4.5. The net upward force on you is $F_N - mg = ma$, where $F_N$ is the supporting force from the elevator floor, $m$ is your mass, and $a$ is the acceleration of the elevator (with up chosen as positive). As the elevator starts from rest and picks up speed $a$ is positive (upward), so $F_N$, which is what the scale reads, is greater than your weight $mg$. As the elevator reaches its cruising speed it is no longer accelerating (i.e., $a = 0$), so the scale reading equals your weight. As the elevator slows down, $a$ becomes negative (downward), and the reading is less than your weight. Finally, as the elevator reaches a complete stop $a = 0$, so the reading goes back to your weight.

4.17. One way to do it is to exert a know force on the object and measure the resulting acceleration. For example, pull the mass with a spring scale with a constant force $F$ (which is the case when the scale reading is a constant) over a certain distance $x$ and clock it. The acceleration can be found from $x = at^2/2$ and the mass from $m = F/a$. Another way would be to attach the mass to a spring, set it into oscillation, and observe the period of the oscillation (the time for one complete cycle of oscillation), which depends on the mass of the object (see Chapter 13 for details.)

4.22. The rock is in circular motion and must be subject to a centripetal force that is radially inward, along the string. That force is provided by your hand (through the string). Due to Newton’s third law, your hand must be subject to its reaction, which is exerted by the rock, radially outward.

4.38. Let’s assume that the forces involved are steady. One side being stronger than the other means that the net force on one group is greater than the net force on the other. (Note that these forces involve not only direct forces on the rope but friction between feet and ground.) The motion of both groups is the same because they are connected by the taut rope, and this motion is matched by the motion of the handkerchief. This motion will be steady acceleration towards the winning side.

5.15 Drag forces on boats are a type of friction that depends on the surface area of the boat in contact with the water. The more people in a scull, the lower she sits in the water. This increases the area of surface in contact with the water, and as a consequence the drag increases as well.

5.27. The coefficient of static friction between the ground and the shoes would be low, and so would be the maximum available static friction from the ground that can cause you to accelerate. If you try just a little too hard, your feet would slip on ice.
**Solve yourself problems**

**4.22.** If we assume that the electron starts from rest, the acceleration and resulting motion will be in the direction of the force, so we have a one-dimensional system. We can find \( a \) from \( \sum F = ma \): \( 5 \times 10^{-14} \text{ N} = (10^{-30} \text{ kg})a \), which gives \( a = 5 \times 10^{16} \text{ m/s}^2 \).

The speed is found from \( v = v_0 + at = 0 + (5 \times 10^{16} \text{ m/s}^2)t \):

- for \( t = 10^{-10} \text{ s} \), \( v = 5 \times 10^6 \text{ m/s} \),
- for \( t = 10^{-9} \text{ s} \), \( v = 5 \times 10^7 \text{ m/s} \).

**4.25.** The force the automobile exerts on Earth is the reaction to the force of gravity on the automobile, so the two forces must have the same magnitude:

\[
F_{\text{auto}} = F_{\text{earth}};
\]

\[
m_{\text{auto}}a_{\text{auto}} = m_{\text{earth}}a_{\text{earth}};
\]

\((950 \text{ kg})(9.8 \text{ m/s}^2) = (6.0 \times 10^{24} \text{ kg})a_{\text{earth}}\), which gives \( a_{\text{earth}} = 1.6 \times 10^{-21} \text{ m/s}^2 \).
4.48. The coordinate system and the forces on the block are shown. Since the system is at rest, \( a = 0 \) and we can write:

\[
\sum F_x = ma_x
\]

\[
T \cos \theta - f = 0, \text{ which gives } f = T \cos \theta.
\]

\[
\sum F_y = ma_y
\]

\[
T \sin \theta + F_N - Mg = 0, \text{ which gives } F_N = Mg - T \sin \theta.
\]

4.68. (a)

(b) We choose the direction of motion as the \( x \)-axis.

For the \( y \)-direction, we can write \( \sum F_y = ma_y \):

\[
T_1 \sin 30^\circ - T_2 \sin 30^\circ = T \sin 30^\circ - T \sin 30^\circ = 0
\]

For the \( x \)-direction, we can write \( \sum F_x = ma_x \):

\[
T_1 \cos 30^\circ - T_2 \cos 30^\circ - F_D = 0;
\]

\[ F_D = 2(2000 \text{ N}) \cos 30^\circ = 3.5 \times 10^3 \text{ N}. \]

4.77. From the force diagram for the system of the frame and plumb bob, we can write

\[
\sum F_x = ma_x;
\]

\( (m_B + m)g \sin \theta = (m_B + m)a \); and

\[
\sum F_y = ma_y;
\]

\[ F_N - (m_B + m)g \cos \theta = 0. \]

From the \( x \)-equation we find
\[ a = g \sin \theta. \]

From the force diagram for the system of the plumb bob, we can write

\[
\sum F_x = m_a: \\
m_B g \sin \theta + T \sin (\phi - \theta) = m_B a; \text{ and} \\
\sum F_y = m_a: \\
T \cos (\phi - \theta) - m_B g = 0.
\]

Using \( a = g \sin \theta \) in the \( x \)-equation, we find \( \sin (\phi - \theta) = 0 \), so \( \phi = \theta \).

5.13. For the largest value of \( M \), the block is on the verge of slipping down the plane, so the static friction force will be up the plane and maximum, \( f_s = f_{s, \text{max}} = \mu F_N \).

From the force diagram, with the block \( M \) as the system, we can write \( \Sigma F = Ma \).

- \( x \)-component: \( T - M_{\text{max}} g \sin \theta + f_{x, \text{max}} = 0; \)
- \( y \)-component: \( F_N - M_{\text{max}} g \cos \theta = 0; \text{ or } F_N = M_{\text{max}} g \cos \theta. \)

From the force diagram, with the block \( m \) as the system, we can write \( \Sigma F = mx \).

- \( y \)-component: \( T - mg = 0; \text{ or } T = mg. \)

The \( x \)-equation becomes

\[ mg - M_{\text{max}} g \sin \theta + \mu M_{\text{max}} g \cos \theta = 0, \text{ or } M_{\text{max}} (\sin \theta - \mu \cos \theta) = m; \]
\[ M_{\text{max}}(\sin 30^\circ - 0.20 \cos 30^\circ) = 3.0 \text{ kg}, \text{ which gives } M_{\text{max}} = 9.2 \text{ kg}. \]

For the smallest value of \( M \), the block is on the verge of slipping up the plane, so the static friction force will be down the plane and maximum, \( f_s = f_{s,\text{max}} = \mu_s F_N \). The only change will be in the \( x \)-equation. From the force diagram, with the block \( M \) as the system, we can write \( \Sigma F = M\alpha \):

\[
\text{\textbf{x-component: } } T - M_{\min}g \sin \theta - f_{s,\text{max}} = 0; \quad mg - M_{\min}g \sin \theta - \mu_s M_{\min}g \cos \theta = 0, \text{ or }
\]

\[ M_{\text{min}}(\sin 30^\circ + 0.20 \cos 30^\circ) = 3.0 \text{ kg}, \text{ which gives } M_{\text{min}} = 4.5 \text{ kg}. \]

If \( M = 6 \text{ kg} \), the block will remain at rest. We assume that the static friction force will be up the plane. The \( x \)-equation becomes \( mg - \)

\[
Mg \sin \theta + f_s = 0;
\]

\[
(3.0 \text{ kg})(9.8 \text{ m/s}^2) - (6.0 \text{ kg})(9.8 \text{ m/s}^2) \sin 30^\circ + f_s = 0, \text{ which gives } f_s = 0.
\]

**Hand-in Problems**

4.28. In the diagrams for the set and each of the blocks below, only the horizontal forces are shown (as vertical normal forces balance the gravity forces).
(a) For the set we have $\sum F_x = ma_x$: $8.0 \, N = (2.0 \, kg + 3.0 \, kg + 4.0 \, kg) \, a$, which gives

$$ a = 0.89 \, m/s^2. $$

(b) For block 1 we have $\sum F_x = ma_x$: $F - F_{21} = m_1 a$;

$$ 8.0 \, N - F_{12} = (2.0 \, kg)(0.89 \, m/s^2), $$
which gives $F_{12} = 6.2 \, N$ to the left.

The forces are $F = 8.0 \, N$ to the right, $F_{12} = 6.2 \, N$ to the left, and $F_{\text{net}1} = 1.8 \, N$ to the right.

(c) For block 2 we have $\sum F_x = ma_x$: $F_{21} - F_{23} = m_2 a$ and $F_{21} = F_{12}$ (Newton’s third law):

$$ 6.2 \, N - F_{23} = (3.0 \, kg)(0.89 \, m/s^2), $$
which gives $F_{23} = 3.5 \, N$ to the left.

The forces are $F_{21} = 6.2 \, N$ to the right, $F_{23} = 3.5 \, N$ to the left, and $F_{\text{net}2} = 2.7 \, N$ to the right.

(d) For block 3 we have $\sum F_x = ma_x$: $F_{32} = m_3 a$:

$$ F_{32} = (4.0 \, kg)(0.89 \, m/s^2), $$
which gives $F_{32} = 3.6 \, N$ to the right ($= F_{23}$, Newton’s third law).

The forces are $F_{32} = 3.6 \, N$ to the right, and $F_{\text{net}3} = 3.6 \, N$ to the right.

4.46. (a) A massive rope can never be perfectly horizontal, since there has to be a vertical component of its tension to balance its weight. But in our case the rope is massless, so it can be perfectly horizontal.

(b) No. The weight of the hanging mass must be balanced by the vertical component
of the tension in the rope.

(c) The answer to (a) was yes.

4.49. As shown, the coordinate system has the $x$-direction down the plane.

In the $x$-direction

$$\sum F_x = F_g \sin 21^\circ - f = ma,$$

and in the $y$-direction

$$\sum F_y = F_N - F_g \cos 21^\circ = 0.$$

Also, note that $F_g = mg$, $f = \mu F_N$, and $f = -f\hat{i}$.

4.71. We take up as positive, so $F_g = -mg\hat{j}$, $F_d = Av^2\hat{j}$, and $v = -v\hat{j}$.

(a) We do a dimensional analysis of $F_d = Av^2$:

$$[F_d] = [A][v^2] = [A][LT^{-2}][LT^{-1}]^2 = [A][MLT^{-3}],$$

which gives $[A] = [ML^{-1}]$ with units of kg/m.

(b) $\frac{dv}{dt} = \sum F/m = (Av^2 - mg)/m = Av^2/m - g$.

(c) At constant velocity: $\frac{dv}{dt} = 0$; $(A/m)v^2 - g = 0$, which gives $v = \sqrt{\frac{mg}{A}}$.

5.12. Forces are drawn for each of the blocks for the situation when $m_1$ leaves the floor (no normal force). Because the string doesn’t stretch, the tension is the same at each end of the string, and the accelerations of the blocks have the same magnitude. Note
that we take the positive direction in the direction of the acceleration for each block.

(a) We write $\Sigma F = ma$ from the force diagram for each block:

$y$-component (block 1): $T - m_1g = m_1a$.

$y$-component (block 2): $m_2g - T = m_2a$.

By adding the equations, we find the acceleration:

$$a = \frac{(m_2 - m_1)g}{m_1 + m_2}$$

$$= \frac{(1.700 \text{ kg} - 1.650 \text{ kg})(9.8 \text{ m/s}^2)}{1.70 \text{ kg} + 1.65 \text{ kg}}$$

$$= 0.15 \text{ m/s}^2 \text{ for both blocks.}$$

(b) For the motion of block 2:

$$v_2^2 = v_{02}^2 + 2a(y_2 - y_{02}) = 0 + 2(0.15 \text{ m/s}^2)(2.15 \text{ m} - 0),$$

which gives $v_2 = 0.80 \text{ m/s}$.

(Note: block 1 has the same speed. Once block 2 hits the floor, $T \to 0$ and the motions of the two blocks will differ.)

(c) To find the time to reach the floor, for block 2:

$$v_t = v_{02} + at; 0.803 \text{ m/s} = 0 + (0.15 \text{ m/s}^2)t,$$

which gives $t = 5.4 \text{ s.}$