Chapter 5 – Part 2 – Solutions

QUESTIONS:

Q5.2.  **Reason:** Objects in static equilibrium do not accelerate and remain at rest. Objects in dynamic equilibrium do not accelerate and move with constant velocity.
(a) The girder is moving at constant speed. We assume it’s being lifted straight up. If so, it’s in dynamic equilibrium.
(b) Since the girder is slowing down it is accelerating, and therefore not in static or dynamic equilibrium.
(c) Since the barbell is not accelerating and remains at rest it is in static equilibrium.
(d) Once the plane has reached its cruising speed and altitude the plane is moving with constant speed and direction. It is in dynamic equilibrium.
(e) A rock in free fall is accelerating due to gravity. It is not in equilibrium.
(f) The box is accelerating since the truck is accelerating and the box is not sliding relative to the truck. The box is not in equilibrium.

**Assess:** For an object in equilibrium \( F_{net} = 0 \).

Q5.24. **Reason:** We will use Equation 5.2 since neither the dog nor the floor is in equilibrium.
(a) From the free-body diagram above, we have 
\[
\begin{align}
\sum F_y &= n - w - a_y \\
\sum F_x &= a_x \\
\end{align}
\]
Solving for the normal force, 
\[
n = w + ma_y = mg + ma_y = (5.0 \text{ kg})(9.80 \text{ m/s}^2) + (5.0 \text{ kg})(-1.20 \text{ m/s}^2) = 43 \text{ N}
\]
The correct choice is B.
(b) The normal force on the dog is the force of the floor of the elevator on the dog. The force of the dog on the elevator floor is the reaction force to this. The correct choice is D.

**Assess:** This result make sense, the normal force will be less than the weight of the dog, which is 49 N.

Q5.25. **Reason:** We must remember the east-west coordinate is independent of the north-south coordinate. The eastward component of velocity (4.5 m/s) will remain constant.
(a) We treat the northward component of the motion as a constant acceleration problem. First we use \( F = ma \) to solve for \( a = \frac{F}{m} = (6.0 \text{ N})(3.0 \text{ kg}) - 2.0 \text{ m/s}^2 \).

Then we use \( \Delta v = a\Delta t \), remembering that \( v_i = 0.0 \text{ m/s} \). So the northward component of the velocity is 
\[
v_f = v_i + a\Delta t = (2.0 \text{ m/s}^2)(1.5 \text{ s}) = 3.0 \text{ m/s}
\]
The correct choice is C.
(b) We have a northward component of 3.0 m/s and an eastward component of 4.5 m/s.

\[
\begin{align}
v &= \sqrt{(v_{north})^2 + (v_{east})^2} \\
&= \sqrt{(3.0 \text{ m/s})^2 + (4.5 \text{ m/s})^2} = 5.4 \text{ m/s}
\end{align}
\]
The correct choice is B.

**Assess:** This question is reminiscent of projectile motion problems with a constant velocity in one direction and a constant acceleration in a perpendicular direction.

A puck with a mass of 3 kg is quite heavy, much more so than a hockey puck.
Q5.28. **Reason:** For the two blocks to remain stationary, they must be in static equilibrium. We will use Equation 5.1. Refer to the figure below. We label the block on the left Block 1 and the block on the right Block 2.

For the 10 kg block,

\[ T = m_1 g \sin(\theta_1) = (10 \text{ kg})(9.80 \text{ m/s}^2)\sin(23^\circ) = 38 \text{ N} \]

For the block on the right,

\[ T = m_2 g \sin(\theta_2) = 38 \text{ N} \]

Solving for the mass of the second block,

\[ m_2 = \frac{T}{g \sin(\theta_2)} = \frac{38 \text{ N}}{9.80 \text{ m/s}^2 \sin(40^\circ)} = 6.1 \text{ kg} \]

The correct choice is B.

**Assess:** This makes sense, since the angle of incline of the second block is much greater.

Q5.30. **Reason:** Friction will slow down and stop the sled once the players stop pushing. The only horizontal force on the sled while it is slowing down is the force of kinetic friction. See the diagram below.

In the vertical direction, Equation 5.1 gives \( n = w \). The force of kinetic friction is given by Equation 5.11.

\[ f_k = \mu_k n = \mu_k mg \]

The net force in the horizontal direction is \( \vec{F}_{\text{net}} = \vec{F}_k \). We can find the acceleration of the sled using Newton’s second law.

\[ a_x = \frac{-f_k}{m} = \frac{-\mu_k mg}{m} = -\mu_k g = -(0.30)(9.80 \text{ m/s}^2) = -2.94 \text{ m/s}^2 \]

Additional significant figures have been retained in this intermediate calculation.

We can find how far the sled slides before stopping using kinematic equations. We have the initial velocity of the sled is \( v_i = 2.0 \text{ m/s} \). The final velocity of the sled is \( v_f = 0.0 \text{ m/s} \). Using Equation 2.13 and solving for \( \Delta x \),

\[ \Delta x = \frac{(v_f)^2}{2a_x} = \frac{(2.0 \text{ m/s})^2}{2(2.94 \text{ m/s}^2)} = 0.68 \text{ m} \]

The correct choice is B.

**Assess:** This result is reasonable. The sled would be expected to stop in a short distance.
Q5.32. **Reason:** Friction will slow down and stop the truck once the truck starts to skid. The only horizontal force on the truck while it is skidding is the force of kinetic friction. See the diagram below.

In the vertical direction, Equation 5.1 gives \( n = w \). The force of kinetic friction is given by Equation 5.11.

\[
f_k = \mu_k n = \mu_k mg
\]

The net force in the horizontal direction is \( \vec{F}_{\text{net}} = \vec{F}_k \). We can find the acceleration of the truck using Newton’s second law.

\[
a_x = \frac{-f_k}{m} = \frac{-\mu_k mg}{m} = -\mu_k g = -(0.20)(9.80 \text{ m/s}^2) = -1.96 \text{ m/s}^2
\]

Additional significant figures have been retained in this intermediate calculation for use later.

We can find how far the truck skids before stopping using the kinematic equations. We have the initial velocity of the truck is \( v_i = 30 \text{ m/s} \). The final velocity of the truck is \( v_f = 0.0 \text{ m/s} \). Using Equation 2.13 and solving for \( \Delta x \),

\[
\Delta x = \frac{(v_i)^2}{2a_x} = \frac{(30 \text{ m/s})^2}{2(1.96 \text{ m/s}^2)} = 230 \text{ m}
\]

The correct choice is A.

**Assess:** A speed of 30 m/s is almost 70 mph. Note that the truck takes nearly a quarter of a kilometer to skid to a stop.

**Problems**

P5.33. **Prepare:** We assume that the skydiver is shaped like a box. The following shows a pictorial representation of the skydiver and a free-body diagram at terminal speed. The skydiver falls straight down toward the earth’s surface, that is, the direction of fall is vertical. Since the skydiver falls feet first, the surface perpendicular to the drag has the cross-sectional area \( A = 20 \text{ cm} \times 40 \text{ cm} \). The physical conditions needed to use Equation 5.15 for the drag force to be satisfied. The terminal speed corresponds to the situation when the net force acting on the skydiver becomes zero.

\[
\vec{F}_{\text{net}} = \vec{0}
\]

**Solve:** The expression for the magnitude of the drag with \( v \) in m/s is

\[
D = \frac{1}{4} \rho A v^2 = 0.25(1.22 \text{ kg/m}^3)(0.20 \text{ m} \times 0.40 \text{ m}) v^2 \text{ N} = 0.0244 v^2 \text{ N}
\]

The skydiver’s weight is \( w = mg = (75 \text{ kg})(9.8 \text{ m/s}^2) = 735 \text{ N} \). The mathematical form of the condition defining dynamical equilibrium for the skydiver and the terminal speed is
\[
\vec{F}_{\text{net}} = \vec{w} + \vec{D} = 0 \text{ N} \Rightarrow 0.0244v_{\text{term}}^2 \quad \text{N} - 735 \text{ N} = 0 \Rightarrow v_{\text{term}} = \frac{\sqrt{735}}{0.0244} \approx 170 \text{ m/s}
\]

Assess: The result of the above simplified physical modeling approach and subsequent calculation, even if approximate, shows that the terminal velocity is very high. This result implies that the skydiver will be very badly hurt at landing if the parachute does not open in time.

**P5.34. Prepare:** The car and the truck will be denoted by the symbols C and T, respectively. The ground will be denoted by the symbol G. A visual overview shows a pictorial representation, a list of known and unknown values, and a free-body diagram for both the car and the truck. Since the car and the truck move together in the positive x-direction, they have the same acceleration.

![Free-body diagram of car and truck](image.png)

**Prepare:** The car and the truck will be denoted by the symbols C and T, respectively. The ground will be denoted by the symbol G. A visual overview shows a pictorial representation, a list of known and unknown values, and a free-body diagram for both the car and the truck. Since the car and the truck move together in the positive x-direction, they have the same acceleration.

**Solve:** (a) The x-component of Newton’s second law for the car is

\[
\sum(F_{\text{on C}})_x = F_{G_{\text{on C}}} - F_{T_{\text{on C}}} = m_c a_c
\]

The x-component of Newton’s second law for the truck is

\[
\sum(F_{\text{on T}})_x = F_{C_{\text{on T}}} = m_T a_T
\]

Using \(a_c = a_T = a\) and \(F_{T_{\text{on C}}} = F_{C_{\text{on T}}}\), we get

\[
(F_{C_{\text{on G}}} - F_{C_{\text{on T}}}) \left( \frac{1}{m_c} \right) = a \\
(F_{C_{\text{on T}}} \left( \frac{1}{m_T} \right) = a
\]

Combining these two equations,

\[
(F_{C_{\text{on G}}} - F_{C_{\text{on T}}}) \left( \frac{1}{m_c} \right) = (F_{C_{\text{on T}}} \left( \frac{1}{m_T} \right) = F_{C_{\text{on T}}} \left( \frac{1}{m_c} + \frac{1}{m_T} \right) = (F_{C_{\text{on G}}} \left( \frac{1}{m_c}\right)
\]

\[
\Rightarrow F_{C_{\text{on T}}} = (F_{C_{\text{on G}}} \left( \frac{m_T}{m_c + m_T} \right) = (4500 \text{ N}) \left( \frac{2000 \text{ kg}}{1000 \text{ kg} + 2000 \text{ kg}} \right) = 3000 \text{ N}
\]

(b) Due to Newton’s third law, \(F_{T_{\text{on C}}} = 3000 \text{ N}\).

**P5.37. Prepare:** A visual overview shows below a pictorial representation, a list of known and unknown values, and a free-body diagram for both the ice (I) and the rope (R). The force \(F_{\text{exl}}\) acts only on the rope. Since the rope and the ice block move together, they have the same acceleration. Also because the rope has mass, \(F_{\text{exl}}\) on the front end of the rope is not the same as \(F_{1_{\text{on R}}}\) that acts on the rear end of the rope.
Solve: (a) Newton’s second law along the x-axis for the ice block is
\[ \sum (F_{\text{on}1})_x = F_{\text{R on}1} = m_1 a = (10 \text{ kg})(2.0 \text{ m/s}^2) = 20 \text{ N} \]
(b) Newton’s second law along the x-axis for the rope is
\[ \sum (F_{\text{on}R})_x = F_{\text{ext}} - F_{\text{1 on}R} = m_2 a \Rightarrow F_{\text{ext}} - F_{\text{R on}1} = m_2 a \Rightarrow F_{\text{ext}} = F_{\text{R on}1} + m_2 a = 20 \text{ N} + (0.5 \text{ kg})(2.0 \text{ m/s}^2) = 21 \text{ N} \]

P5.42. Prepare: Note that the medal would hang straight down if the car were going at a constant velocity, so the deviation from vertical only occurs while the car is accelerating. We apply Newton’s second law.

Solve: (a) Because she accelerates onto the highway we assume she is accelerating forward so the medal hangs away from the windshield.
(b) Use Newton’s law in vertical and horizontal directions. In the horizontal direction there is only one (component of) force, but there is an acceleration.
\[ \sum F_x = T \sin \theta = ma_x \]
There is no acceleration in the y direction.
\[ \sum F_y = T \cos \theta - mg = 0 \Rightarrow T \cos \theta = mg \]
Divide the first equation by the second and cancel \( m \) and \( T \).
\[ \frac{\sin \theta}{\cos \theta} = \frac{a_x}{g} \Rightarrow a_x = g \tan \theta = (9.8 \text{ m/s}^2)(\tan 10^\circ) = 1.7 \text{ m/s}^2 \]
Assess: This is a reasonable acceleration for a car.
P5.43. Prepare: Please refer to Figure P5.43. To find the net force at a given time, we need the acceleration at that time. Because the times where we are asked to find the net force fall on distinct slopes of the velocity versus time graph, we can use the constant slopes of the three segments of the graph to calculate the three accelerations.

Solve: For $t$ between 0 s and 3 s,

$$a_t = \frac{\Delta v}{\Delta t} = \frac{12 \text{ m/s} - 0 \text{ s}}{3 \text{ s}} = 4 \text{ m/s}^2$$

For $t$ between 3 s and 6 s, $\Delta v = 0$ m/s, so $a_t = 0$ m/s$^2$. For $t$ between 6 s and 8 s,

$$a_t = \frac{\Delta v}{\Delta t} = \frac{0 \text{ m/s} - 12 \text{ m/s}}{2 \text{ s}} = -6 \text{ m/s}^2$$

From Newton’s second law, at $t = 1$ s we have

$$F_{net} = ma_t = (2.0 \text{ kg})(4 \text{ m/s}^2) = 8 \text{ N}$$

At $t = 4$ s, $a_t = 0$ m/s$^2$, so $F_{net} = 0$ N.

At $t = 7$ s,

$$F_{net} = ma_t = (2.0 \text{ kg})(-6.0 \text{ m/s}^2) = -12 \text{ N}$$

Assess: The magnitudes of the forces look reasonable, given the small mass of the object. The positive and negative signs are appropriate for an object first speeding up, then slowing down.

P5.44. Prepare: Please refer to Figure P5.44. Positive forces result in the object gaining speed and negative forces result in the object slowing down. The final segment of zero force is a period of constant speed. We have the mass and net force for all the three segments. This means we can use Newton’s second law to calculate the accelerations. Kinematics equations then allow us to find velocity.

Solve: The acceleration from $t = 0$ s to $t = 3$ s is

$$a_t = \frac{F}{m} = \frac{4 \text{ N}}{2.0 \text{ kg}} = 2 \text{ m/s}^2$$

The acceleration from $t = 3$ s to $t = 5$ s is

$$a_t = \frac{F}{m} = \frac{-2 \text{ N}}{2.0 \text{ kg}} = -1 \text{ m/s}^2$$

The acceleration from $t = 5$ s to 8 s is $a_t = 0$ m/s$^2$. In particular, $a_t$ (at $t = 6$ s) = 0 m/s$^2$.

We can now use one-dimensional kinematics to calculate $v$ at $t = 6$ s in three steps as follows:

\[
\begin{align*}
  v_1 &= v_0 + a_{x,2}(t_2 - t_1) = 0 + (2 \text{ m/s}^2)(3 \text{ s}) = 6 \text{ m/s} \\
  v_3 &= v_1 + a_{x,3}(t_3 - t_2) = 6 \text{ m/s} + (-1 \text{ m/s}^2)(2 \text{ s}) = 4 \text{ m/s} \\
  v_6 &= v_3 + a_{x,y}(t_6 - t_3) = 4 \text{ m/s} + (0)(3 \text{ s}) = 4.0 \text{ m/s}
\end{align*}
\]

Assess: The positive final velocity makes sense, given the greater magnitude and longer duration of the positive $F_1$. A velocity of 4 m/s also seems reasonable, given the magnitudes and directions of the forces and the mass involved.

P5.47. Prepare: We will assume constant acceleration so we can use the equations of Table 2.4. Assume the baseball is initially moving in the positive x-direction.

We list the known quantities:

<table>
<thead>
<tr>
<th>Known</th>
<th>m = 0.14 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(v_x)_i = 30 \text{ m/s}$</td>
<td>$\Delta t = 0.0015 \text{ s}$</td>
</tr>
</tbody>
</table>

Find
Solve: (a) With \((v_i)_t = 0 \text{ m/s}\), we solve for \(a\) from \((v_f)_t = (v_i)_t + a\Delta t\).

\[
a_t = \frac{-(v_f)_t - (v_i)_t}{\Delta t} = \frac{-(30 \text{ m/s}) - 0 \text{ m/s}}{0.0015 \text{ s}} = -20,000 \text{ m/s}^2
\]

The magnitude of this is 20,000 m/s\(^2\) or 2.0 \times 10^4 \text{ m/s}^2.

(b) Apply Newton’s second law: \(\sum F_i = ma_i\), where the force of the body on the ball is the only force (and is therefore the net force).

\[
\sum F_i = ma = (0.14 \text{ kg})(-20,000 \text{ m/s}^2) = -2800 \text{ N}
\]

The magnitude of this is 2800 N. This force is exerted by the body the ball hits.

(c) By Newton’s third law if the body exerts a force on the ball, then the ball exerts a force equal in magnitude and opposite in direction on the body. Therefore the ball applies a force of 2800 N to the object it hits.

(d) This force of 2.8 kN is less than 6.0 kN, so the forehead is not in danger (although it would still hurt and maybe raise a lump). This force of 2.8 kN is greater than 1.3 kN, so the cheek is in danger of fracture.

Assess: This is a nice real-life problem that employs the definition of acceleration and Newton’s second and third laws. The data provided are typical of real baseballs and real pitching speeds, so the conclusion is also true-to-life. Catchers, whose faces are in the line of fire, wear masks for this reason.

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P5.48. Prepare: We can assume the person is moving in a straight line under the influence of the combined decelerating forces of the air bag and seat belt or, in the absence of restraints, the dashboard or windshield. The following is an overview of the situation in a pictorial representation and the occupant’s free-body diagram is shown below. Note that the occupant is brought to rest over a distance of 1 m in the former case, but only over 5 mm in the latter.

Solve: (a) In order to use Newton’s second law for the passenger, we’ll need the acceleration. Since we don’t have the stopping time,

\[
v_f^2 = v_i^2 + 2a(x_f - x_i) \Rightarrow a = \frac{v_f^2 - v_i^2}{2(x_f - x_i)} = \frac{0 \text{ m}^2/\text{s}^2 - (15 \text{ m/s})^2}{2(1 \text{ m} - 0 \text{ m})} = -112.5 \text{ m/s}^2
\]

\[
\Rightarrow F_{\text{net}} = F = ma = (60 \text{ kg})(-112.5 \text{ m/s}^2) = -6750 \text{ N}
\]

The net force is 6800 N to the left.

(b) Using the same approach as in part (a),

\[
F = ma = m \frac{v_f^2 - v_i^2}{2(x_f - x_i)} = (60 \text{ kg}) \frac{0 \text{ m}^2/\text{s}^2 - (15 \text{ m/s})^2}{2(0.005 \text{ m})} = -1,350,000 \text{ N}
\]

The net force is 1.4 \times 10^6 \text{ N} to the left.

(c) The passenger’s weight is \(mg = (60 \text{ kg})(9.8 \text{ m/s}^2) = 590 \text{ N}\). The force in part (a) is 11.5 times the passenger’s weight. The force in part (b) is 2300 times the passenger’s weight.

Assess: An acceleration of 11.5\(g\) is well within the capability of the human body to withstand. A force of 2300 times the passenger’s weight, on the other hand, would surely be catastrophic.
P5.50. Prepare: The astronaut and the satellite are the two systems of our interest. The astronaut and the satellite accelerate in opposite directions for 0.5 s. The force on the satellite and the force on the astronaut are an action/reaction pair, so both are 100 N. A pictorial representation and a list of values are given below. The motion is assumed to be along the x-direction.

\[ F_{A_{onS}} = F_{S_{onA}} = 100 \text{ N} \]

Solve: Newton’s second law for the satellite along the \( x \)-direction is

\[ \sum (F_{onS})_x = F_{A_{onS}} = m_S a_s \Rightarrow a_s = \frac{F_{A_{onS}}}{m_s} = \frac{-100 \text{ N}}{640 \text{ kg}} = -0.156 \text{ m/s}^2 \]

Newton’s second law for the astronaut along the \( x \)-direction is

\[ \sum (F_{onA})_x = F_{S_{onA}} = m_A a_a \Rightarrow a_a = \frac{F_{S_{onA}}}{m_A} = \frac{100 \text{ N}}{80 \text{ kg}} = 1.25 \text{ m/s}^2 \]

Let us first calculate the positions and velocities of the astronaut and the satellite at \( t_1 = 0.5 \text{ s} \) under the accelerations \( a_A \) and \( a_S \):

\[
(x_f)_A = (x_i)_A + (v_i)_A (t_1 - t_i) + \frac{1}{2} a_A (t_1 - t_i)^2 = 0 \text{ m} + 0 \text{ m} + \frac{1}{2} (1.25 \text{ m/s}^2)(0.5 \text{ s} - 0 \text{ s})^2 = 0.156 \text{ m}
\]

\[
(x_f)_S = (x_i)_S + (v_i)_S (t_1 - t_i) + \frac{1}{2} a_S (t_1 - t_i)^2 = 0 \text{ m} + 0 \text{ m} + \frac{1}{2} (-0.156 \text{ m/s}^2)(0.5 \text{ s} - 0 \text{ s})^2 = -0.02 \text{ m}
\]

\[
(v_f)_A = (v_i)_A + a_A (t_1 - t_i) = 0 \text{ m/s} + (1.25 \text{ m/s}^2)(0.5 \text{ s} - 0 \text{ s}) = 0.625 \text{ m/s}
\]

\[
(v_f)_S = (v_i)_S + a_S (t_1 - t_i) = 0 \text{ m/s} + (-0.156 \text{ m/s}^2)(0.5 \text{ s} - 0 \text{ s}) = -0.078 \text{ m/s}
\]

With \((x_i)_A \) and \((x_i)_S \) as initial positions, \((v_i)_A \) and \((v_i)_S \) as initial velocities, and zero accelerations, we can now obtain the new positions at \((t_2 - t_1) = 59.5 \text{ s} \):

\[
(x_f)_A = (x_i)_A + (v_i)_A (t_2 - t_i) + \frac{1}{2} a_A (t_2 - t_i)^2 = 0.156 \text{ m} + (0.625 \text{ m/s})(59.5 \text{ s}) = 37.34 \text{ m}
\]

\[
(x_f)_S = (x_i)_S + (v_i)_S (t_2 - t_i) = -0.02 \text{ m} + (-0.078 \text{ m/s})(59.5 \text{ s}) = -4.66 \text{ m}
\]

Thus the astronaut and the satellite are \((37.34 \text{ m}) - (-4.66 \text{ m}) = 42 \text{ m} \) apart.

P5.53. Prepare: Your body is moving in a straight line along the \( y \)-direction under the influence of two forces: gravity and the support force of the scale. The free-body diagrams for you for the following three cases are shown below: no acceleration, upward acceleration, and downward acceleration. The apparent weight (see Equation 5.8) of an object moving in an elevator is

\[ w_{app} = w(1 + \frac{a}{g}) \Rightarrow a = (\frac{w_{app}}{w} - 1)g \]

\[ w = 150 \text{ lb} \]

\[ w_{app} = 170 \text{ lb} \] (upward acceleration)

\[ w_{app} = 120 \text{ lb} \] (deceleration)

Find \( a \) for both upward acceleration and deceleration.
Solve: (a) When accelerating upward, the acceleration is

\[
a = \left( \frac{170 \text{ lb}}{150 \text{ lb}} - 1 \right) (9.8 \text{ m/s}^2) = 1.3 \text{ m/s}^2
\]

(b) When braking, the acceleration is

\[
a = \left( \frac{120 \text{ lb}}{150 \text{ lb}} - 1 \right) (9.8 \text{ m/s}^2) = -2.0 \text{ m/s}^2
\]

Assess: A 10–20% change in apparent weight seems reasonable for a fast elevator, as the one in the Empire State Building must be. Also note that we did not have to convert the units of the weights from pounds to newtons because the weights appear as a ratio.

P5.55. Prepare: The length of the hill is \( \Delta x = h / \sin \theta \). The acceleration is \( g \sin \theta \).

Solve: First use the kinematic equation, with \( v_i = 0 \text{ m/s} \) at the top of the hill, to determine the speed at the bottom of the hill.

\[
(v_f)^2 = (v_i)^2 + 2a\Delta x \quad \Rightarrow \quad (v_f)^2 = 2(g \sin \theta)(h / \sin \theta) = 2gh
\]

Now apply the same kinematic equation to the horizontal patch of snow, only this time we want \( \Delta x \). To connect the two parts \( (v_f) = (v_i)_h \). The final speed is zero: \( (v_f)_h = 0 \).

\[
(v_f)^2 = (v_i)^2 + 2a\Delta x = (v_i)^2 + 2a\Delta x = 2gh + 2a\Delta x = 0
\]

The friction force is the net force, so \( a = -f_k / m \). Note \( f_k = \mu \, n = \mu \, mg \). Solve for \( \Delta x \).

\[
\Delta x = \frac{-2gh}{2a} = -\frac{gh}{\mu \, m / m} = \frac{gh}{\mu} = \frac{3.0 \text{ m}}{0.05} = 60 \text{ m}
\]

Assess: It seems reasonable to glide 60 m with such a low coefficient of friction. It is interesting that we did not need to know the angle of the (frictionless) slope; this will become clear in the chapter on energy. The answer is also independent of Josh’s mass.

P5.57. Prepare: The force plate reads the normal force \( n \) of the plate on the woman. The other force on the woman is her weight (the gravitational force of the earth down on her). The net force will be the sum of these two and will be different at different times as the normal force of the force plate changes according to the graph. Since the graph is piecewise constant, the acceleration will be constant during (within) each phase of the jump.

We can do a preliminary calculation to find the woman’s mass. During the standing still phases, the force plate reads 500 N. During these equilibrium phases the force plate reads the same magnitude as her weight (so \( w = 500 \text{ N} \)); hence her mass must be \( m = \frac{w}{g} = \frac{500 \text{ N}}{9.8 \text{ m/s}^2} = 51 \text{ kg} \).

We will assume air resistance is negligible during all portions of the problem.

Solve: (a) We now know \( m \) and the normal force during push-off (1000 N). Apply the second law:

\[
\Sigma F_y = n - w = ma_y
\]

\[
a_y = \frac{n - w}{m} = \frac{1000 \text{ N} - 500 \text{ N}}{51 \text{ kg}} = \frac{500 \text{ N}}{51 \text{ kg}} = 9.8 \text{ m/s}^2
\]

This result looks familiar, but it is not the acceleration of an object in free fall for two reasons: (1) she is not in free fall, and (2) this acceleration is up while objects in free fall accelerate down.

(b) After she leaves the force plate she is in free fall, so her acceleration is \( a = -g \) or, in other words, 9.8 m/s\(^2\), down.

(c) During the landing phase the normal force of the plate on her is 1500 N while her weight is still 500 N. Apply the second law:

\[
\Sigma F_y = n - w = ma_y
\]

\[
a_y = \frac{n - w}{m} = \frac{1500 \text{ N} - 500 \text{ N}}{51 \text{ kg}} = \frac{1000 \text{ N}}{51 \text{ kg}} = 20 \text{ m/s}^2
\]

This acceleration is positive, or up (opposite the direction of motion, as she is slowing down).
We’ll assume she accelerates from rest. We are given that the push-off phase lasts $\Delta t = 0.25 \text{ s}$. We’ll use the answer from part (a) for $a_y$.

$$v_y = v_y + a_y \Delta t = 0.0 \text{ m/s} + (9.8 \text{ m/s}^2)(0.25 \text{ s}) = 2.45 \text{ m/s} \approx 2.5 \text{ m/s}$$

After she leaves the force table she is in free fall (see part (b)). What was the final velocity in part (d) becomes the initial velocity now. Use Equation 2.13 with $v_y = 0.0 \text{ m/s}$.

$$v_y = (v_y)^2 + 2a_y \Delta t$$

Solve for $\Delta y$:

$$\Delta y = \frac{-(v_y)^2}{2a_y} = \frac{-(2.45 \text{ m/s})^2}{2(-9.8 \text{ m/s}^2)} = 0.31 \text{ m}$$

Assess: All of these results appear reasonable. The accelerations are within the expectations of daily life experience. The result of part (d) is used in part (e), so we kept a third significant figure to use in the last calculation, but still reported the answers to two significant figures. The last answer is kind of a check on the previous ones, and it is quite reasonable: 31 cm is just over one foot.

Also review each calculation to verify that the units work out.

**P5.60. Prepare:** The book is in static equilibrium so Equation 5.1 can be applied. The maximum static frictional force the person can exert will determine the heaviest book he can hold.

**Solve:** Consider the free-body diagram below. The force of the fingers on the book is the reaction force to the normal force of the book on the fingers, so is exactly equal and opposite the normal force on the fingers.

The maximal static friction force will be equal to $f_{s \text{ max}} = \mu n = (0.80)(6.0 \text{ N}) = 4.8 \text{ N}$. The frictional force is exerted on both sides of the book. Considering the forces in the $y$-direction, we have that the weight supported by the maximal frictional force is

$$w = f_{s \text{ max}} + f_{s \text{ max}} = 2f_{s \text{ max}} = 9.6 \text{ N}$$

Assess: Note that the force on both sides of the book are exactly equal also because the book is in equilibrium.

**P5.71. Prepare:** Call the 10 kg block $m_2$ and the 5.0 kg block $m_1$. Assume the pulley is massless and frictionless.

**Solve:** On block 2 use tilted axes.

$$\Sigma F_x = T - m_2 g \sin \theta = m_2 a_2$$

Block 1 is also accelerating.

$$\Sigma F_y = T - m_1 g = m_1 a_1$$

The acceleration constraint is $(a_x) = -(a_y) = a$. Solve for $T$ in the second equation and insert in the first. $T = m_1 (g - a)$.

$$m_1 (g - a) - m_2 g \sin \theta = m_2 a$$

$$m_1 g - m_2 g \sin \theta = m_1 a + m_2 a$$
\[ a = \frac{g(m_1 - m_2 \sin \theta)}{m_1 + m_2} = \frac{(9.8 \text{ m/s}^2)(1.0 \text{ kg} - (2.0 \text{ kg}) \sin 40^\circ)}{1.0 \text{ kg} + 2.0 \text{ kg}} = 1.96 \text{ m/s}^2 \approx 2.0 \text{ m/s}^2 = -0.93 \text{ m/s}^2 \]

Or 0.93 m/s², down the ramp.

Assess: The answer depends on \( \theta \); for a shallow angle the block accelerates up the ramp, for a steep angle the block accelerates down the ramp. This is expected behavior.