as the tangential acceleration \( a_t \) of the cart is a constant, the fact that the ramp is curved is irrelevant.

3.73
The total stopping distance \( s = 23.3 \text{ m} \) for the car is divided into two parts. In part (1), which lasts a time interval \( t_R \) (the reaction time of the driver), the brakes have not yet been engaged and the car was still moving at a speed of \( v_0 = 60 \text{ km/h} = (60 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h/}3600 \text{ s}) = 16.7 \text{ m/s} \). The distance the car traverses during that period is \( s_1 = v_0 t_R \). In part (2), the brakes are engaged and the car decelerates at a rate of \( a \) over a distance \( s_2 \), before coming to a complete stop with \( v = 0 \). Here \( s_2 \) satisfies \( v^2 - v_0^2 = -2a s_2 \), or \( s_2 = -v_0^2/2a \).
The acceleration stage lasts a time duration $t_1$, where $v_{\text{max}} = a_1 t_1$. Solve for $t_1$:

$$
t_1 = \frac{v_{\text{max}}}{a_1} = \frac{(40.0 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})}{4.00 \text{ m/s}^2} = 2.778 \text{ s}.
$$

Thus the distance $s_1$ the car covers during the acceleration stage is given by

$$
s_1 = \frac{1}{2} a_1 t_1^2 = \frac{1}{2} (4.00 \text{ m/s}^2)(2.778 \text{ s})^2 = 15.43 \text{ m}.
$$

Similarly, for the deceleration stage from $v_{\text{max}}$ to $v = 0$, the time duration $t_2$ satisfies $v - v_{\text{max}} = a_2 t_2$, or

$$
t_2 = \frac{v - v_{\text{max}}}{a_2} = \frac{0 - (40.0 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})}{-6.00 \text{ m/s}^2} = 1.852 \text{ s};
$$

while the corresponding distance the car covers can be found from $v^2 - v_{\text{max}}^2 = 2a_2 s_2$:

$$
s_2 = \frac{v^2 - v_{\text{max}}^2}{2a_2} = \frac{0 - [(40.0 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})]^2}{2(-6.00 \text{ m/s}^2)} = 10.29 \text{ m}.
$$

Since the total distance the car has to cover is $s = 1.00 \text{ km} = 1.00 \times 10^3 \text{ m}$, it must traverse at its top speed $v$ by as much as $s_3 = s - s_1 - s_2$ for a time $t_3$, where $s_3 = vt_3$, or

$$
t_3 = \frac{s_3}{v} = \frac{1.00 \times 10^3 \text{ m} - 15.43 \text{ m} - 10.29 \text{ m}}{(40.0 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})} = 87.69 \text{ s}.
$$

The total time it takes to complete the journey is therefore $t = t_1 + t_2 + t_3 = 2.778 \text{ s} + 1.852 \text{ s} + 87.69 \text{ s} = 92.32 \text{ s}$. Retain three significant figures to obtain $t = 92.3 \text{ s}$.

### 3.77

The stopping distance for the Express (E) satisfies $v^2 - v_{0}^2 = 2a s_E$, where $v = 0$, $v_0 = 96 \text{ km/h}$, and $a = -4 \text{ m/s}^2$. Thus

$$
s_E = \frac{v^2 - v_0^2}{2a} = \frac{0 - [(96 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})]^2}{2(-4 \text{ m/s}^2)} = 88.9 \text{ m}.
$$

Similarly, for the Flyer (F) we have $v = 0$, $v_0 = 110 \text{ km/h}$, and $a = -3 \text{ m/s}^2$. So its stopping distance is given by

$$
s_F = \frac{v^2 - v_0^2}{2a} = \frac{0 - [(110 \text{ km/h})(10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s})]^2}{2(-3 \text{ m/s}^2)} = 155.6 \text{ m}.
$$

Since $s_E + s_F = 88.9 \text{ m} + 155.6 \text{ m} = 244.5 \text{ m} < 250 \text{ m}$, the two trains won't collide.
80.0 s. Since the cop (C) spent 2.0 s getting his motorcycle started, he has a total of \( t_C = 80.0 \text{ s} - 2.0 \text{ s} = 78.0 \text{ s} \) left to capture the Ferrari (i.e. to cover a distance of \( s \)). Suppose he first accelerates at a rate of \( a_C \) for a time \( t_1 \) to reach his top speed, \( v_C = (110 \text{ km/h}) = (10^3 \text{ m/km})(1 \text{ h}/3600 \text{ s}) = 30.56 \text{ m/s} \). Then \( t_1 = v_C/a_C \), during which he traverses a distance of \( s_1 = \frac{1}{2} a_C t_1^2 = \frac{1}{2} a_C (v_C/a_C)^2 = v_C^2/2a_C \). To reach the border, which is now a distance \( s - s_1 \) away, he must continue to move at \( v_C \) for another time duration \( t_2 \) for the remainder of the 2.00-km pursuit: \( t_2 = (s - s_1)/v_C \). Now write \( t_C = t_1 + t_2 \) and substitute the expressions for \( t_1 \) and \( t_2 \) into this equation to obtain

\[
t_C = t_1 + t_2 = \frac{v_C}{a_C} + \frac{s - s_1}{v_C} = \frac{v_C}{a_C} + \frac{s - v_C^2/2a_C}{v_C} = \frac{v_C}{2a_C} + \frac{s}{v_C}.
\]

Solve for \( a_C \):

\[
a_C = \frac{v_C^2}{2(v_C t_C - s)} = \frac{(30.56 \text{ m/s})^2}{2[(30.56 \text{ m/s})(78.0 \text{ s}) - 2.00 \times 10^3 \text{ m}]} = 1.22 \text{ m/s}^2.
\]

3.03

If your friend catches the ruler after it has dropped by \( s \), then his/her reaction time \( t \) can be estimated from \( s = \frac{1}{2} gt^2 \). For example, if \( s \approx 10 \text{ in.} \approx 25 \text{ cm} = 0.25 \text{ m} \), then

\[
t = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2(0.25 \text{ m})}{9.81 \text{ m/s}^2}} = 0.23 \text{ s}.
\]

To catch a dollar bill on time, \( s \) has to be no more than about 3.0 in., which is half the length of the bill. The corresponding reaction time can be estimated from the formula above to be equal or less than 0.12 s. See if you can do it. (Most people probably cannot.)

3.04

Use Eq. (3.18) for the peak altitude: \( s_p = -v_0^2/2g \). Solve for \( v_0 \):

\[
v_0 = \sqrt{-2s} g = \sqrt{-2(2.5 \text{ m})(-9.81 \text{ m/s}^2)} = 7.0 \text{ m/s}.
\]

3.05

Your initial speed \( v_0 \), displacement \( s \), final speed \( v \) and acceleration \( g \) are related by \( v^2 - v_0^2 = 2gs \). Since \( v_0 = 0 \),

\[
v = \sqrt{2gs} = \sqrt{2(9.81 \text{ m/s}^2)(0.50 \text{ m})} = 3.1 \text{ m/s}.
\]

Use 1 ft = 0.3048 m to convert \( v \) to ft/s: \( v = (3.1 \text{ m/s})(1 \text{ ft}/0.3048 \text{ m}) = 10 \text{ ft/s} \). Use 1 mi = 1609 m and 1 h = 3600 s to convert \( v \) to mi/h: \( v = (3.13 \text{ m/s})(1 \text{ mi}/1609 \text{ m})(3600 \text{ s/h}) = 7.0 \text{ mi/h} \).
3.96
Since the stone is in free fall with zero initial speed for \( t = 3.7 \text{s} \), its displacement (which is the same as the height of the rock-dropper above the water) is

\[
s = \frac{1}{2}gt^2 = \frac{1}{2}(9.81 \text{ m/s}^2)(3.7 \text{s})^2 = 67 \text{ m}.
\]

3.97
The velocity of the object in free fall as a function of time \( t \) is given by \( v = v_0 + gt \). Taking the upward direction to be positive, we have \( g = -9.81 \text{ m/s}^2 \). Also, \( v_0 = 0 \). Thus \( v = gt = (-9.81 \text{ m/s}^2)t \). Plug in the various values of \( t \) to obtain \( v = -9.8 \text{ m/s}, -20 \text{ m/s}, -49 \text{ m/s} \) and \(-98 \text{ m/s} \) at \( t = 1.0 \text{s}, 2.0 \text{s}, 5.0 \text{s} \) and \( 10 \text{s} \), respectively.

The displacement of the same object satisfies \( s = v_0 t + \frac{1}{2}gt^2 = \frac{1}{2}gt^2 = \frac{1}{2}(-9.81 \text{ m/s}^2)t^2 = (-4.9 \text{ m/s}^2)t^2 \). The values of \( s \) at \( t = 1.0 \text{s}, 2.0 \text{s}, 5.0 \text{s} \) and \( 10 \text{s} \) are then \( s = -4.9 \text{ m}, -20 \text{ m}, -0.12 \text{ km} \) and \(-0.49 \text{ km} \), respectively.

3.98
Use Eq. (3.18) for the maximum altitude:

\[
s_p = \frac{-v_0^2}{2g} = \frac{- (9.8 \text{ m/s})^2}{2(-9.81 \text{ m/s}^2)} = 4.9 \text{ m}.
\]

At the maximum altitude the velocity of the cannonball is \( v = 0 \). Thus from \( v = v_0 + gt \) we get the time of flight:

\[
t = \frac{v - v_0}{g} = \frac{0 - 9.8 \text{ m/s}}{-9.81 \text{ m/s}^2} = 1.0 \text{s}.
\]

3.99
The final speed \( v \) of the hailstone, which has been undergoing an acceleration of \( g \) over a distance of \( s \), satisfies \( v^2 - v_0^2 = 2gs \), where \( v_0 = 0 \). Taking the downward direction to be positive, then \( g = +9.80665 \text{ m/s}^2 \) and \( s = +0.9144 \times 10^4 \text{ m} \). Solve for \( v \):

\[
v = \sqrt{2gs} = \sqrt{2(9.80665 \text{ m/s}^2)(0.9144 \times 10^4 \text{ m})} = 423 \text{ m/s}.
\]

You may also use \( 1 \text{ mi} = 1609 \text{ m} \) and \( 1 \text{ h} = 3600 \text{ s} \) to convert the unit of \( v \) to \( \text{mi/h} \):

\[
(423.6 \text{ m/s})(1 \text{ mi/1609 m})(3600 \text{ s/h}) = 947 \text{ mi/h}.
\]

3.100
From Eq. (3.18) we know that the peak altitude the ball attains above its initial position is given by

\[
s_p = \frac{-v_0^2}{2g} = \frac{- (5.0 \text{ m/s})^2}{2(-9.81 \text{ m/s}^2)} = 1.3 \text{ m}.
\]

Since the initial position of the ball is at \( 15.0 \text{ m} + 1.0 \text{ m} = 16.0 \text{ m} \) above the ground, the ball's maximum altitude is \( 1.3 \text{ m} + 16.0 \text{ m} = 17.3 \text{ m} \) above the ground.
3.102
From Eq. (3.18) we know that the peak altitude attained satisfied \( s_p = -v_0^2 / 2g \propto 1/g \). Thus for the same initial speed \( v_0 \)

\[
\frac{s_{pm}}{s_{pe}} = \frac{1/g_m}{1/g_e} = \frac{g_e}{g_m} = \frac{g}{g/6} = 6.
\]
Here the subscripts E and M are used to denote the Earth and the Moon, respectively. If \( s_{pe} = 25 \text{ m} \), then on the Moon \( s_{pm} = 6s_{pe} = 6(25 \text{ m}) = 150 \text{ m} \).

3.103
The displacement \( s \) of the baseball in free fall as a function of time \( t \) is given by \( s = v_0 t + \frac{1}{2}gt^2 \).
Since the ball returns to the boy’s hand, its net displacement is \( s = 0 \), so \( v_0 t + \frac{1}{2}gt^2 = 0 \). Take the upward direction to be positive and solve for the initial speed \( v_0 \):

\[
v_0 = -\frac{1}{2}gt = -\frac{1}{2}(-9.8 \text{ m/s}^2)(1.0 \text{ s}) = 4.9 \text{ m/s}.
\]

3.104
The speed \( v \) of the arrow in free fall as a function of time \( t \) is given by \( v = v_0 + gt \). Taking the upward direction to be positive, we have \( g = -9.81 \text{ m/s}^2 \) and \( v_0 = +98.1 \text{ m/s} \). Thus at \( t = 10 \text{ s} \)

\[
v = v_0 + gt = 98.1 \text{ m/s} + (-9.81 \text{ m/s}^2)(10 \text{ s}) = 0.
\]
3.111
Take the downward direction as positive. Let the initial speed of the bag as it passes the top of his head be \( v_o \), then a time \( t = 0.20 \text{s} \) later as it hit the ground its speed becomes \( v = v_o + gt \). The average speed of the bag during time \( t \) is then \( v_{av} = (v_o + v)/2 = v_o + \frac{1}{2}gt = v - \frac{1}{2}gt \). Let \( s = +2 \text{ m} = v_{av} t \) and solve for \( v \):

\[
v = \frac{s}{t} + \frac{1}{2}gt = \frac{2 \text{ m}}{0.20 \text{s}} + \frac{1}{2}(9.81 \text{ m/s}^2)(0.20 \text{s}) = 10.98 \text{ m/s}.
\]

To reach this final speed, the bag must have fallen freely from a height \( s_B \), where \( v^2 = 2gs_B \). Thus the height of the building is

\[
s_B = \frac{v^2}{2g} = \frac{(10.98 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = 6.14 \text{ m} \approx 6 \text{ m}.
\]

(Note that the final answer has only one significant figure, since the height of the gangster is given by \( s = 2 \text{ m} \).)

3.112
The total time of flight \( t_T \) is twice the time it takes for the shoe to reach its peak altitude: \( t_T = 2(2.0 \text{s}) = 4.0 \text{s} \). As the shoe reaches the peak altitude of its flight its velocity is purely horizontal, at 6.0 \text{ m/s}. Since there is no horizontal acceleration, the horizontal component of the velocity of the shoe for the entire flight must be \( v_x = 6.0 \text{ m/s} \). Thus the shoe lands at a distance \( s_x = v_x t_T = (6.0 \text{ m/s})(4.0 \text{s}) = 24 \text{ m} \) away from its starting point.

3.113
Since the horizontal component \( v_{ox} \) of the velocity of a projectile is a constant, the horizontal range is given by \( s_R = v_{ox} t_T \). Now, during the time when the projectile ascends to its peak altitude, the vertical component of its velocity changes from \( v_{oy} \) to zero. So the ascending time \( t \) satisfies \( 0 - v_{oy} = gt \), or \( t = -v_{oy}/g \). The total time of flight \( t_T \) is twice as long as \( t \):

\[
t_T = 2t = -2v_{oy}/g. \text{ Hence}
\]

\[
s_R = v_{ox} t_T = v_{ox} \left( \frac{-2v_{oy}}{g} \right) = -\frac{2v_{ox} v_{oy}}{g}.
\]

3.114
Since the bullet is fired horizontally, \( v_{ox} = v_o = 1000 \text{ m/s} \). At this speed it will strike the target in \( t_T = 100 \text{ m}/1000 \text{ m/s} = 0.100 \text{s} \). Meanwhile, the bullet descends vertically in a free fall through a distance

\[
s_v = \frac{1}{2}gt_T^2 = \frac{1}{2}(-9.81 \text{ m/s}^2)(0.100 \text{s})^2 = -0.0490 \text{ m} = -4.90 \text{ cm},
\]
where the negative sign means that the bullet strikes at a point 4.9 cm below the target (since we have chosen the upward direction as positive by setting $g < 0$).

### 3.115
Take the downward direction to be positive. Since the egg falls vertically for $t = 2.0 \text{ s}$, its vertical displacement, which is equal in magnitude to the height of its launch point, is given by

$$s_v = \frac{1}{2} gt^2 = \frac{1}{2} (9.81 \text{ m/s}^2)(2.0 \text{ s})^2 = 20 \text{ m}.$$  

Here we noted that, since the egg is projected out of the window horizontally, the vertical component of its initial velocity is zero.

### 3.116
So far as the vertical component of the motion is concerned, the marble starts with zero initial speed and drops for $t = 3.0 \text{ s}$ at an acceleration of $g$. So it drops vertically by

$$s = \frac{1}{2} gt^2 = \frac{1}{2} (9.81 \text{ m/s}^2)(3.0 \text{ s})^2 = 44 \text{ m},$$

meaning that the flower pot is 44 m beneath the sill.

### 3.117
Obviously, the water bag was thrown horizontally by the first clown. So its initial velocity in the vertical direction is zero, and in $t = 1.5 \text{ s}$ it should drop by

$$s = \frac{1}{2} gt^2 = \frac{1}{2} (9.81 \text{ m/s}^2)(1.5 \text{ s})^2 = 11 \text{ m}.$$  

Since the water bag's initial position was $20.0 \text{ m}$ above the ground, it hits the third clown's head at $20.0 \text{ m} - 11 \text{ m} = 9 \text{ m}$ above the ground.

### 3.118
Take the upward direction as positive. Then $g = -9.81 \text{ m/s}^2$. From Eq. (3.19) for the range, $s_R = -(2v_o^2/g) \sin \theta \cos \theta$, we may solve for $v_o$, the desired initial speed of the golf ball:

$$v_o = \sqrt{\frac{gs_R}{2 \sin \theta \cos \theta}} = \sqrt{\frac{(-9.81 \text{ m/s}^2)(50 \text{ m})}{2 \sin 45^\circ \cos 45^\circ}} = 22 \text{ m/s}. \quad \blacksquare$$

### 3.119
Denote the dimensions of length and time as $[L]$ and $[T]$, respectively. Then the dimension of $v_o$, for example, is $[L/T]$. Thus in terms of dimensions the equation to be checked reads

$$[L/T][L]^2 = [T][L/T]^2 + [L/T^2][L/T][T^2].$$
where the negative sign means that the bullet strikes at a point 4.9 cm below the target (since we have chosen the upward direction as positive by setting $g < 0$).

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Take the downward direction to be positive. Since the egg falls vertically for $t = 2.0 \text{ s}$, its vertical displacement, which is equal in magnitude to the height of its launch point, is given by

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So far as the vertical component of the motion is concerned, the marble starts with zero initial speed and drops for $t = 3.0 \text{ s}$ at an acceleration of $g$. So it drops vertically by

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Obviously, the water bag was thrown horizontally by the first clown. So its initial velocity in the vertical direction is zero, and in $t = 1.5 \text{ s}$ it should drop by

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Take the upward direction as positive. Then $g = -9.81 \text{ m/s}^2$. From Eq. (3.19) for the range, $s_R = -(2v_o^2/g) \sin \theta \cos \theta$, we may solve for $v_o$, the desired initial speed of the golf ball:

$$v_o = \sqrt{\frac{-gs_R}{2 \sin \theta \cos \theta}} = \sqrt{\frac{-(-9.81 \text{ m/s}^2)(50 \text{ m})}{2 \sin 45^\circ \cos 45^\circ}} = 22 \text{ m/s}.$$ 

3.119
Denote the dimensions of length and time as $[L]$ and $[T]$, respectively. Then the dimension of $v_o$, for example, is $[L/T]$. Thus in terms of dimensions the equation to be checked reads

$$[L/T][L]^2 = [T][L/T]^2 + [L/T^2][L/T][T^2].$$
Now check the dimension of the L.H.S. against that of the first term on the R.H.S. Since $[L/T][L]^2 = [L^3]/[T] \neq [T][L^2]/[T]$, the dimensions of these terms do not match and the equation cannot be valid.

3.120
Take the upward direction as positive. The range $s_R$ of the flea $[(8.0 \text{ in.})(0.0254 \text{ m/in.}) = 0.2032 \text{ m}]$ is related with $v_0$, its initial speed, via Eq. (3.19): $s_R = -(2v_0^2/g) \sin \theta \cos \theta = -(v_0^2/g) \sin 2\theta$, which we solve for $v_0$:

$$v_0 = \sqrt{\frac{-g s_R}{\sin 2\theta}} = \sqrt{\frac{-(-9.81 \text{ m/s}^2)(0.2032 \text{ m})}{\sin(2 \times 45^\circ)}} = 1.4 \text{ m/s}.$$  

3.121
In the vertical direction, each clown will fall by $s_y = 10 \text{ m}$ to reach the surface of the pool. The time $t$ it takes to fall freely through this much distance satisfies $s_y = \frac{1}{2}gt^2$, which gives the time of flight to be

$$t = \sqrt{\frac{2s_y}{g}} = \sqrt{\frac{2(10 \text{ m})}{9.81 \text{ m/s}^2}} = 1.428 \text{ s}.$$  

Meanwhile, each clown must also move horizontally by $s_x = \frac{1}{2}(30 \text{ m}) = 15 \text{ m}$ to meet in the middle of the pool. Thus their horizontal speed $v_x$ must satisfy $s_x = v_x t$, or

$$v_x = \frac{s_x}{t} = \frac{15 \text{ m}}{1.428 \text{ s}} = 11 \text{ m/s}.$$  

3.122
Take the upward direction as positive. Then $g = -9.81 \text{ m/s}^2$.

(a) Use Eq. (3.19) for the range:

$$s_R = -\frac{2v_0^2}{g} \sin \theta \cos \theta = -\frac{2(54.86 \text{ m/s})}{(-9.81 \text{ m/s}^2)} (\sin 40.0^\circ)(\cos 40.0^\circ) = 302 \text{ m}.$$  

(b) The total time of flight is given by Eq. (3.17):

$$t_T = -\frac{2v_0 \sin \theta}{g} = -\frac{2(54.86 \text{ m/s})(\sin 40.0^\circ)}{(-9.81 \text{ m/s}^2)} = 7.19 \text{ s},$$

i.e., the golf ball will strike the ground 7.19 s after it has been hit.
Now check the dimension of the L.H.S. against that of the first term on the R.H.S. Since 
\[ [L/T][L]^2 = [L^3]/[T] \neq [T][L^2]/[T] = [L^2]/[T], \]
the dimensions of these terms do not match and the equation cannot be valid.

3.120
Take the upward direction as positive. The range \( s_r \) of the flea \([=(8.0 \text{ in.})(0.0254 \text{ m/in.}) = 0.2032 \text{ m}]\) is related with \( v_o \), its initial speed, via Eq. (3.19): 
\[ s_r = -(2v_o^2/g) \sin \theta \cos \theta = -(v_o^2/g) \sin 2\theta, \]
which we solve for \( v_o \):
\[
v_o = \sqrt{-\frac{gs_r}{\sin 2\theta}} = \sqrt{-\frac{(-9.81 \text{ m/s}^2)(0.2032 \text{ m})}{\sin(2 \times 45^\circ)}} = 1.4 \text{ m/s}.
\]

3.121
In the vertical direction, each clown will fall by \( s_y = 10 \text{ m} \) to reach the surface of the pool. The
time \( t \) it takes to fall freely through this much distance satisfies \( s_y = \frac{1}{2}gt^2 \), which gives the time of flight to be
\[
t = \sqrt{\frac{2s_y}{g}} = \sqrt{\frac{2(10 \text{ m})}{9.81 \text{ m/s}^2}} = 1.428 \text{ s}.
\]
Meanwhile, each clown must also move horizontally by \( s_x = \frac{1}{2}(30 \text{ m}) = 15 \text{ m} \) to meet in the middle of the pool. Thus their horizontal speed \( v_x \) must satisfy \( s_x = v_x t \), or
\[
v_x = \frac{s_x}{t} = \frac{15 \text{ m}}{1.428 \text{ s}} = 11 \text{ m/s}.
\]

3.122
Take the upward direction as positive. Then \( g = -9.81 \text{ m/s}^2 \).
(a) Use Eq. (3.19) for the range:
\[
s_r = -\frac{2v_o^2}{g} \sin \theta \cos \theta = -\frac{2(54.86 \text{ m/s})}{(-9.81 \text{ m/s}^2)} (\sin 40.0^\circ)(\cos 40.0^\circ) = 302 \text{ m}.
\]
(b) The total time of flight is given by Eq. (3.17):
\[
t_T = -\frac{2v_o \sin \theta}{g} = -\frac{2(54.86 \text{ m/s})(\sin 40.0^\circ)}{(-9.81 \text{ m/s}^2)} = 7.19 \text{ s},
\]
i.e., the golf ball will strike the ground 7.19 s after it has been hit.
3.123

Taking the downward direction as positive, then for the vertical part of the motion the initial velocity of the silver dollar is \( v_{0v} = -v_0 \sin 60.0^\circ = -(40.0 \text{ m/s})(\sin 60.0^\circ) = 34.64 \text{ m/s} \), while its acceleration is \( g = +9.81 \text{ m/s}^2 \). So after falling by \( s_v = +50.0 \text{ m} \) its final speed in the vertical direction satisfies \( v_v^2 - v_{0v}^2 = 2gs_v \), which gives

\[
v_v = \sqrt{v_{0v}^2 + 2gs_v} = \sqrt{(34.64 \text{ m/s})^2 + 2(9.81 \text{ m/s}^2)(50.0 \text{ m})} = +46.70 \text{ m/s}.
\]

The total time of flight of the projectile can then be determined from the mean speed theorem

\[
s_v = (v_{0v})v_T = \frac{1}{2}(v_{0v} + v_v)v_T \text{ to be}
\]

\[
t_T = \frac{2s_v}{v_{0v} + v_v} = \frac{2(50.0 \text{ m})}{34.64 \text{ m/s} + 46.70 \text{ m/s}} = 1.229 \text{ s}.
\]

Thus the landing point is at a distance \( s_z \) downrange, where

\[
s_z = v_zt_T = (v_0 \cos 60.0^\circ)t_T = (40.0 \text{ m/s})(\cos 60.0^\circ)(1.229 \text{ s}) = 24.6 \text{ m}.
\]

Upon striking the water, the projectile's speed is

\[
v = \sqrt{v_x^2 + v_y^2} = \sqrt{[(40.0 \text{ m/s})(\cos 60.0^\circ)]^2 + (46.70 \text{ m/s})^2} = 50.8 \text{ m/s}.
\]

3.124

The horizontal speed of the ball is a constant during its flight: \( v_x = v_0 \cos 45.0^\circ = (25.0 \text{ m/s}) \times (\cos 45.0^\circ) = 17.68 \text{ m/s} \). Choosing the downward direction to be positive, then the initial value of the vertical speed of the ball is \( v_{0y} = v_0 \sin 45.0^\circ = (25.0 \text{ m/s})(\sin 45.0^\circ) = 17.68 \text{ m/s} \). Thus the final vertical speed \( v_v \) satisfies \( v_v^2 = v_{0y}^2 + 2gh \), where \( h = 12.0 \text{ m} \) is the vertical displacement. Here \( g = +9.81 \text{ m/s}^2 \). The final speed of the ball as it strikes the sidewalk can then be obtained from the Pythagorean theorem:

\[
v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_x^2 + (v_{0y}^2 + 2gh)}
\]

\[
= \sqrt{(17.68 \text{ m/s})^2 + (17.68 \text{ m/s})^2 + 2(9.81 \text{ m/s}^2)(12.0 \text{ m})}
\]

\[
= 29.3 \text{ m/s}.
\]

(Note: You can easily check from \( v_x^2 + v_{0y}^2 = v_0^2 \) that \( v = \sqrt{v_0^2 + 2gh} \), which is independent of the angle at which the ball is thrown.)

3.125

This problem is similar to the previous one, Problem (3.124). As the rocket passes by the observer, its initial speed is \( v_o = 30.0 \text{ m/s} \). After dropping vertically by \( h = 20.0 \text{ m} \), it will hit the ground at a final speed \( v \), where (see the note on the solution to the previous problem)

\[
v = \sqrt{v_o^2 + 2gh} = \sqrt{(30.0 \text{ m/s})^2 + 2(9.81 \text{ m/s}^2)(20.0 \text{ m})} = 35.9 \text{ m/s},
\]