problem 1
The figure below is an overhead view of a 12 kg tire that is to be pulled by three ropes. One force \( F_1 \), with magnitude 50 N, is indicated. Orient the other two forces \( F_2 \) and \( F_3 \) so that the magnitude of the resulting acceleration of the tire is least, and find that magnitude if (a) \( F_2 = 30 \text{N}, \ F_3 = 20 \text{N} \); (b) \( F_2 = 30 \text{N}, \ F_3 = 10 \text{N} \); and (c) \( F_2 = F_3 = 30 \text{N} \).

(a) Obviously, if we orient both \( F_2 \) and \( F_3 \) in the negative \( x \) direction, opposite to the direction of \( F_1 \), then the magnitude of the net force will be \( F = 50 \text{N} - 30 \text{N} - 10 \text{N} = 0 \), resulting in zero acceleration.
(b) Let \( F_2 \) and \( F_3 \) again be in the negative \( x \) direction, we get

\[
a = \frac{F_1 - F_2 - F_3}{m} = \frac{50 \text{N} - 30 \text{N} - 10 \text{N}}{12 \text{kg}} = 0.83 \text{m/s}^2.
\]

(c) \( F_2 \) and \( F_3 \) should be oriented such that

\[
\begin{align*}
F_{2x} + F_{3x} &= -F_1 \\
F_{2y} + F_{3y} &= 0,
\end{align*}
\]

i.e.

\[
\begin{align*}
(30 \text{N}) \cos \theta_2 + (30 \text{N}) \cos \theta_3 &= 50 \text{N} \\
(30 \text{N}) \sin \theta_2 &= (30 \text{N}) \sin \theta_3,
\end{align*}
\]

which gives

\[
\theta_2 = \theta_3 = \frac{1}{2} \cos^{-1} \left( \frac{50 \text{N}}{60 \text{N}} \right) = 34^\circ.
\]

problem 2
A weight-conscious penguin with a mass of 15.0 kg rests on a bathroom scale (see figure below). What are (a) the penguin's weight \( W \) and (b) the normal force \( N \) on the penguin? (c) What is the reading on the scale, assuming it is calibrated in weight units?

(a) The downward weight of the penguin is \( W = mg = (15.0 \text{kg}) (9.80 \text{m/s}^2) = 147 \text{N} \).
(b) Since the penguin is at rest, \( N - W = 0 \), which gives \( N = 147 \text{N} \). The direction of \( N \) is vertically upward.
(c) The reading of the scale is \( N = 147 \text{N} \).
problem 3
If a nucleus captures a stray neutron, it must bring the neutron to a stop within the diameter of the nucleus by means of the strong force. That force, which "glues" the nucleus together, is essentially zero outside the nucleus. Suppose that a stray neutron with an initial speed of $1.4 \times 10^7 \text{ m/s}$ is just barely captured by a nucleus with diameter $d = 1.0 \times 10^{-14} \text{ m}$. Assuming that the force on the neutron is constant, find the magnitude of that force. The neutron's mass is $1.67 \times 10^{-27} \text{ kg}$.

According to Newton's second law the magnitude of the force is given by $F = ma$, where $a$ is the acceleration of the neutron. Use kinematics to find the acceleration that brings the neutron to rest in a distance $d$. Assume the acceleration is constant and solve $v^2 = v_0^2 + 2ad$ for $a$:

$$a = \frac{v^2 - v_0^2}{2d} = \frac{-(1.4 \times 10^7 \text{ m/s})^2}{2(1.0 \times 10^{-14} \text{ m})} = -9.8 \times 10^{27} \text{ m/s}^2.$$

The magnitude of the force is $F = ma = (1.67 \times 10^{-27} \text{ kg})(9.8 \times 10^{27} \text{ m/s}^2) = 16 \text{ N}$.

problem 4
Sunjamming. A "sun yacht" is a spacecraft with a large sail that is pushed by sunlight. Although such a push is tiny in everyday circumstances, it can be large enough to send the spacecraft outward from the Sun on a cost-free but slow trip. Suppose that the spacecraft has a mass of 900 kg and receives a push of 20 N. (a) What is the magnitude of the resulting acceleration? If the craft starts from rest, (b) how far will it travel in 1 day and (c) how fast will it then be moving?

(a) The acceleration is

$$a = \frac{F}{m} = \frac{20 \text{ N}}{900 \text{ kg}} = 0.022 \text{ m/s}^2.$$

(b) The distance traveled in 1 day (= 86,400 s) is

$$s = \frac{1}{2} at^2 = \frac{1}{2}(0.0222 \text{ m/s}^2)(86400 \text{ s})^2 = 8.3 \times 10^7 \text{ m}.$$

(c) The speed it will be traveling is

$$v = at = (0.0222 \text{ m/s}^2)(86400 \text{ s}) = 1.9 \times 10^3 \text{ m/s}.$$

problem 5
A 40 kg girl and an 8.4 kg sled are on the surface of a frozen lake, 15 m apart. By means of a rope, the girl exerts a horizontal 5.2 N force on the sled, pulling it toward her. (a) What is the acceleration of the sled? (b) What is the acceleration of the girl? (c) How far from the girl's initial position do they meet, assuming that no frictional forces act?

(a) Since friction is negligible the force of the girl on the sled is the only horizontal force on the sled. The vertical forces, the force of gravity and the normal force of the ice, sum to zero. The acceleration of the sled is

$$a_s = \frac{F}{m_s} = \frac{5.2 \text{ N}}{8.4 \text{ kg}} = 0.62 \text{ m/s}^2.$$

(b) According to Newton's third law, the force of the sled on the girl is also 5.2 N. Her acceleration is

$$a_g = \frac{F}{m_g} = \frac{5.2 \text{ N}}{40 \text{ kg}} = 0.13 \text{ m/s}^2.$$

(c) The accelerations of the sled and girl are in opposite directions. Suppose the girl starts at the origin and moves in the positive $x$ direction. Her coordinate is given by $x_g = \frac{1}{2}a_g t^2$. The sled starts at $x = x_0 (= 1.5 \text{ m})$ and moves in the negative $x$ direction. Its coordinate is given by $x_s = x_0 - \frac{1}{2}a_s t^2$. They meet when $x_g = x_s$ or $\frac{1}{2}a_g t^2 = x_0 - \frac{1}{2}a_s t^2$. This occurs at time

$$t = \sqrt{\frac{2x_0}{a_g + a_s}}.$$

By that time the girl has gone the distance

$$x_g = \frac{1}{2}a_g t^2 = \frac{x_0 a_g}{a_g + a_s} = \frac{(15 \text{ m})(0.13 \text{ m/s}^2)}{0.13 \text{ m/s}^2 + 0.62 \text{ m/s}^2} = 2.6 \text{ m}.$$
problem 6
Two blocks are in contact on a frictionless table. A horizontal force is applied to one block, as shown in the figure below. (a) If \(m_1 = 2.3 \text{ kg}, m_2 = 1.2 \text{ kg}, \) and \(F = 3.2 \text{ N}, \) find the force between the two blocks. (b) Show that if a force of the same magnitude \(F\) is applied to \(m_2\) but in the opposite direction, the force between the blocks is 2.1 N, which is not the same value calculated in (a). Explain the difference

(a) The free-body diagrams are shown to the right. \(F\) is the applied force and \(f\) is the force \(m_1\) exerts on \(m_2\). Note that \(F\) is applied only to \(m_1\) and that \(m_2\) exerts the force \(-f\) on \(m_1\). Newton’s third law has been taken into account.

Newton’s second law for \(m_1\) is \(F - f = m_1a\), where \(a\) is the acceleration. The second law for \(m_2\) is \(f = m_2a\). Since the blocks move together they have the same acceleration and the same symbol is used in both equations. Use the second equation to obtain an expression for \(a\): \(a = f/m_2\). Substitute into the first equation to get \(F - f = m_1f/m_2\). Solve for \(f\):

\[
f = \frac{F m_2}{m_1 + m_2} = \frac{(3.2 \text{ N})(1.2 \text{ kg})}{2.3 \text{ kg} + 1.2 \text{ kg}} = 1.1 \text{ N}.
\]

problem 7
An elevator and its load have a combined mass of 1600 kg. Find the tension in the supporting cable when the elevator, originally moving downward at 12 m/s, is brought to rest with constant acceleration in a distance of 42 m.

The free-body diagram is shown to the right. \(T\) is the tension in the cable and \(mg\) is the force of gravity. If the upward direction is positive then Newton’s second law is \(T - mg = ma\), where \(a\) is the acceleration. Solve for the tension:

\(T = m(g + a)\). Use constant acceleration kinematics to find the acceleration. If \(v = 0\) is the final velocity, \(v_0 = -12 \text{ m/s}\) is the initial velocity, and \(y = -42 \text{ m}\) is the coordinate at the stopping point, then \(a^2 = v_0^2 + 2ay\). Solve for \(a\): \(a = -v_0^2/2y = -(-12 \text{ m/s})^2/[2(-42 \text{ m})] = 1.71 \text{ m/s}^2\). Now go back to calculate the tension: \(T = m(g + a) = (1600 \text{ kg})(9.8 \text{ m/s}^2 + 1.71 \text{ m/s}^2) = 1.8 \times 10^4 \text{ N}\).
problem 8
An object is hung from a spring balance attached to the ceiling of an elevator. The balance reads 65 N when the elevator is standing still. What is the reading when the elevator is moving upward (a) with a constant speed of 7.6 m/s and (b) with a speed of 7.6 m/s while decelerating at a rate of 2.4 m/s²?

(a) Since there is no acceleration, the reading of the scale is still 65 N.
(b) Let the mass of the object be m and its weight be W. Choose the upward direction to be positive. Since the direction of the acceleration is downward, a is negative. The reading of the scale N satisfies \( N - W = ma = -W\frac{|a|}{g} \), from which we get

\[
N = W\left(1 - \frac{|a|}{g}\right) = (56 \text{ N})\left(1 - \frac{2.4 \text{ m/s}^2}{9.80 \text{ m/s}^2}\right) = 49 \text{ N}.
\]

problem 9
Three blocks are connected, as shown in the figure below, on a horizontal frictionless table and pulled to the right with a force \( T_3 = 65.0 \text{ N} \). If \( m_1 = 12.0 \text{ kg} \), \( m_2 = 24.0 \text{ kg} \), and \( m_3 = 31.0 \text{ kg} \), calculate (a) the acceleration of the system and (b) the tensions \( T_1 \) and \( T_2 \) in the interconnecting cords.

(a) Refer to Fig. 5-47 of the text. Choose the positive direction to be toward left. The net horizontal force exerted on the three objects is \( T_3 \). The resulting acceleration is

\[
a = \frac{T_3}{m_1 + m_2 + m_3} = \frac{65.0 \text{ N}}{12.0 \text{ kg} + 24.0 \text{ kg} + 31.0 \text{ kg}} = 0.970 \text{ m/s}^2.
\]

(b) Applying Newton’s second law to \( m_1 \) alone, we have

\[
T_1 = m_1a = (12.0 \text{ kg})(0.970 \text{ m/s}^2) = 11.6 \text{ N}.
\]

problem 10
An elevator weighing 6240 lb is pulled upward by a cable with an acceleration of 4.00 ft/s². (a) Calculate the tension in the cable. (b) What is the tension when the elevator is decelerating at the rate of 4.00 ft/s² but is still moving upward?

(a) Denote the mass of the elevator as \( m \), its weight as \( W \), and its acceleration as \( a \). The net upward force exerted on it is \( F_{\text{net}} = T - W \), where \( T \) is the upward supporting force of the cable. From \( F_{\text{net}} = ma \), we get

\[
T = W + ma = W\left(1 + \frac{a}{g}\right) = (6240 \text{ lb})\left(1 + \frac{4.00 \text{ ft/s}^2}{32.2 \text{ ft/s}^2}\right) = 7.02 \times 10^3 \text{ lb}.
\]

(b) Regardless of whether it is moving upward or downward, as long as the acceleration of the elevator is now downward, we can simply reverse the sign in front of \( a \) in part (a), and get

\[
T = W - ma = W\left(1 - \frac{a}{g}\right) = (6240 \text{ lb})\left(1 - \frac{4.00 \text{ ft/s}^2}{32.2 \text{ ft/s}^2}\right) = 5.46 \times 10^3 \text{ lb}.
\]
problem 11
A chain consisting of five links, each of mass 0.100 kg, is lifted vertically with a constant acceleration of 2.50 m/s², as shown in the figure below. Find (a) the forces acting between adjacent links, (b) the force \( F \) exerted on the top link by the person lifting the chain, and (c) the net force accelerating each link.

\[ a \]

Number the links from bottom to top. The forces acting on the bottom link are the force of gravity \( mg \), downward, and the force \( F_{201} \) of link 2, upward. Take the positive direction to be upward. Then Newton’s second law for this link is \( F_{201} = mg = ma \). Thus \( F_{201} = m(a + g) = (0.100 \text{ kg})(2.50 \text{ m/s}^2 + 9.8 \text{ m/s}^2) = 1.23 \text{ N} \).

The forces acting on the second link are the force of gravity \( mg \), downward, the force \( F_{102} \) of link 1, downward, and the force \( F_{302} \) of link 3, upward. \( F_{102} \) has the same magnitude as \( F_{201} \). Newton’s second law for the second link is \( F_{302} - F_{102} - mg = ma \), so \( F_{302} = m(a + g) + F_{102} = (0.100 \text{ kg})(2.50 \text{ m/s}^2 + 9.8 \text{ m/s}^2) + 1.23 \text{ N} = 2.46 \text{ N} \).

problem 12
A 1.0 kg mass on a 37° incline is connected to a 3.0 kg mass on a horizontal surface (see figure below). The surfaces and the pulley are frictionless. If \( F = 12 \text{ N} \), what is the tension in the connecting cord?

\[ b \]

Let the tension in the connection cord be \( T \) and the acceleration of both masses be \( a \).

Then
\[
\begin{align*}
F - m_1 g \sin \theta - T &= m_1 a \\
T &= m_2 a
\end{align*}
\] (object 1) (object 2).

Solve for \( T \):
\[
T = \frac{m_2(F - m_1 g \sin \theta)}{m_1 + m_2} = \frac{(3.0 \text{ kg})(12 \text{ N} - (1.0 \text{ kg})(9.80 \text{ m/s}^2)(\sin 37°))}{1.0 \text{ kg} + 3.0 \text{ kg}} = 4.6 \text{ N}.
\]
A block of mass $m_1 = 3.70 \text{ kg}$ on a frictionless inclined plane of angle $30.0^\circ$ is connected by a cord over a massless, frictionless pulley to a second block of mass $m_2 = 2.30 \text{ kg}$ hanging vertically (Fig. 5-52). What are (a) the magnitude of the acceleration of each block and (b) the direction of the acceleration of $m_2$? (c) What is the tension in the cord?

The free-body diagram for each block is shown to the right. $T$ is the tension in the cord and $\theta (= 30^\circ)$ is the angle of the incline. For $m_1$ take the $x$ axis to be up the plane and the $y$ axis to be in the direction of the normal force of the plane on the block. For $m_2$ take the $y$ axis to be downward. Then the accelerations of the two blocks can be represented by the same symbol $a$.

The $x$ component of Newton’s second law for $m_1$ is $T - m_1 g \sin \theta = m_1 a$ and the $y$ component is $N - m_1 g \cos \theta = 0$, where $N$ is the normal force of the plane on the block. Newton’s second law for $m_2$ is $m_2 g - T = m_2 a$.

These two equations are to be solved for $a$ and $T$. The first equation gives $T = m_1 a + m_1 g \sin \theta$. When this is substituted into the third equation the result is $m_2 g - m_1 a - m_1 g \sin \theta = m_2 a$. Solve for $a$:

$$a = \frac{(m_2 - m_1) g \sin \theta}{m_1 + m_2} = \frac{(2.30 \text{ kg} - 3.70 \text{ kg})(9.80 \text{ m/s}^2)(\sin 30.0^\circ)}{3.70 \text{ kg} + 2.30 \text{ kg}} = 0.735 \text{ m/s}^2.$$

(b) The result is positive, indicating that the acceleration of $m_1$ is the up the plane and the acceleration of $m_2$ is downward.
A 10 kg monkey climbs up a massless rope that runs over a frictionless tree limb and back down to a 15 kg package on the ground (see figure below). (a) What is the magnitude of the least acceleration the monkey must have if it is to lift the package off the ground? If, after the package has been lifted, the monkey stops its climb and holds onto the rope, what are (b) the monkey's acceleration and (c) the tension in the rope?

(a) Refer to the free-body diagram. Since the package is barely lifted, $m_2g = T$. Choose the upward direction to be positive. Let the minimum upward acceleration that the monkey should have be $a_{\text{min}}$, then $T - m_1g = m_2g - m_1g = m_1a_{\text{min}}$, which gives

\[
a = \left( \frac{m_2 - m_1}{m_1} \right) g = \left( \frac{15 \text{ kg} - 10 \text{ kg}}{10 \text{ kg}} \right)(9.80 \text{ m/s}^2) = 4.9 \text{ m/s}^2.
\]

(b) and (c) For the monkey $T - m_1g = m_1a$ and for the package $m_2g - T = m_2a$. Solve for $a$ and $T$ to obtain

\[
a = \left( \frac{m_2 - m_1}{m_1 + m_2} \right) g = \left( \frac{15 \text{ kg} - 10 \text{ kg}}{10 \text{ kg} + 15 \text{ kg}} \right)(9.80 \text{ m/s}^2) = 2.0 \text{ m/s}^2
\]

and

\[
T = m_1(g + a) = (10 \text{ kg})(9.80 \text{ m/s}^2 - 2.0 \text{ m/s}^2) = 120 \text{ N}.
\]
problem 15
A hot-air balloon of mass \( M \) is descending vertically with downward acceleration \( a \) (see figure below). How much mass must be thrown out to give the balloon an upward acceleration \( a \) (same magnitude but opposite direction)? Assume that the upward force from the air (the lift) does not change because of the mass (the ballast) that is lost.

![Diagram of a hot-air balloon with ballast and forces labeled.]

The forces acting on the balloon are the force of gravity \( mg \), down, and the force of the air \( F_a \), up. Take the positive direction to be up. When the mass is \( M \) (before the ballast is thrown out) the acceleration is downward and Newton’s second law is \( F_a - Mg = -Ma \). After the ballast is thrown out the mass is \( M - m \), where \( m \) is the mass of the ballast, and the acceleration is upward. Newton’s second law is \( F_a - (M - m)g = (M - m)a \). The first equation gives \( F_a = M(g - a) \) and the second gives \( M(g - a) - (M - m)g = (M - m)a \). Solve for \( m \): \( m = 2Ma/(g + a) \).
problem 16
The figure below shows a man sitting in a bosun's chair that dangles from a massless rope, which runs over a massless, frictionless pulley and back down to the man's hand. The combined mass of the man and chair is 95.0 kg. (a) With what force must the man pull on the rope for him to rise at constant speed? (b) What force is needed for an upward acceleration of 1.30 m/s²? (c) Suppose, instead, that the rope on the right is held by a person on the ground. Repeat (a) and (b) for this new situation. (d) In each of the four cases, what is the force exerted on the ceiling by the pulley system?

(a) Consider both the man and the chair as one system. Choose the upward direction to be positive. Let the tension in each side of the rope be \( T \) and the mass of the man plus the chair be \( m \), then \( 2T - mg = ma = 0 \), which gives \( T = \frac{mg}{2} = \frac{(95.0 \text{ kg})(9.80 \text{ m/s}^2)}{2} = 466 \text{ N} \).

(b) In this case \( a = 1.30 \text{ m/s}^2 \), so

\[
T = \frac{m(g + a)}{2} = \frac{(95.0 \text{ kg})(9.80 \text{ m/s}^2 + 1.30 \text{ m/s}^2)}{2} = 527 \text{ N}.
\]

(c) If the rope is pulled up by another person, then the force \( T \) that person has to exert on the rope to pull the man-chair system up at constant speed (i.e. with \( a = 0 \)) is equal to the combined weight of the man and the chair: \( T = mg = (95.0 \text{ kg})(9.80 \text{ m/s}^2) = 931 \text{ N} \). If the acceleration of the system is \( a \), then \( T - mg = ma \), which gives

\[
T = m(g + a) = (95.0 \text{ kg})(9.80 \text{ m/s}^2 + 1.30 \text{ m/s}^2) = 1050 \text{ N}.
\]