4

FORCE AND MOTION

EXERCISES

Section 4.2 Newton's First and Second Laws

12. **INTERPRET** This problem involves the application of Newton's second law. The object under consideration is the train and the physical quantity of interest is the net force acting on the train.

DEVELOP The net force can be found by using Equation 4.3, $\vec{F}_{\text{net}} = m\vec{a}$.

EVALUATE Using Equation 4.3, the magnitude of the force acting on the train is found to be

$$F_{\text{net}} = ma = \left(1.5\times10^6\ \text{kg}\right)\left(2.5\ \text{m/s}^2\right) = 3.8\times10^6\ \text{N}$$

ASSESS The result is reasonable, since by definition, one newton is the force required to accelerate a 1-kg mass at the rate of 1 m/s^2.

13. **INTERPRET** This problem involves Newton's 2nd law for a locomotive with different loads.

DEVELOP By Equation 4.3, the locomotive accelerates due to the force: $a = F/m$.

EVALUATE (a) The mass in this case is just the locomotive itself

$$a = \frac{(1.2\times10^5\ \text{N})}{61\times10^3\ \text{kg}} = 2.0\ \text{m/s}^2$$

(b) If the locomotive is pulling a train then the mass is the sum

$$a = \frac{(1.2\times10^5\ \text{N})}{\left(61\times10^3\ \text{kg}\right) + \left(1.4\times10^6\ \text{kg}\right)} = 0.082\ \text{m/s}^2$$

ASSESS These seem like reasonable accelerations. The locomotive by itself could reach 60 mi/h in 13 s, but pulling the train it would take over 5 and a half minutes to reach this speed.

14. **INTERPRET** We interpret this as a problem involving the application of Newton's second law. The object under consideration is the airplane and the physical quantity of interest is the plane's mass.

DEVELOP We shall assume that the runway is horizontal (so that the vertical force of gravity and the normal force of the surface cancel) and neglect aerodynamic forces (which are small just after the plane begins to move). Then the net force equals the engine's thrust and is parallel to the acceleration. The plane's mass can be found by using Equation 4.3, $\vec{F}_{\text{net}} = m\vec{a}$.

EVALUATE Using Equation 4.3, the mass of the plane is found to be

$$m = \frac{F_{\text{net}}}{a} = \frac{1.1\times10^4\ \text{N}}{7.2\ \text{m/s}^2} = 1.53\times10^3\ \text{kg}$$

ASSESS First, the units are consistent since $1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$. The result is reasonable, since by definition, one newton is the force required to accelerate a 1-kg mass at the rate of 1 m/s^2.

15. **INTERPRET** This problem involves Newton's second law. The object of interest is the passenger, and we are to calculate the force required to stop the passenger in the given time.

DEVELOP Assume that the seatbelt holds the passenger firmly to the seat, so that the passenger also stops in 0.14 s without incurring any secondary impact. The passenger's average acceleration is $a_{av} = (0 - v_0)/t$ and his mass is 60 kg. Insert these quantities into Newton's second law to find the force.

EVALUATE The average force exerted by the seatbelt on the passenger is

$$F_{av} = ma_{av} = -mv_0/t = -\frac{(60\text{ kg})}{0.14\text{ s}}(110\text{ km/h})\left(\frac{1000\text{ m}}{\text{km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right) = -13\text{ kN}$$

ASSESS The negative sign indicates that the force is opposite to the direction of the initial velocity.

16. **INTERPRET** This problem involves Newton's second law and kinematics, with which we need to find the relationship between force and stopping distance.

DEVELOP From Equation 4.3, we see that the net force on a car of given mass is proportional to the acceleration, $F_{net} \propto a$. We can then relate the three quantities, displacement, velocity, and acceleration, by Equation 2.11, $v^2 = v_0^2 + 2a(x - x_0)$.

EVALUATE To stop a car in a distance $x - x_0$, the acceleration is

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{-v_0^2}{2(x - x_0)}$$

Therefore, we see that $F_{net} \propto v_0^2$, so doubling v_0 quadruples the magnitude of F_{net}.

ASSESS The conclusion that $F_{net} \propto v_0^2$ is an important fact to remember when driving at high speeds.

17. **INTERPRET** This problem involves Newton's 2nd law for constant mass.

DEVELOP By Equation 4.3, the kinesin force imparts an acceleration on the molecular complex of $a = F/m$.

EVALUATE Recall from Appendix B that the SI prefix pico (p) corresponds to 10^{-12} , so

$$a = \frac{F}{m} = \frac{6.0\times10^{-12}\text{ N}}{3.0\times10^{-18}\text{ kg}} = 2.0\times10^{6}\text{ m/s}^2$$

ASSESS This is an extraordinarily large acceleration, but it would only be applied for a fraction of a second, so the final velocity would be reasonable.

18. **INTERPRET** This problem involves Newton's second law and kinematics. We want to find the force required to accelerate a car to cover a certain distance within a given time interval.

DEVELOP The displacement of the car as a function of time is given by Equation 2.10, $x = x_0 + v_0 t + \tfrac{1}{2}at^2$. The equation can be used to solve for the acceleration a. Also, from Newton's second law, we see that the net force on a car of given mass is proportional to the acceleration, $F_{net} \propto a$.

EVALUATE Using Equation 2.10 with $v_0 = 0$, the acceleration of the car is

$$a = \frac{2(x - x_0)}{t^2} = \frac{2(400\text{ m})}{(4.95\text{ s})^2} = 32.6\text{ m/s}^2$$

Newton's second law gives the average net force on the car as

$$F_{net} = ma = (940\text{ kg})(32.6\text{ m/s}^2) = 3\times10^4\text{ N}$$

to a single significant figure. The force acts in the direction of the motion.

ASSESS Our answer for the acceleration a can be checked by using other kinematic equations. The speed of the car after 4.95 s is $v = at = (32.6\text{ m/s}^2)(4.95\text{ s}) = 161\text{ m/s}$. Using Equation 2.11, $v^2 = v_0^2 + 2a(x - x_0)$ we find the distance traveled to be

$$x - x_0 = \frac{v^2 - v_0^2}{2a} = \frac{(161\text{ m/s})^2 - 0}{2(32.6\text{ m/s}^2)} = 400\text{ m}$$

in agreement with the value given in the problem statement.

19. **INTERPRET** This problem involves Newton's second law and kinematics. The object of interest is the egg, and we are to calculate the minimum stopping distance so that the egg does not experience a force greater than 1.5 N.

DEVELOP For the average net force on the egg to not exceed the stated limit, the magnitude of the deceleration should satisfy $a_{av} \le F_{max}/m = 1.5\text{ N}/0.085\text{ kg} = 17.6\text{ m/s}^2$. Insert this acceleration into kinematic Equation 2.11 $v^2 = v_0^2 + 2a(x - x_0)$ to find the minimum stopping distance.

EVALUATE The minimum stopping distance is

$$x - x_0 \ge \frac{(1.2\text{ m/s})^2}{35.3\text{ m/s}^2} = 0.041\text{ m} = 4.1\text{ cm}$$

ASSESS Notice that the units work out to units of distance, as expected.

20. **INTERPRET** We interpret this as a problem involving the application of Newton's second law. The object under consideration is the car and the physical quantity of interest is the bumper deformation to withstand the impact force and avoid damage.

DEVELOP For the force on the bumper not to exceed the stated limit, the magnitude of the deceleration should satisfy $a_{av} \le F_{max}/m$. The deformation of the bumper can then be calculated from Equation 2.11, $v^2 = v_0^2 + 2a(x - x_0)$.

EVALUATE From the reasoning above, the magnitude of the maximum acceleration is

$$a_{av} = \frac{F_{max}}{m} = \frac{65{,}000\text{N}}{1300\text{ kg}} = 50\text{ m/s}^2$$

With an initial speed of $v_0 = 10\text{ km/h} = 2.78\text{ m/s}$, the minimum bumper deformation is

$$x - x_0 = \frac{|v^2 - v_0^2|}{2a} = \frac{|0 - (2.78\text{ m/s})^2|}{2(50\text{ m/s}^2)} = 0.0772\text{ m} = 7.7\text{ cm}$$

ASSESS A bumper is typically allowed to deform up to a maximum of 12.5 cm before stopping the car.

Section 4.4 The Force of Gravity

21. **INTERPRET** This problem involves using Newton's second law to convert the usual units of acceleration (m/s^2) to N/kg. We are also asked to explain why it makes sense to express acceleration in N/kg when speaking of mass and weight.

DEVELOP Newton's second law relates the units of mass (kg), distance (m), time (s), and force (N). Use this to solve the problem.

EVALUATE From Newton's second law (for constant mass), $\vec{F}_{net} = m\vec{a}$, we see that force (N) is the same as mass (kg) × acceleration (m/s^2), which can be expressed mathematically as $\text{N} = \text{kg}\cdot\text{m/s}^2$. This can be rearranged to find $\text{m/s}^2 = \text{N/kg}$. It makes sense to use the units N/kg when speaking of mass and weight because kg is a unit of mass and N is a unit of force (i.e., a weight).

ASSESS An acceleration is thus a mass per unit force.

22. **INTERPRET** This problem involves the acceleration due to gravity. We are to use it to identify the planet on which the spaceship has crashed based on the gravitational force experienced.

DEVELOP If the mass and weight are known, then the gravitational acceleration of the planet can be obtained by using Equation 4.5, $\vec{w} = m\vec{g}$.

EVALUATE The surface gravity of the planet is thus

$$g = \frac{w}{m} = \frac{532\text{ N}}{60\text{ kg}} = 8.87\text{ m/s}^2$$

which is precisely the value for Venus in Appendix E.

ASSESS The gravitational acceleration of Venus is lower than that of the Earth. Therefore, the person's weight is less on Venus. The mass, however, remains unchanged.

23. **INTERPRET** This problem asks us to find the mass of an object whose weight on the Moon corresponds to the weight of 35-kg object on the Earth.

DEVELOP Use Equation 4.5 to find the weight of the block on the Earth. Use the gravitational acceleration g_M from Appendix E to calculate the mass that corresponds to an object of this weight on the Moon.

EVALUATE To lift a 35-kg block on Earth requires a force at least equivalent to its weight, which is $w = mg = (35\text{ kg})(9.8\text{ m/s}^2) = 343\text{ N}$. The same force on the moon could lift a mass $m = w/g_M = (343\text{ N})/(1.62\text{ m/s}^2) = 212\text{ kg} \approx 210\text{ kg}$ to two significant figures.

ASSESS The weight of a 212-kg object on Earth is $w = mg = (212\text{ kg})(9.8\text{ m/s}^2) = 2078\text{ N}$, which is a factor g/g_M = (9.8 m/s^2)/(1.62 m/s^2) = 6 times more than the weight on the Moon. Thus, you can lift 6 times the mass on the Moon than you can on the Earth.

24. **INTERPRET** In this problem we are asked about the actual weight, given the mass, of a cereal box in SI units and in ounces.

DEVELOP In many contexts, the phrase "net weight" actually refers to the mass, rather than the actual weight (as in this case). Use Equation 4.5 to find the weight of the cereal, and then convert this to ounces using the conversion factor 1 oz = weight of 0.02835 kg = (9.81 m/s2)(0.02835 kg) = 0.2778 N (Appendix C). Recall that 340 g = 0.340 kg.

EVALUATE **(a)** The actual weight (equal to the gravitational force on the object at the surface of the Earth) is

$$w = mg = (0.340\text{ kg})(9.81\text{ m/s}^2) = 3.33\text{ N}$$

(b) Using the conversion factor from Appendix C we find the weight in ounces is

$$w = (3.33\text{ N})\left(\frac{1\text{ oz}}{0.2778\text{ N}}\right) = 12.0\text{ oz}$$

ASSESS The word "net" in net weight means just the weight of the contents; gross weight includes the weight of the container, etc. This may be compared with the use of the word in net force, which means the sum of all the forces or the resultant force. A net weight, profit, or other amount is the resultant after all corrections have been taken into account.

25. **INTERPRET** This is an exercise in converting between mass and weight.

DEVELOP The weight on the US side is 10 tons. From Appendix C, we see that 1 ton is equivalent to the weight of 908 kg. Use this conversion to translate the given weight into a mass in kg.

EVALUATE If 1 ton = weight of 908 k, 10 = weight of 9080 kg. Thus, you should specify 9000 kg (to a single significant figure) on the Canadian side of the border.

ASSESS The conversion between mass and weight on Earth is $m = w/g$. Because the English unit of mass (the slug) is rarely used, the direct equivalence between mass in SI units and weight (force) in English units is usually given, as in Appendix C. Thus, 10 tons = 2×10^4 lbs is equivalent to the weight of $(2\times10^4\text{ lb})(0.4536\text{ kg/lb}) = 9\times10^3\text{ kg}$.

26. INTERPRET The problem is to find the weight of an object, given its mass and the magnitude of gravitational acceleration.

DEVELOP If the mass and the gravitational acceleration are known, the weight can be obtained by using Equation 4.5, $\vec{w} = m\vec{g}$. The gravitational acceleration is smaller the farther one is from the Earth's surface.

EVALUATE The magnitude of the astronaut's weight on the space station is

$$w = (68\text{ kg})(0.89\cdot 9.8\text{ m/s}^2) = 590\text{ N}$$

ASSESS This would be the weight if the astronaut were somehow standing still at the altitude of the space station. But in fact, the astronaut is in free fall with the space station, so his/her "weight" is zero. That's because an operational definition of weight is the force read on a scale at rest relative to the object being weighed, and the astronaut would float above any scale placed on the space station.

Section 4.5 Using Newton's Second Law

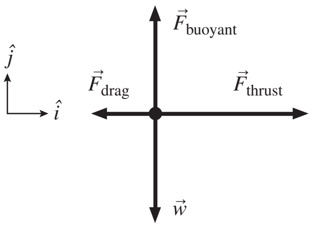
27. **INTERPRET** This problem involves kinematics with constant velocity and Newton's second law. We are asked to find the force on the parachute due to air drag. The other force involved is the gravitational force.

DEVELOP From kinematics (see, for example, Equation 3.6) we know that a body moving with constant velocity experiences an acceleration of $a = 0$. Inserting this into Newton's second law (for constant mass), $F_{net} = ma$, tells us that the net force is $F_{net} = 0$. From the free-body diagram of the situation (see figure below), we see that a zero net force implies that $F_{drag} = w$, from which we can find the drag force exerted by the air.

EVALUATE Thus, the drag force is $F_{drag} = w = mg = (50\text{ kg})(9.8\text{ m/s}^2) = 490\text{ N}$.

ASSESS Because the acceleration gives the change in velocity over time, a body moving with constant velocity experiences zero instantaneous and zero average acceleration (cf. Equations 3.6 and 2.7).

28. **INTERPRET** This problem involves Newton's second law. There are four forces acting on the boat: two in the horizontal direction and two in the vertical direction. The vertical force pair are the gravitational force and the buoyant force of the water (which hopefully cancel out so that the boat floats on the water). The horizontal forces are the motor's thrust and the drag of the water, which act in opposite directions (see free-body diagram below).



DEVELOP Apply Newton's second law to the boat. This gives

$$\vec{F}_{net} = \left(F_{thrust} - F_{drag}\right)\hat{i} + \left(F_{bouyant} - w\right)\hat{j} = m\vec{a} = m\left(a_x\hat{i} + a_y\hat{j}\right)$$

Because the boat does not accelerate in the $\hat{j}$ direction ($a_y = 0$), so $F_{buoyant} = w$. The drag force can be found from the $\hat{i}$ component of this vector equation, knowing that the mass m =930 kg, $a_x = 2.3\text{ m/s}^2$, and $F_{thrust} = 3.9\text{ N}$.

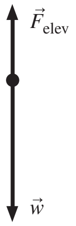
EVALUATE The horizontal component of Newton's second law gives

$$F_{thrust} - F_{drag} = ma_y$$
$$F_{drag} = F_{thrust} - ma_y = 3900\text{ N} - (930\text{ kg})\left(2.3\text{ m/s}^2\right) = 1761\text{ N} = 1800\text{ N}$$

to two significant figures. This is the magnitude of the drag force; its direction is $-\hat{i}$, so the complete drag force is $\vec{F}_{drag} = (-1800\text{ N})\hat{i}$.

ASSESS As expected, the horizontal component of the drag force is negative, i.e., opposite to the direction of the acceleration.

29. **INTERPRET** This problem involves Newton's second law. The forces acting on the elevator passenger are the gravitational force and the normal force F_{elev} that the elevator floor applies on her feet (see free-body diagram below). We are asked to find the latter force.



DEVELOP Because this problem involves forces in only one direction, we can dispense with the vector notation. Apply Newton's second law (for constant mass) $F_{net} = ma$ to find the force applied by the floor of the elevator. The net force is the sum of the forces acting on our passeger, so $F_{\text{net}} = F_{\text{elev}} - w$ (where $w = mg$), the mass of the passenger is $m = 52$ kg, and her acceleration is $a = -2.4\ \text{m/s}^2$.

Evaluate Newton's second law gives

$$\begin{aligned} F_{\text{net}} &= ma \\ F_{\text{elev}} - w &= ma \\ F_{\text{elev}} &= mg + ma = (52\ \text{kg})(9.8\ \text{m/s}^2 - 2.4\ \text{m/s}^2) = 380\ \text{N} \end{aligned}$$

Assess Because the elevator accelerates downward, it does not need to support the entire weight of the person, so the force it applies is slightly less than that necessary to counter the gravitational force on the person. What would happen if the elevator accelerated downward at the 9.8 m/s^2? At $a > 9.8$ m/s^2?

30. **Interpret** We need to use Newton's 2$^{\text{nd}}$ law to find the lifting force on the plane.

Develop There are two forces on the plane: the upward lift provided by the wings and the downward weight from gravity: $F_{\text{net}} = F_{\text{up}} - mg = ma_{\text{net}}$, or solving for the lift: $F_{\text{up}} = m(g + a_{\text{net}})$. In part (a) the plane holds a constant altitude, so the net acceleration and force must be zero. In part (b), the plane is climbing so the acceleration is positive.

Evaluate (a) When there's no acceleration, the upward force balances the weight:

$$F_{\text{up}} = mg = (560\ \text{t})\left(\frac{1000\ \text{kg}}{1\ \text{t}}\right)(9.8\ \text{m/s}^2) = 5.5\times10^6\ \text{N}$$

(b) When the plane climbs at $a_{\text{net}} = 1.1$ m/s,

$$F_{\text{up}} = (560\ \text{t})\left(\frac{1000\ \text{kg}}{1\ \text{t}}\right)(9.8\ \text{m/s}^2 + 1.1\ \text{m/s}^2) = 6.1\times10^6\ \text{N}$$

Assess It obviously takes a lot of force to keep a plane that big in the air. The lift of an airplane is proportional to its wing area. The Airbus A-380 has a wing area of 845 m^2, compared to 541 m^2 for a Boeing 747, which has a smaller mass of 397 metric tons.

31. **Interpret** We assume the rocket's acceleration is constant, so we'll need the equations from Chapter 2, Section 4. Once we know the acceleration, we can find the force from the rocket engines using Newton's 2$^{\text{nd}}$ law.

Develop The rocket has to go from rest to $v = 7200$ km/h in 2 min. We can use Equation 2.7 ($v = v_0 + at$) to find the acceleration. From this we use Equation 4.3 ($F = ma$) to find the force of the rocket and the force on the astronaut.

Evaluate The rocket accelerates at

$$a = \frac{v - v_0}{t} = \frac{7200\ \text{km/h}}{2.0\ \text{min}} = 66.7\ \text{m/s}^2$$

To accelerate a load of 630 Mg, the rocket will need a thrust of

$$F = ma = (630\times10^3\ \text{kg})(66.7\ \text{m/s}^2) = 4.2\times10^7\ \text{N}$$

During launch, a 75-kg astronaut experiences a force of

$$F = ma = (75\ \text{kg})(66.7\ \text{m/s}^2) = 5.0\times10^3\ \text{N}$$

Assess This is nearly 7 g of acceleration, but astronauts and modern pilots are often trained to handle up to around 9 g without losing consciousness.

32. **Interpret** This problem involves kinematics (to find the acceleration of the person), Newton's second law (to find forces acting on the person), and Newton's third law. The forces involved are the gravitational force and the normal force exerted by the floor of the elevator on the person's feet (see free-body diagram from Problem 4.29).

Develop Because this is a one-dimensional problem, we can dispense with the vector notation, provided we assign positive values to upward vectors and negative values to downward vectors. The average acceleration is (see Equation 3.5) $\bar{a} = \Delta v/\Delta t = (-9.3\ \text{m/s}^2)/(2.1\ \text{s}) = -4.38\ \text{m/s}^2$. The apparent weight w_{ap} is simply the force you exert on the floor of the elevator, which is equal and opposite to the upward force $F_{\rm elev}$ ($w_{\rm ap} = -F_{\rm elev}$) that the floor exerts on you (Newton's third law). $F_{\rm elev}$ and the gravitational force $w = mg$, are the two forces that determine your vertical acceleration a_y. Apply Newton's second law to find your apparent weight and compare it to your actual weight $w = mg$.

EVALUATE Newton's second law gives

$$\begin{aligned} F_{\rm net} &= ma \\ F_{\rm elev} + mg &= ma \\ -w_{\rm ap} &= m(a-g) = m\left[-4.38\ {\rm m/s^2} - \left(-9.8\ {\rm m/s^2}\right)\right] = m\left(5.43\ {\rm m/s^2}\right) \\ w_{\rm ap} &= m\left(-5.43\ {\rm m/s^2}\right) \end{aligned}$$

Comparing the apparent weight to the actual weight gives

$$\frac{w_{\rm ap}}{w} = \frac{m\left(-5.43\ {\rm m/s^2}\right)}{m\left(-9.8\ {\rm m/s^2}\right)} = 55\%$$

Thus, $w_{\rm ap}$ is only 55% of the actual weight.

ASSESS To see that the expression for $w_{\rm ap}$ makes sense, consider the case of free fall. In this limit, $a = g$ and we have the expected weightless situation, $w_{\rm ap} = 0$.

Section 4.6 Newton's Third Law

33. **INTERPRET** This problem involves Newton's third law. We are asked to find the third-law force that pairs with the gravitational force from the Earth pulling the elephant toward the Earth.

DEVELOP As shown in Figure 4.17, the third-law force that pairs with the Earth's gravitational pull is the gravitational force exerted by the elephant on the Earth, pulling the Earth upward. Apply Newton's third law to calculate this force.

EVALUATE Newton's third law gives $F_{eE} = F_{Ee} = mg = (5600\ {\rm kg})\left(9.8\ {\rm m/s^2}\right) = 55\ {\rm kN}$.

ASSESS Note that the magnitudes of the forces in a third-law force pair are equal, but they are oriented in opposite directions.

34. **INTERPRET** This problem involves Newton's third law, Newton's second law, and kinematics. The third-law force pair are the gravitational force the Earth exerts on your friend and the gravitation force your friend exerts on the Earth. Newton's second law allows us to find the acceleration of the objects given the force that acts on them (and their mass). Finally, we will use kinematics to find the displacement of the objects given their acceleration.

DEVELOP By Newton's third law, the force the Earth exerts on your friend ($F_{\rm Ef}$) has the same magnitude as the force your friend exerts on the Earth ($F_{\rm fE}$) (but is in the opposite direction), so $F_{\rm Ef} = F_{\rm fE}$. The force exerted by the Earth on your friend is simply her weight, so $F_{\rm Ef} = w = mg$. Use this force in Newton's second law ($F = ma$) to find the accelerations of your friend and of the Earth, then use Equation 2.1, $x = x_0 + v_0 t + at^2/2$, to find the displacement of each object.

EVALUATE From Newton's second law, the magnitude of your friend's acceleration is $a_{\rm f} = F_{\rm Ef}/m_{\rm f} = m_{\rm f} g/m_{\rm f} = g$. The magnitude of the acceleration of the Earth is $a_{\rm E} = F_{\rm fE}/M_{\rm E} = F_{\rm Ef}/M_{\rm E} = m_{\rm f} g/M_{\rm E}$. By Newton's third law, $\vec{a}_{\rm f}$ and $\vec{a}_{\rm E}$ point in the opposite directions. If your friend and the Earth both start from rest, the displacement of each is

$$\begin{aligned} d_{\rm f} &= \frac{1}{2}a_{\rm f} t^2 = \frac{1}{2}gt^2 \ \ \text{(down)} \\ d_{\rm E} &= \frac{1}{2}a_{\rm E} t^2 = \frac{1}{2}\frac{m_{\rm f} g}{M_{\rm E}}t^2 = \left(\frac{m}{M_{\rm E}}\right)d_{\rm f} \ \ \text{(up)} \end{aligned}$$

with $d_{\rm f} + d_{\rm E} = 1.2$ m. Solving for $d_{\rm E}$ gives

$$d_{\rm E} = \frac{1.2\ {\rm m}}{1 + M_{\rm E}/m_{\rm f}} = \frac{1.2\ {\rm m}}{1 + \left(5.97\times10^{24}\ {\rm kg}\right)/(65\ {\rm kg})} = 1.3\times10^{-23}\ {\rm m}$$

ASSESS The displacement of the Earth is too small to be noticeable; it is about 10^5 times smaller than the smallest physically meaningful distances studied to date!

35. **INTERPRET** This is a one-dimensional problem that involves calculating a force using Hooke's law, and applying Newton's third law to find the force necessary to stretch the spring.

DEVELOP Choose a coordinate system in which the extension of the spring is in the positive x direction. Hooke's law (Equation 4.9) states that a spring will resist compression or extension with a force proportional to the change in the spring's length, or $F_{sp} = -kx$, where k is the spring constant an x is the extension ($x > 0$) or compression ($x < 0$) of the spring. We are given $k = 270$ N/m and $x = 48$ cm = 0.48 m, so we can use Hooke's law to solve the problem.

EVALUATE Inserting the given quantities into Hooke's law gives $F_{sp} = -(270\text{ N/m})(0.48\text{ m}) = -130\text{ N}$. This means the spring exerts a force in the negative-x direction of 130 N, so by Newton's third law, we must apply a force $F_{app} = -F_{sp} = 130$ N (i.e., in the positive-x direction).

ASSESS If we stretch the spring too far, it will permanently deform and Hooke's law will no longer apply.

36. **INTERPRET** This is a one-dimensional problem that involves Hooke's law and Newton's third law. We are asked to find the distance a spring with a given spring constant is stretched if we apply a given force to it.

DEVELOP Choose a coordinate system in which the applied force is in the positive-x direction. Given the spring force F_{sp} and the spring constant k, the length stretched can be calculated by using Hooke's law (Equations 4.9), $F_{sp} = -kx$. From Newton's third law, the force applied has the same magnitude as F_{sp}, but is oriented in the opposite direction, so $F_{app} = -F_{sp}$. The problem states that $F_{app} = 35$ N and $k = 220$ N/m.

EVALUATE Inserting the given quantities into Hooke's law gives

$$x = -\frac{F_{sp}}{k} = \frac{F_{app}}{k} = \frac{35\text{ N}}{220\text{ N/m}} = 0.16\text{ m} = 16\text{ cm}$$

ASSESS Notice that the spring is extended in the positive-x direction, as expected if we apply a force in that direction.

37. **INTERPRET** This is a one-dimensional problem that involves Hooke's law and Newton's third law. We are asked to find the distance a spring with a given spring constant is stretched if we apply a given force to it.

DEVELOP We apply the same reasoning as per Problem 4.36, except that we choose a coordinate system in which the applied force is in the negative-x direction. The problem states that $k = 340$ N/m and the applied force is the gravitational force (Equation 4.5) on the fish: $F_{app} = w = mg = -(6.7\text{ kg})(9.8\text{ m/s}^2)$.

EVALUATE Inserting the given quantities into Hooke's law gives

$$x = -\frac{F_{sp}}{k} = \frac{F_{app}}{k} = \frac{-(6.7\text{ N})(9.8\text{ m/s}^2)}{340\text{ N/m}} = -0.19\text{ m} = -19\text{ cm}$$

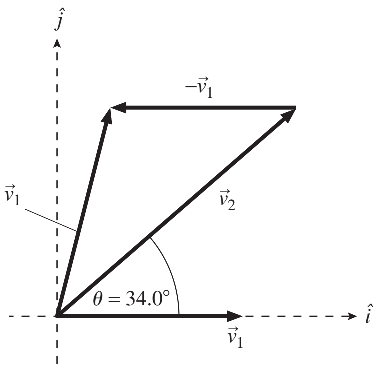
Thus the spring stretches 19 cm downward.

ASSESS Notice that the spring is extended in the negative-x direction, as expected if we apply a force in that direction.

PROBLEMS

38. **INTERPRET** This problem involves Newton's second law and kinematics. We are asked to find the force required to accelerate an object a given amount, where the acceleration must be calculated from the given mass, initial velocity, and final velocity.

DEVELOP Draw a diagram of the situation to define a coordinate system (see figure below). Equation 4.2, which is Newton's second law for constant mass ($\vec{F}_{net} = m\vec{a}$), states that the average force acting on an object is equal to the average acceleration, $\bar{\vec{F}}_{net} = m\bar{\vec{a}}$. From Equation 3.5 $\bar{\vec{a}} = \Delta\bar{\vec{v}}/\Delta t = (\vec{v}_2 - \vec{v}_1)/\Delta t$, we can calculate the average acceleration, which we can insert into Newton's second law to find the force. We are given the initial velocity, $\vec{v}_1 = (17.4\text{ m/s})\hat{i}$ the final velocity, $\vec{v}_2 = (26.8\text{ m/s})\left[\cos(34°)\hat{i} + \sin(34°)\hat{j}\right] = (22.2\text{ m/s})\hat{i} + (15\text{ m/s})\hat{j}$, the time interval $\Delta t = 3.41$ s, and the mass $m = 1.25$ kg.



EVALUATE The average acceleration is

$$\bar{\vec{a}} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(22.2\text{ m/s} - 17.4\text{ m/s})\hat{i} + (15\text{ m/s})\hat{j}}{3.41\text{ s}} = (1.408\text{ m/s}^2)\hat{i} + (4.399\text{ m/s}^2)\hat{j}$$

Inserting this result into Newton's second law gives

$$\bar{\vec{F}}_{\text{net}} = m\bar{\vec{a}} = (1.25\text{ kg})\left[(1.408\text{ m/s}^2)\hat{i} + (4.399\text{ m/s}^2)\hat{j}\right] = (1.76\text{ N})\hat{i} + (5.50\text{ N})\hat{j}$$

The magnitude of this force is $\bar{\vec{F}}_{\text{net}} = \sqrt{(1.76\text{ N})^2 + (5.50\text{ N})^2} = 5.77\text{ N}$ and the direction is $\theta = \text{atan}\left(F_{\text{net},y}/F_{\text{net},x}\right) = \text{atan}(5.50\text{ N}/1.76\text{ N}) = 72.3°$, measured CCW from the x axis.

ASSESS Note that the force $\bar{\vec{F}}_{\text{net}}$ is in the same direction as $\Delta\vec{v}$, not the final velocity $\vec{v}_2$. The latter holds only when the object is initially at rest so that $\Delta\vec{v} = \vec{v}_2$.

39. **INTERPRET** This is a one-dimensional problem that involves Newton's second law. We are asked to find an acceleration given the forces acting on a body.

DEVELOP We use a coordinate system where the upward direction corresponds to the positive-x direction. For constant mass, Newton's second law is $\vec{F}_{\text{net}} = m\vec{a}$. The forces acting on your body are the gravitational force, $\vec{F}_g = (-mg)\hat{i}$, and the normal force $\vec{n}$ of your seat pushing upward, which is what you feel as your weight ($n = w = mg$, see Equation 4.5). We are told that your weight is 70% of its usual value, so we set $\vec{n} = 0.7\vec{w} = (0.7mg)\hat{i}$. Insert these quatnities into Newton's second law to find the plane's acceleration.

EVALUATE From Newton's second law, the plane's acceleration is

$$\vec{F}_{\text{net}} = (-mg)\hat{i} + (0.7mg)\hat{i} = m\vec{a}$$
$$\vec{a} = (-0.3g)\hat{i} = (-0.3)(9.81\text{ m/s}^2)\hat{i} = (-2.94\text{ m/s}^2)\hat{i}$$

ASSESS The airplane accelerates downward, as expected.

40. **INTERPRET** This is a one-dimensional problem that involves Newton's second law. Two forces are acting on the tree surgeon: the downward gravitational force $\vec{F}_g$ and the upward normal force $\vec{n}$ from the bucket. We are asked to calculate $\vec{n}$ under various conditions.

DEVELOP We shall assume that the only vertical forces acting on the tree surgeon are those given; namely, the force of gravity, $\vec{F}_g = m\vec{g}$ acting downward, and the normal force $\vec{n}$ of the bucket acting upward. Taking the upward direction to be positive, the net force is $F_{\text{net}} = -mg + n = ma$, which gives $n = m(g + a)$.

EVALUATE For parts **(a)**, **(b)**, and **(c)**, the tree surgeon is not accelerating, so the normal force has the same magnitude as the weight:

$n = mg = (74\text{ kg})(9.8\text{ m/s}^2) = 730\text{ N}$

(d) If $a = +1.7\text{ m/s}^2$, $n = (74\text{kg})(9.8\text{ m/s}^2 + 1.7\text{ m/s}^2) = 850\text{ N}$.

(e) For $a = -1.7\text{ m/s}^2$, we have $n = (74\text{kg})(9.8\text{ m/s}^2 - 1.7\text{ m/s}^2) = 600\text{ N}$.

ASSESS The upward normal force exerted by the bucket is greatest when the lift is moving upward with a non-zero acceleration. The tree surgeon's feet will feel "heavy."

41. **INTERPRET** This is a one-dimensional problem that involves Newton's second law. We are asked to find the acceleration of the dancer given the forces acting on him.

DEVELOP We choose a coordinate system in which the positive -*y* direction is upward. For constant mass, Newton's second law is $\vec{F}_{\rm net} = m\vec{a}$, where $\vec{F}_{\rm net}$ is the sum of all the forces acting on the dancer. These forces are the gravitational force, which is his weight $\vec{w} = (-mg)\hat{j}$ (see Equation 4.5) pulling him down, and the normal force of the floor, which we are told is $\vec{n} = (1.5mg)\hat{j}$. Sum these to find the net force and his acceleration.

EVALUATE Inserting the known quantities into Newton's second law gives

$$\vec{F}_{\rm net} = m\vec{a}$$
$$(-mg + 1.5mg)\hat{j} = m\vec{a}$$
$$\vec{a} = (0.50g)\hat{j} = (0.5)(9.8\ {\rm m/s^2})\hat{j} = (4.9\ {\rm m/s^2})\hat{j}$$

where we have given the answer to two significant figures to match the precision of the input.

ASSESS Notice that the acceleration is upward, as expected.

42. **INTERPRET** We're asked for the force needed to bring an object from rest to a certain speed. We will assume that the acceleration is constant.

DEVELOP If the speed is attained in a time of Δt, then the acceleration is $a = v/\Delta t$ (Equation 2.7). If the speed is attained over a distance of Δx, then the acceleration is $a = v^2/2\Delta x$ (Equation 2.11).

EVALUATE (a) The force needed to accelerate the object in Δt is

$$F = ma = \frac{mv}{\Delta t}$$

(b) The force needed to accelerate the object over Δx is

$$F = ma = \frac{mv^2}{2\Delta x}$$

ASSESS If we equate these forces, we get $\Delta x = \frac{1}{2}(v_0 + v)\Delta t$, which is Equation 2.9.

43. **INTERPRET** The is a one-dimensional problem that involves Newton's second law and kinematics. We are asked to compute the minimum stopping time for the elevator that allows the passengers to remain on the floor.

DEVELOP We shall take the positive-*y* axis as upward. To use Newton's second law, $\vec{F}_{\rm net} = m\vec{a}$, we need to know all the forces acting on the passenger. There are two vertical forces on a passenger, the gravitational force $\vec{F}_g = \vec{w} = -mg\hat{j}$ downward (see Equation 4.5), and the upward normal force $\vec{n} = n\hat{j}$ of the floor. The latter is a contact force and always acts in a direction perpendicular to and away from the surface of contact. If the magnitude of this force drops below zero, our passenger will have lost contact with the floor.

EVALUATE Inserting the forces into Newton's second law and demanding that n > 0 gives us a condition whereby the passenger stays in contact with the floor:

$$\vec{F}_{\rm net} = m\vec{a}$$
$$n - mg = ma$$
$$n = ma + mg > 0$$
$$a > -g$$

Note that m is positive. Using Equation 3.8, the time required for the elevator to stop ($v = 0$) from an initial upward velocity ($v_0 = 5.2$ m/s) is $t = (v - v_0)/a = -v_0/a$. Inserting the limiting condition of $a = -g$ gives $t > v_0/g = (5.2\ {\rm m/s})/(9.8\ {\rm m/s^2}) = 0.53\ {\rm s}$.

ASSESS Half a second is a reasonable value. The condition $n = 0$ is the limit for the person and the floor to remain in contact. As long as the passenger is in contact with the floor, his or her vertical acceleration is the same as that of the floor and the elevator.

44. **INTERPRET** This problem involves the application of Newton's 2nd law in two dimensions.

DEVELOP The motion is in the *x*-*y* plane, but the object's acceleration $\vec{a} = (\vec{F}_1 + \vec{F}_2)/m$ is only in the *y* direction: $a_x = 0$, $a_y = (F_{1y} + F_{2y})/m$. We assume the forces are constant, so the acceleration is constant as well. We can find the magnitude of this acceleration from the fact that the object goes from $y_0 = 0$ to $y = 10.8$ m in 3.00 s. Since it originally only had velocity in the *x* direction ($v_{y0} = 0$), Equation 2.10 tells us:

$$a_y = \frac{2(y - y_0)}{t^2}$$

Evaluate Solving for the unknown force's magnitude

$$F_{2y} = ma_y - F_{1y} = (2.50 \text{ kg})\frac{2(10.8 \text{ m})}{(3.00 \text{ s})^2} - 15.0 \text{ N} = -9.0 \text{ N}$$

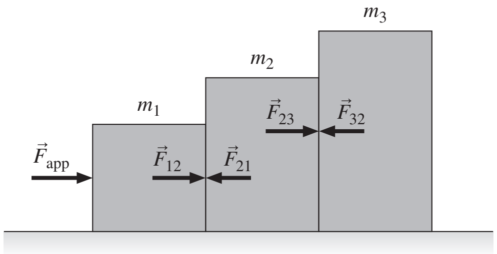
In vector format, our answer is

$$\vec{F}_2 = -9.0\hat{j} \text{ N}$$

ASSESS Because there is no acceleration in the *x* direction, the velocity in the *x* direction should be constant $v_x = 1.60$ m/s . Therefore, over $t = 3.00$ s , the object should move from the origin to $x = v_x t = 4.80$ m , which agrees with what is reported in the text.

45. **INTERPRET** This problem deals with interaction between different pairs of objects. The key concepts involved here are Newton's second and third laws.

DEVELOP Let the three masses be denoted, from left to right, as $m_1, m_2,$ and $m_3,$ as shown in the figure below.



We take the right direction to be +*x*. We are told that the table is frictionless, so the only horizontal forces are the applied force and the contact forces between the blocks. For example, $\vec{F}_{12}$ denotes the force exerted by block 1 on block 2. Since the blocks are in contact, they all have the same acceleration *a*, to the right. Newton's second law can be applied to each block separately:

$$\vec{F}_{\text{app}} + \vec{F}_{21} = m_1\vec{a}$$
$$\vec{F}_{12} + \vec{F}_{32} = m_2\vec{a}$$
$$\vec{F}_{23} = m_3\vec{a}$$

EVALUATE Adding all three equations and using Newton's third law ($\vec{F}_{12} + \vec{F}_{21} = 0,$ etc.), one finds

$$\vec{a} = \frac{\vec{F}_{\text{app}}}{m_1 + m_2 + m_3} = \frac{12 \text{ N}}{1.0 \text{kg} + 2.0 \text{kg} + 3.0 \text{kg}} = 2.0 \text{ m/s}^2 \quad \text{(to the right)}$$

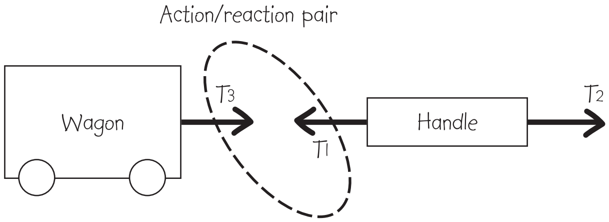
Thus, the force block 2 exerts on block 3 is

$$F_{23} = m_3 a = (3.0 \text{ kg})(2.0 \text{ m/s}^2) = 6.0 \text{ N} \quad \text{(to the right)}$$

ASSESS You might be tempted to assume that the force on block 3 is just the applied force, $\vec{F}_{\text{app}}$, but from that you would wrongly conclude that block 3 is accelerating at 4 m/s^2, which would no longer be the same as for the other 2 blocks.

46. **INTERPRET** This problem asks us to consider the tension in the handle when the handle and the wagon are accelerated. The key concepts involved here are Newton's second and third laws.

DEVELOP There are two forces on the handle: the tension from the wagon resisting the motion (we'll call this $\vec{T}_1$) and the tension from the child's pulling (we'll call this $\vec{T}_2$). See the figure below.



We'll assume that the only force on the wagon is from the tension in the handle, which we have denoted as $\vec{T}_3$. Using the second law, the net horizontal force on the handle and wagon are, respectively,

$$F_{\text{net,h}} = T_2 - T_1 = m_\text{h} a$$
$$F_{\text{net,w}} = T_3 = m_\text{w} a$$

Where we have assumed that the positive direction is to the right. Since by the third law, $\vec{T}_1$ and $\vec{T}_3$ are an action/reaction pair, $T_1 = m_\text{w} a$. Plugging this in above, we have $T_2 = (m_\text{w} + m_\text{h}) a$.

Evaluate Solving for the tension on both sides of the handle

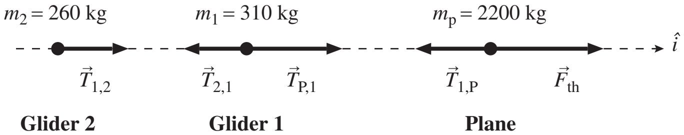
$$T_1 = (11\text{ kg})(2.3\text{ m/s}^2) = 25\text{ N}$$
$$T_2 = (11\text{ kg} + 1.8\text{ kg})(2.3\text{ m/s}^2) = 29\text{ N}$$

These tensions are not equal because if they were, the net force on the handle would be zero and it wouldn't accelerate (contrary to what we are told). One can also argue that the T_3 - T_1 pair is less than T_2 because the former has only has to accelerate the wagon, whereas latter has to accelerate both the wagon and the handle.

Assess Often times physics problems involving a string (or some other force-transferring object) will assume for simplicity that the string is massless. Under such an approximation, the tensions on the two ends of the string will be equal, since the net force on a massless object is always zero.

47. **Interpret** This is a one-dimensional problem that involves Newton's second and third laws. We are asked to find the force applied by the plane, the tension in the ropes, and the net force on the first glider.

Develop Make a free-body diagram of the situation (see figure below), on which we have noted all the horizontal forces, the masses of each object, and the coordinate system where the positive-*x* direction is to the right. Note that we are neglecting the mass of the ropes and any friction forces. From Newton's third law, we know that the third-law force pairs have equal magnitude, but act in opposing directions. Therefore, $\vec{T}_{1,\text{P}} = -\vec{T}_{\text{P},1}$ and $\vec{T}_{2,1} = -\vec{T}_{1,2}$ .To find the thrust of the propeller, note that the propeller has to accelerate at $\vec{a} = (1.9\text{ m/s}^2)\hat{i}$ a total mass m_T of $m_\text{T} = m_\text{P} + m_2 + m_1$, which we can insert into Newton's second law to find the thrust. Applying Newton's second law to the airplane, glider 1, and glider 2 will also allow us to find the tension in the two ropes, which will then allow us to find the net force on the first glider.



Evaluate **(a)** The net force on the three-body object is $\vec{F}_{\text{net}} = \vec{F}_{\text{th}} + \vec{T}_{1,\text{P}} + \vec{T}_{\text{P},1} + \vec{T}_{2,1} + \vec{T}_{1,2} = \vec{F}_{\text{th}}$, where the last equality follows from Newton's third law. Inserting this into Newton's second law gives

$$\vec{F}_{\text{net}} = m_\text{T}\vec{a}$$
$$\vec{F}_{\text{th}} = (m_1 + m_2 + m_\text{P})\vec{a} = (2200\text{kg} + 310\text{kg} + 260\text{kg})(1.9\text{ m/s}^2)\hat{i} = (5.26\times10^3\text{ N})\hat{i}$$

(b) Applying Newton's second law to the airplane gives the tension $\vec{T}_{1,P}$ in the first rope as

$$\vec{F}_{\text{net}} = m_\text{P}\vec{a}$$
$$\vec{F}_{\text{th}} + \vec{T}_{1,\text{P}} = m_\text{P}\vec{a}$$
$$\vec{T}_{1,\text{P}} = m_\text{P}\vec{a} - \vec{F}_{\text{th}} = (m_2 + m_1)\vec{a} = -(310\text{ kg} + 260\text{kg})(1.9\text{ m/s}^2)\hat{i} = (-1.08\times10^3\text{ N})\hat{i}$$

where we have used $\vec{F}_{\text{th}} = (m_1 + m_2 + m_\text{P})\vec{a}$ from part (a). Because the tension force in the rope acts in both directions ($\pm\hat{i}$), we give only the magnitude of the tension force; $T_1 = 1.1 \times 10^3$ N (to two significant figures).

(c) Applying Newton's second law to the first glider gives the tension $\vec{T}_{2,1}$ in the second rope as

$$\vec{F}_{\text{net}} = m_1\vec{a}$$
$$\vec{T}_{P,1} + \vec{T}_{2,1} = m_1\vec{a}$$
$$\vec{T}_{2,1} = m_2\vec{a} - \vec{T}_{P1} = m_1\vec{a} - (m_2 + m_1)\vec{a} = (-260 \text{ kg})(1.9 \text{ m/s}^2) = (-494 \text{ N})\hat{i}$$

The tension force in the rope is therefore $T_2 = 490$ N (to two significant figures).

(d) The net force on the first glider is $\vec{F}_{\text{net}} = \vec{T}_{2,1} + \vec{T}_{\text{P},1} = (-494 \text{ N} + 1080 \text{ N})\hat{i} = (590 \text{ N})\hat{i}$ (to two significant figures), where we have used $\vec{T}_{1,\text{P}}$ from part (b) and Newton's third law, which gives $\vec{T}_{\text{P},1} = -\vec{T}_{1,\text{P}}$.

ASSESS The tension in the first rope provides the force to accelerate m_2 and m_3, whereas the tension in the second force accelerates only m_3.

48. **INTERPRET** This problem involves applying Newton's second law to find the mass of the rat, given the mass of the cage, the acceleration of the cage + rat system, and the force applied to the cage + rat system.

DEVELOP Because this is a one-dimensional, unidirectional problem, we can dispense with vector notation. In this scenario, for constant mass, Newton's second law (Equation 4.3) reads $F_{\text{net}} = ma$, where the $m = m_\text{r} + m_\text{c}$ is the mass of the rat m_r plus the mass of the cage $m_\text{c} = 0.320$ kg, and $F_{\text{net}} = 0.46$ N. Use this formula to find the mass of the cage and the rat, then take the difference to find the mass of the rat.

EVALUATE Inserting the given quantities into Newton's second law gives

$$F_{\text{net}} = ma = (m_\text{r} + m_\text{c})a$$
$$m_\text{r} = \frac{F_{\text{net}}}{a} - m_\text{c} = \frac{0.46 \text{ N}}{0.40 \text{ m/s}^2} - 0.32 \text{ kg} = \quad 0.83 \text{ kg} = 830 \text{ g}$$

ASSESS A mass of 830 g corresponds to 1.8 lbs on the surface of the Earth. This is a fairly large rat!

49. **INTERPRET** This is a one-dimensional, unidirectional problem that involves Newton's second law, Hooke's law, and kinematics. We are asked to find the distance traveled by the car in 1 min, given the information necessary to find the acceleration of the car.

DEVELOP We must assume that the rope is taught when the truck and car begin to move. Furthermore, because this is unidirectional problem, we will dispense with vector notation. From Hooke's law (Equation 4.9), we know that the elastic towrope exerts a force on the car of magnitude $F_{\text{sp}} = |-kx|$, where $k = 1300$ N/m and $x = 55$ cm = 0.55 m. Insert this force into Newton's second law to find the acceleration of the car (with mass = 1900 kg). Next, use the kinematic Equation 2.10 for constant acceleration, $x = x_0 + v_0 t + at^2/2$, with $v_0 = 0$ and $t = 1$ min = 60 s to find the distance $x - x_0$ traveled by the car.

EVALUATE From Newton's second law, the acceleration of the car is

$$F_{\text{net}} = F_{sp} = |-kx| = ma$$
$$a = \frac{|-kx|}{m} = \frac{(1300 \text{ N/m})(0.55 \text{ m})}{1900 \text{ kg}} = 0.376 \text{ m/s}^2$$

The distance traveled is therefore

$$x - x_0 = \overbrace{v_0}^{=0} t + \frac{1}{2}at^2 = \frac{(0.376 \text{ m/s}^2)(60 \text{ s})^2}{2} = 680 \text{ m}$$

ASSESS If the towrope is not taught at $t = 0$ s, then the car will undergo a non-constant acceleration until the rope becomes taught (because the towrope will be supplying a time-varying force as it stretches). Because we do not have information regarding this period of non-constant acceleration, we are obliged to disregard it and assume that the rope is taught at $t = 0$ s.

50. **INTERPRET** This problem involves applying Newton's second law and Hooke's law to a spring that connects two blocks, with a given force applied to one of the blocks. We are asked to find distortion of the spring.

DEVELOP Given the spring force F_{sp} and the spring constant *k*, the length stretched can be calculated by using Hooke's law in Equation 4.9: $F_{\text{sp}} = -kx$ (the negative sign means that the spring force opposes the distortion). The spring stretches until the acceleration of both masses is the same.

EVALUATE The magnitude of the spring tension is given by Hooke's law, $F_{\text{sp}} = k\,|x|$, where $|x|$ is the stretch of the spring. The horizontal component of Newton's second law applied to each mass gives

$$F_{\text{net}}^{(1)} = F_{\text{app}} - F_{\text{sp}} = m_3 a$$
$$F_{\text{net}}^{(2)} = F_{\text{sp}} = m_2 a$$

as indicated in the sketch below. Adding these two equations, the acceleration of the entire system is

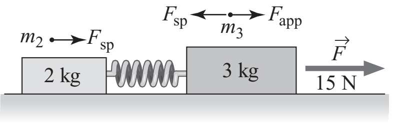
$$a = \frac{F_{\text{app}}}{m_2 + m_3} = \frac{15\text{ N}}{2.0\,\text{kg} + 3.0\,\text{kg}} = 3.0\text{ m/s}^2$$

The spring force is therefore

$$F_{\text{sp}} = m_2 a = (2.0\,\text{kg})(3.0\text{ m/s}^2) = 6.0\text{ N}$$

Applying Hooke's law, the spring stretches a distance

$$|x| = \frac{F_{\text{sp}}}{k} = \frac{6.0\text{ N}}{140\text{ N/m}} = 0.0429\text{ m} = 4.3\text{ cm}$$



ASSESS The spring force may be rewritten as

$$F_{\text{sp}} = m_2 a = \left(\frac{m_2}{m_2 + m_3}\right) F_{\text{app}}$$

In the limit that $m_2 \gg m_3$, $F_{\text{sp}} \approx F_{\text{app}}$. Conversely, if the mass m_2 is negligible, then $F_{\text{sp}} \approx 0$, as expected.

51. **INTERPRET** The problem asks us to determine the crumple zone of a car, in order to keep the stopping force on a passenger below a given value.

DEVELOP We can think of the crumple zone as the distance, Δx, the car and its passengers continue to travel as they go from the initial speed to zero. We can use Equation 2.11 to relate this distance to the deceleration of the car,

$$v^2 = 0 = v_0^2 - 2a\Delta x$$

Note that we have included a negative sign, so that *a* is a positive quantity. Using Equation 4.3, we can derive a limit on the crumple zone from the requirement that the force on the passenger must be less than 20 times his/her weight:

$$F \le 20F_g \quad \rightarrow \quad a \le 20g$$

EVALUATE The crumple zone is the distance during the crash over which the car comes to rest, so $\Delta x = v_0^2/2a$. Using the limit on the acceleration, the crumple zone must be at least

$$\Delta x = \frac{v_0^2}{2a} \ge \frac{v_0^2}{2(20g)} = \frac{(70\text{ km/h})^2}{40(9.8\text{ m/s}^2)} = 0.96\text{ m}$$

ASSESS This says the car would have to crumple by almost a meter. That's quite a bit, but the pictures of cars in high-speed collisions seem to imply that modern cars can compress by this much.

52. **INTERPRET** This is an application of Newton's 2nd law.

DEVELOP We're given the acceleration of the frog tongue and its mass, so the force needed is just $F = ma$.

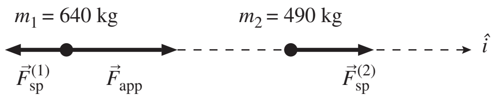
EVALUATE Plugging in the given values

$$F = ma = \left(500\times10^{-6}\,\text{kg}\right)\left(250\ \text{m/s}^2\right) = 0.13\ \text{N}$$

ASSESS This is a reasonable amount of force to expect from a frog. The acceleration is so large because the frog's tongue has such a small mass.

53. **INTERPRET** This problem involves applying Hooke's law to a spring and applying Newton's second law to the two-block system that is connected by the spring. We are asked to find the horizontal force applied to the system given the compression of the spring.

DEVELOP Make a free-body diagram of the situation (see figure below). Because the problem is one-dimensional, we will forego the vector notation until the end. From Hooke's law (Equation 4.9) we know that the magnitude of the force exerted on each block by the spring is $F_{sp} = k|x|$, where k = 8.1 kN = 8100 N and $|x|$ = 5.1 cm = 0.051 m. Apply Newton's second law to both blocks and solve for the applied force.



EVALUATE Applying Newton's second law to both blocks gives

$$F_{net}^{(1)} = F_{app} - F_{sp} = m_1 a$$
$$F_{net}^{(2)} = F_{sp} = m_2 a$$

Solving this, with the help of Hooke's law, for the applied force gives

$$F_{app} = F_{sp} + m_1\left(\frac{F_{sp}}{m_2}\right) = k|x|\left(\frac{m_1 + m_2}{m_2}\right) = (8100\ \text{N/m})(0.051\ \text{m})\left(\frac{640\ \text{m} + 490\ \text{m}}{490\ \text{m}}\right) = 950\ \text{N}$$

This force is applied in the direction indicated in the free-boy diagram, so $\vec{F}_{app} = (950\ \text{N})\hat{i}$.

ASSESS Does the result make sense in the limiting situations? Letting $m_2 = m_1$ gives $F_{app} = 2F_{sp}$, which makes sense because the applied force has to accelerate both blocks, whereas the spring only accelerates a single block. If $m_2 \to 0$, then from equations above resulting from Newton's second law, we see that $F_{app} = m_1 a$, as expected. Finally, if $m_2 \gg m_1$, then $F_{app} = F_{sp} = m_2 a$, which is reasonable if m_1 is very small.

54. **INTERPRET** The problem involves finding the force exerted on the air by the blade of a helicopter under various conditions. The key concept involved here is Newton's third law.

DEVELOP We're asked for the force that the helicopter exerts on the air, $F_{h\to a}$. But by Newton's third law, this is equal and opposite to the force that the air exerts on the helicopter, $F_{a\to h}$, which is an upward force called the engine's thrust. If we neglect air resistance, the thrust and gravity are the only vertical forces acting on the helicopter, so Newton's second law for the helicopter (positive component up) is: $F_{a\to h} - mg = ma$. Therefore, the helicopter exerts a downward force on the air of

$$F_{h\to a} = -F_{a\to h} = -m(g + a)$$

We'll guard the negative sign to remind us that this force is downward.

EVALUATE (a) Hovering means zero acceleration, $a = 0$ (also $v = 0$, but the velocity doesn't enter the equation of motion if air resistance is neglected). Therefore, the downward force on the air is

$$F_{h\to a} = -mg = -(4300\ \text{kg})(9.8\ \text{m/s}^2) = -42\ \text{kN}$$

(b) If v is decreasing downward, then the acceleration must be $a = 3.2\ \text{m/s}^2$ upward, and

$$F_{h\to a} = -m(g + a) = -(4300\ \text{kg})(9.8\ \text{m/s}^2 + 3.2\ \text{m/s}^2) = -56\ \text{kN}$$

(c) In this case, the acceleration a is the same as in part (b), $a = 3.2\ \text{m/s}^2$ upward, so $F_{h\to a} = -56\ \text{kN}$ as before.

(d) If the speed v is constant, then $a = 0$ as the hovering case in part (a), so $F_{h\to a} = -42\ \text{kN}$ as before.

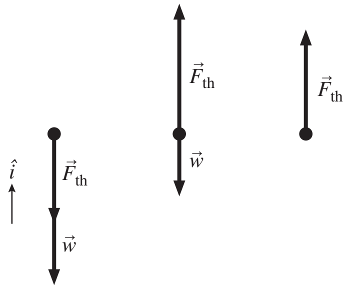
(e) If v is decreasing upward, then the acceleration points downward: $a = -3.2\ \text{m/s}^2$, and

$$F_{\text{h}\to\text{a}} = -m(g+a) = -(4300\text{ kg})(9.8\text{ m/s}^2 - 3.2\text{ m/s}^2) = -28\text{ kN}$$

Assess The thrust force from the engine is greatest when the helicopter is either moving upward and accelerating, or moving downward and decelerating. In this case, the magnitude of the force exerted on the air is also the greatest, by Newton's third law.

55. **Interpret** This problem involves applying Newton's second law to the spacecraft to find the thrust force required to achieve the various accelerations.

Develop Draw free-body diagrams of the different situations (see figure below), and apply Newton's second law in each situation to find the requisite thrust. Note that the positive-*x* direction is upward away from the surface of the Earth. For parts (a) and (b), the weight of the rocket is $w = mg$ (see Equation 4.5). For part (c), the weight of the rocket is $w = 0$ because the rocket is in a zero-gravity environment.



Evaluate (**a**) For the rocket accelerating toward the Earth, Newton's second law gives

$$\vec{F}_{\text{net}} = \vec{w} + \vec{F}_{\text{th}} = m\vec{a}$$
$$\vec{F}_{\text{th}} = m\vec{a} - \vec{w} = m\vec{a} - (-mg)\hat{i} = m(\vec{a} + g\hat{i})$$

for this part, $\vec{a} = (-1.40g)\hat{i}$, so

$$\vec{F}_{\text{th}} = m(-1.40g + g)\hat{i} = (-0.40mg)\hat{i}$$

(**b**) For this part, $\vec{a} = (1.40g)\hat{i}$, so

$$\vec{F}_{\text{th}} = m(1.40g + g)\hat{i} = (2.40mg)\hat{i}$$

(**c**) For this part, $w = 0$ and $\vec{a} = 1.40g\hat{i}$, so

$$\vec{F}_{\text{th}} = m\vec{a} = (1.40mg)\hat{i}$$

Assess Notice that for part (c), the direction of the acceleration is in the direction of the force, because there are no other forces (i.e., gravity) to modify the direction of the acceleration. Therefore, the choice of $\hat{i}$ as the direction of the force is arbitrary. To be completely general, we could have written

$$F_{th} = (1.40mg)\frac{\vec{F}_{th}}{F_{th}}$$

where the last factor is simply the unit vector in the direction of the thrust force.

56. **Interpret** You are asked to find out how many passengers an elevator can accommodate within the guideline of safety standards. The forces involved here are the downward gravitational force $\vec{F}_g$ and the upward cable tension $\vec{T}$.

Develop Assume that the only forces involved are $\vec{F}_g$ and $\vec{T}$ in the vertical direction. Newton's second law gives $\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g = M\vec{a}$, where *M* is the total mass of the elevator and its passengers. Taking +*y* to point upward, the equation in component form is $T - Mg = Ma_y$, which implies the total mass is

$$T = M(g + a_y)$$

The tension is greatest when the elevator is accelerating upward ($a_y > 0$).

Evaluate For safety's sake, we require that

$$T \le \tfrac{2}{3}T_{\max} = \frac{2}{3}(19.5\text{ kN}) = 13.0\text{ kN}$$

Assuming the elevator is accelerating upward at its maximum rate ($a_y = 2.24\text{ m/s}^2$), the total mass is limited to

$$M = \frac{T}{g + a_y} \le \frac{13.0\text{ kN}}{9.8\text{ m/s}^2 + 2.24\text{ m/s}^2} = 1080\,\text{kg}$$

Subtracting the mass of the elevator (490 kg), the maximum load in terms of kg and 70-kg passengers is:

$$\text{Max load} = 1080\text{ kg} - 490\text{ kg} = 590\text{ kg}$$

$$= 590\text{ kg}\left(\frac{\text{person}}{70\text{ kg}}\right) = 8\text{ persons}$$

Assess An elevator that accommodates 8 passengers, with a total mass of 590 kg sounds reasonable. Many passenger elevators, depending on their size, can accommodate up to about 2500 kg.

57. **Interpret** We're asked if the thrust from these planes' engines could overcome the weight of the planes. We assume the planes are pointed straight up and then calculate the net force.

Develop If the planes were trying to fly upwards (like rockets) their wings would not giving them any lift, so the net force would be:

$$F_{\text{net}} = F_{\text{thrust}} - F_g = ma$$

Evaluate Starting with the F-16:

$$F_{\text{net}} = 132\text{ kN} - \left(12\times10^3\text{kg}\right)\left(9.8\text{ m/s}^2\right) = 14.4\text{ kN}$$

As this is positive, the F-16 can climb vertically at an acceleration of

$$a = \frac{F_{\text{net}}}{m} = \frac{14.4\text{ kN}}{12\times10^3\text{kg}} = 1.2\text{ m/s}^2$$

Now for the A-380:

$$F_{\text{net}} = 1.5\text{ MN} - \left(560\times10^3\text{kg}\right)\left(9.8\text{ m/s}^2\right) = -3.99\text{ MN}$$

The negative sign here means that A-380 would fall if it didn't have the lift from its wings.

Assess You might have guessed that a fighter can climb straight up, whereas a commercial jet liner cannot.

58. **Interpret** This problem involves using Hooke's law to compute the total force exerted by two springs (of spring constants k_1 and k_2) that are connected side-by-side or end-to-end.

Develop For two springs connected side-by-side (in "parallel"), $F_{\text{Tot}} = F_1 + F_2$ and $x = x_1 = x_2$ where F_{Tot} and x are the (magnitude of the) force and the stretch of the spring combination, and subscripts 1 and 2 refer to the individual springs. When the springs are connected end-to-end (in "series"), the tension is the same in both springs, so $F_{\text{Tot}} = F_1 = F_2$ (true for "massless" springs), whereas the total stretch of the two springs is the sum of the stretch of each individual spring; $x = x_1 + x_2$.

Evaluate **(a)** For the "parallel" combination, Hooke's law gives $F_1 = k_1 x_1$ and $F_2 = k_2 x_2$. Therefore, the total force is $F_{\text{Tot}} = k_1 x_1 + k_2 x_2 = (k_1 + k_2)x$.

(b) For the "series" combination, Hooke's law gives

$$x = x_1 + x_2 = \frac{F_1}{k_1} + \frac{F_2}{k_2} = F_{\text{Tot}}\left(\frac{1}{k_1} + \frac{1}{k_2}\right) = F_{\text{Tot}}\left(\frac{k_1 + k_2}{k_1 k_2}\right)$$

$$F_{\text{Tot}} = \left(\frac{k_1 k_2}{k_1 + k_2}\right)x$$

Assess For a system with many springs, we may define an effective spring constant as $k_{\text{eff}} = F_{\text{Tot}}/x$. In the parallel case, we have $k_p = k_1 + k_2$, whereas in the series case, $k_s = k_1 k_2/(k_1 + k_2)$. Common experience tells us that the parallel combination is stiffer than the series combination, and thus requires a greater amount of force to stretch by the same amount. One can readily see this by considering the simple case where $k_1 = k_2 = k$. The above formulae give $k_p = 2k$ and $k_s = k/2$.

59. **INTERPRET** This problem is an exercise in calculus to derive a more general form of Newton's second law for one-dimensional situations.

DEVELOP From Appendix A, we see that the derivative of a product, $d(ab)/dt = a(db/dt) + b(da/dt)$. Apply this rule to Newton's second law, with $a = m$ and $b = v$.

EVALUATE Using the product rule, Newton's second law for one-dimensional situations is

$$F_{\text{net}} = \frac{d}{dt}(mv) = m\overbrace{\frac{dv}{dt}}^{\equiv a} + v\frac{dm}{dt} = ma + v\frac{dm}{dt}$$

where we have used Equation 2.5, a = dv/dt, which defines the instantaneous acceleration.

ASSESS The result shows clearly that if the mass is constant in time, $F = ma$, which is the usual form of Newton's second law.

60. **INTERPRET** This problem involves Newton's second law, in its most general form, to find the force necessary to keep a constant velocity while mass changes. We must find the force applied by the engine on the railroad car as the mass of the railroad car changes.

DEVELOP We use the result of Problem 59: $F = ma + v\frac{dm}{dt}$. The velocity v is a constant 2.0 m/s, so the acceleration is $a = 0$. The car gains mass at a rate of $\frac{dm}{dt} = 450$ kg/s.

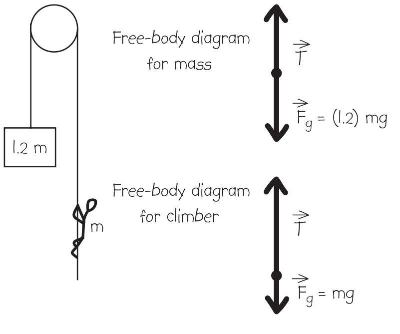
EVALUATE Inserting the given quantities into the general form of Newton's second law gives

$$F = \overbrace{ma}^{=0} + v\frac{dm}{dt} = (2.0\ \text{m/s})(250\ \text{kg/s}) = 500\ \text{N}$$

ASSESS Note that no force is required to keep the railroad car itself moving: The *ma* term is zero. This 500-N force is the force needed to accelerate the grain so that it is moving at the same speed as the car.

61. **INTERPRET** This problem involves Newton's second law. We are asked to find the upward acceleration you must have to keep a mass on the other side of the pulley from accelerating. Because the pulley is massless and frictionless, the tension on either side of the pulley is the same.

DEVELOP First draw free-body diagrams for the hanging mass and for the climber (see figure below). The mass is not accelerating, so the net force on it must be zero. The climber is accelerating, so the upwards tension force on the climber must be greater than the climber's weight. We set the tension on the climber's side equal to the tension on the mass side, and find the resulting acceleration of the climber from Newton's second law (for constant mass and for one dimension), $F = ma$.



EVALUATE The net force on the mass is zero, so $\vec{T} = -\vec{F}_g \Rightarrow T = 1.2mg$. The net force on the climber is $\vec{T} + \vec{F}_g = m\vec{a} \Rightarrow T - mg = ma \Rightarrow T = m(g+a)$. Setting the two tensions equal to each other gives

$$1.2mg = m(g+a)$$
$$1.2g = g + a$$
$$a = 0.2g = (0.2)(9.8\ \text{m/s}^2) = 1.96\ \text{m/s}^2$$

ASSESS This acceleration is 20% of g. The mass is 20% more than the mass of the climber. Makes sense, no?

62. **INTERPRET** This problem is similar to Example 4.5 in the text, except that here the mass is hanging from the spring rather than sitting on top of the spring.

DEVELOP We are asked to find the acceleration of the helicopter, but since the mass/spring device moves with the helicopter, the mass's acceleration will be the same as that of the helicopter. The net force on the mass is

$$F_{\text{net}} = F_{\text{spring}} - F_g = -k\Delta y - mg = ma$$

Note that Δy is the distance that the spring is stretched away from its equilibrium. In general this will be negative, as the spring is stretched downward.

EVALUATE The acceleration of the helicopter is

$$a = -\frac{k\Delta y}{m} - g$$

ASSESS Let's define Δy_{rest} as the displacement of the spring when the helicopter is at rest ($a = 0$): $\Delta y_{\text{rest}} = -mg/k$. Then we can rewrite the equation for the acceleration as

$$a = \frac{g\Delta y}{\Delta y_{\text{rest}}} - g = g\left(\frac{\Delta y}{\Delta y_{\text{rest}}} - 1\right)$$

If the spring is stretching more (i.e. further downward), then $|\Delta y| > |\Delta y_{\text{rest}}|$ and $a > 0$. In this case, the helicopter is accelerating upwards. The opposite argument can be made for downward acceleration.

63. **INTERPRET** We are asked to find the acceleration of your reference frame (the airplane) if objects falling with gravitational acceleration appear in your frame of reference to accelerate upward.

DEVELOP We choose a coordinate system where the positive-y direction is upward. Because the pretzels are no longer supported by the tray, or anything else, we must conclude that they are accelerating downward at g. In your frame of reference (i.e., the airplane), they are accelerating upward at 2 m/s^2, so the airplane must be accelerating downward even faster than g. Consider the one-dimensional form of Equation 3.7, $v = v' + V$, where v is the velocity of the pretzel relative to the Earth, v' is the velocity of the pretzel relative to the airplane, and V is the velocity of the airplane relative to the Earth. Differentiating this equation with respect to time gives $a = a' + A$, where $a = -g$ is the acceleration of the pretzel relative to the Earth, $a' = 2.0$ m/s^2 is the acceleration of the pretzel relative to the airplane, and A is the acceleration of the airplane relative to the Earth.

EVALUATE From the equation of relative accelerations, we find that $-g = 2.0\ \text{m/s}^2 + A$, so $A = -g - 2.0\ \text{m/s}^2 = -11.8\ \text{m/s}^2$, or a downward acceleration of 11.8 m/s^2.

ASSESS This is a downward acceleration that has a larger magnitude than g. That's what we expected.

64. **INTERPRET** We are asked to determine whether the stopping force of EMAS is enough to bring a jetliner to rest. This will require the second law and the equations of motion from Chapter 2.

DEVELOP The cement blocks provide a force that decelerates the jetliner by $a = F/m$. We know the initial velocity of the plane, so the minimum distance of the EMAS to bring the plane to rest ($v = 0$) is

$$\Delta x_{\text{min}} = v_0^2/2a$$

where we have used Equation 2.11. If the EMAS is longer than this, it will be able to stop the plane before it plows through all the blocks.

EVALUATE Solving for the minimum distance gives

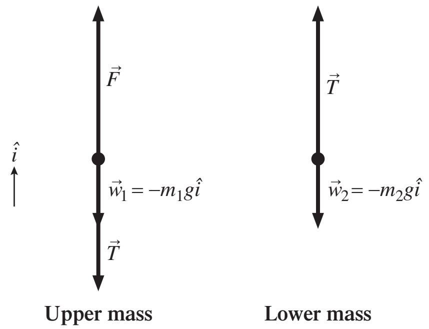
$$\Delta x_{\text{min}} = \frac{mv_0^2}{2F} = \frac{(55\times10^3\,\text{kg})(36\ \text{m/s})^2}{2(300\times10^3\,\text{N})} = 120\ \text{m}$$

Since the EMAS is 132 m long, the plane will stop with 12 m to spare.

ASSESS The plane's initial speed about 80 mi/h, so it seems reasonable that it would take 120 m of concrete blocks to stop the plane.

65. **INTERPRET** We are asked to find the masses, given accelerations and forces. There are two masses, so we'll solve a system of equations. Newton's second law applies.

DEVELOP Begin with a free-body diagram for each mass, as shown in the figure below. Because this is a one-dimensional problem, we will not use vector notation, but instead use negative values for downward vectors and positive values for upward vectors. Apply Newton's second law to both masses to obtain two equations. From these two equations, solve for the two masses, given that $T = 18$ N, $F = 30$ N, and $a = 3.2$ m/s^2.



EVALUATE For mass 1, $F_{\text{net}} = ma \quad \Rightarrow \quad F - T - w_1 = m_1 a$, so $F - T = m_1(g + a)$ Solving for m1 gives

$$m_1 = \frac{F - T}{g + a} = \frac{30\text{ N} - 18\text{ N}}{9.8\text{ m/s}^2 + 3.2\text{ m/s}^2} = 0.92\text{ kg}$$

Similarly for mass 2, $F_{\text{net}} = ma \quad \Rightarrow \quad T - w_2 = m_2 a \quad \Rightarrow \quad T = m_2(g + a)$

$$m_2 = \frac{T}{g + a} = \frac{18\text{ N}}{9.8\text{ m/s}^2 + 3.2\text{ m/s}^2} = 1.4\text{ kg}$$

ASSESS One way to check our result is to see what the acceleration of the total mass would be with an upward force of 30 N. Using Newton's second law, we find

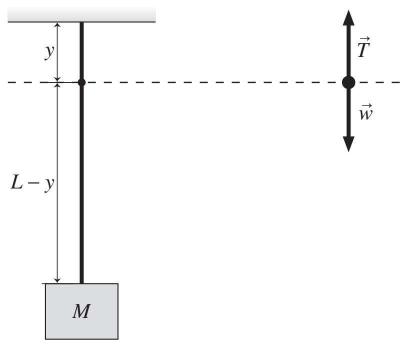
$$F - (m_1 + m_2)g = (m_1 + m_2)a$$

$$a = \frac{F}{m_1 + m_2} - g = \frac{30\text{ N}}{0.92\text{ kg} + 1.4\text{ kg}} - 9.8\text{ m/s}^2 = 3.2\text{ m/s}^2$$

as expected.

66. INTERPRET This is a one-dimensional problem involving Newton's second law. We are asked to find an equation describing the tension in a rope where the rope has a uniform mass per unit length. There is also a mass at the end of the rope. We need an equation in terms of y, where y is the distance measured downward from the support point and the rope has length L.

DEVELOP Because this is a one-dimensional problem, we will not use vector notation, but use negative values for downward vectors and positive values for upward vectors. Draw a schematic of the situation and a corresponding free-body diagram for an arbitrary point on the rope (see figure below). The mass of the rope below the arbitrary point is $m_{\text{below}} = m(L \bullet y)/L$, and the total mass below the arbitrary point is $M + m_{\text{below}}$. The weight hanging from the arbitrary point is therefore $w = (M + m_{\text{below}})g$. Apply Newton's second law to this arbitrary point and solve for the tension T of the rope, given that the acceleration of the point is $a = 0$ because it is stationary.



EVALUATE Applying Newton's second law to the arbitrary point gives

$$F_{\text{net}} = ma$$
$$T - w = 0$$
$$T = w = \left(M + m_{below}\right)g = Mg + mg\left(\frac{L-y}{L}\right)$$

ASSESS To check our answer, we consider some limiting cases. If $M = 0$ and $y = 0$, then the tension should be just the weight of the rope. Inserting these values into the equation above gives

$$T = \overbrace{Mg}^{=0} + mg\overbrace{\left(\frac{L-y}{L}\right)}^{=1} = mg$$

as expected. If the rope is massless, then $T = Mg$, which is also what we expect. Finally, if $y = L$, then $T = Mg$, which is also what we expect.

67. INTERPRET We're asked to calculate the amount of jerk on an amusement ride, where jerk is the rate of change in acceleration.
DEVELOP The word "rate" implies per time. The jerk is the time derivative of the acceleration. We're given an equation for the force, so the acceleration is just this divided by the mass, M, of the car and passengers.
EVALUATE The acceleration on the amusement ride is

$$a = \frac{F}{M} = \frac{F_0}{M}\sin\omega t$$

The jerk is the time derivative of this:

$$\frac{da}{dt} = \frac{F_0}{M}\omega\cos\omega t$$

The maximum value of the cosine is 1, so the maximum jerk is equal to $\omega F_0/M$.
ASSESS If the maximum jerk is too high, some of the passengers may suffer a whiplash.

68. INTERPRET You're asked to analyze data from an accelerometer in your laptop.
DEVELOP The two forces acting on the laptop are gravity (downwards) and the normal force (upwards) from your lap. The apparent weight is just this normal force, which from Newton's 2nd law is equal to: $n = m(g+a)$, assuming the positive direction is upwards.
EVALUATE The first sign of turbulence is at interval B. The apparent weight is greater than the true weight, so the acceleration is in the upward (positive) direction.
The answer is (a).
ASSESS If the plane suddenly goes upwards, everyone on the plane would feel glued to their seats. You and your laptop will feel increases in your apparent weights.

69. INTERPRET You're asked to analyze data from an accelerometer in your laptop.
DEVELOP The vertical acceleration is registered in how much the apparent weight diverges from the true weight.
EVALUATE The apparent weight differs the most from the true weight during interval B.
The answer is (a).
ASSESS The change in the weigh during interval D appears to be about half that during interval B.

70. INTERPRET You're asked to analyze data from an accelerometer in your laptop.
DEVELOP The apparent weight during interval C is just the true weight.
EVALUATE If $n = mg$, then the vertical acceleration must be zero, or to say it another way, the plane must be moving with constant vertical velocity.
The answer is (d).
ASSESS We might be tempted to think the plane has no vertical velocity (at rest with respect to level ground), but the plane can have zero vertical acceleration while still rising or falling steadily.

71. **INTERPRET** You're asked to analyze data from an accelerometer in your laptop.

DEVELOP The acceleration in terms of the apparent (n) and true (mg) weight is:

$$a = g\left(\frac{n}{mg} - 1\right)$$

EVALUATE During interval B, the apparent weight appears to be 5.5 lbs, so the acceleration is $0.1g \approx 1\ \text{m/s}^2$. The answer is (b).

ASSESS An acceleration of roughly 10% gravity seems reasonable. Compare this to the acceleration experienced by the astronaut in Problem 4.31.