5

The Laws of Motion

CHAPTER OUTLINE

5.1 The Concept of Force

5.2 Newton's First Law and Inertial Frames

5.3 Mass

5.4 Newton's Second Law

5.5 The Gravitational Force and Weight

5.6 Newton's Third Law

5.7 Analysis Models Using Newton's Second Law

5.8 Forces of Friction

* An asterisk indicates a question or problem new to this edition.

ANSWERS TO OBJECTIVE QUESTIONS

OQ5.1 Answer (d). The stopping distance will be the same if the mass of the truck is doubled. The normal force and the friction force both double, so the backward acceleration remains the same as without the load.

OQ5.2 Answer (b). Newton's 3rd law describes all objects, breaking or whole. The force that the locomotive exerted on the wall is the same as that exerted by the wall on the locomotive. The framing around the wall could not exert so strong a force on the section of the wall that broke out.

OQ5.3 Since they are on the order of a thousand times denser than the surrounding air, we assume the snowballs are in free fall. The net force on each is the gravitational force exerted by the Earth, which does not depend on their speed or direction of motion but only on the snowball mass. Thus we can rank the missiles just by mass: d > a = e > b > c.

OQ5.4 Answer (e). The stopping distance will decrease by a factor of four if the initial speed is cut in half.

OQ5.5 Answer (b). An air track or air table is a wonderful thing. It exactly cancels out the force of the Earth's gravity on the gliding object, to display free motion and to imitate the effect of being far away in space.

OQ5.6 Answer (b). 200 N must be greater than the force of friction for the box's acceleration to be forward.

OQ5.7 Answer (a). Assuming that the cord connecting m_1 and m_2 has constant length, the two masses are a fixed distance (measured along the cord) apart. Thus, their speeds must always be the same, which means that their accelerations must have equal magnitudes. The magnitude of the downward acceleration of m_2 is given by Newton's second law as

$$a_2 = \frac{\sum F_y}{m_2} = \frac{m_2 g - T}{m_2} = g - \left(\frac{T}{m_2}\right) < g$$

where T is the tension in the cord, and downward has been chosen as the positive direction.

OQ5.8 Answer (d). Formulas a, b, and e have the wrong units for speed. Formulas a and c would give an imaginary answer.

OQ5.9 Answer (b). As the trailer leaks sand at a constant rate, the total mass of the vehicle (truck, trailer, and remaining sand) decreases at a steady rate. Then, with a constant net force present, Newton's second law states that the magnitude of the vehicle's acceleration ($a = F_{net}/m$) will *steadily increase*.

OQ5.10 Answer (c). When the truck accelerates forward, the crate has the natural tendency to remain at rest, so the truck tends to slip under the crate, leaving it behind. However, friction between the crate and the bed of the truck acts in such a manner as to oppose this relative motion between truck and crate. Thus, the friction force acting on the crate will be in the forward horizontal direction and tend to accelerate the crate forward. The crate will slide only when the coefficient of static friction is inadequate to prevent slipping.

OQ5.11 Both answers (d) and (e) are *not true*: (d) is not true because the value of the velocity's constant magnitude need not be zero, and (e) is not true because there may be *no force* acting on the object. An object in equilibrium has zero acceleration $(\vec{\mathbf{a}} = 0)$, so both the magnitude and direction of the object's velocity must be *constant*. Also, Newton's second law states that the *net force* acting on an object in equilibrium is zero.

OQ5.12 Answer (d). All the other possibilities would make the total force on the crate be different from zero.

OQ5.13 Answers (a), (c), and (d). A free-body diagram shows the forces exerted on the object by other objects, and the net force is the sum of those forces.

ANSWERS TO CONCEPTUAL QUESTIONS

CQ5.1 A portion of each leaf of grass extends above the metal bar. This portion must accelerate in order for the leaf to bend out of the way. If the bar moves fast enough, the grass will not have time to increase its speed to match the speed of the bar. The leaf's mass is small, but when its acceleration is very large, the force exerted by the bar on the leaf puts the leaf under tension large enough to shear it off.

CQ5.2 When the hands are shaken, there is a large acceleration of the surfaces of the hands. If the water drops were to stay on the hands, they must accelerate along with the hands. The only force that can provide this acceleration is the friction force between the water and the hands. (There are adhesive forces also, but let's not worry about those.) The static friction force is not large enough to keep the water stationary with respect to the skin at this large acceleration. Therefore, the water breaks free and slides along the skin surface. Eventually, the water reaches the end of a finger and then slides off into the air. This is an example of Newton's first law in action in that the drops continue in motion while the hand is stopped.

CQ5.3 When the bus starts moving, the mass of Claudette is accelerated by the force of the back of the seat on her body. Clark is standing, however, and the only force on him is the friction between his shoes and the floor of the bus. Thus, when the bus starts moving, his feet start accelerating forward, but the rest of his body experiences almost no accelerating force (only that due to his being attached to his accelerating feet!). As a consequence, his body tends to stay almost at rest, according to Newton's first law, relative to the ground. Relative to Claudette, however, he is moving toward her and falls into her lap.

CQ5.4 The resultant force is zero, as the acceleration is zero.

CQ5.5 First ask, "Was the bus moving forward or backing up?" If it was moving forward, the passenger is lying. A fast stop would make the suitcase fly toward the front of the bus, not toward the rear. If the bus was backing up at any reasonable speed, a sudden stop could not make a suitcase fly far. Fine her for malicious litigiousness.

CQ5.6 Many individuals have a misconception that throwing a ball in the air gives the ball some kind of a "force of motion" that the ball carries after it leaves the hand. This is the "force of the throw" that is mentioned in the problem. The upward motion of the ball is explained by saying that the "force of the throw" exceeds the gravitational force—of course, this explanation confuses upward velocity with downward acceleration—the hand applies a force on the ball *only* while they are in contact; once the ball leaves the hand, the hand no longer has any influence on the ball's motion. The *only* property of the ball that it carries from its interaction with the hand is the *initial* upward velocity imparted to it by the thrower. Once the ball leaves the hand, the only force on the ball is the gravitational force. (a) If there were a "force of the throw" felt by the ball after it leaves the hand and the force exceeded the gravitational force, the ball would accelerate upward, not downward! (b) If the "force of the throw" equaled the gravitational force, the ball would move upward with a constant velocity, rather than slowing down and coming back down! (c) The magnitude is zero because there is no "force of the throw." (d) The ball moves away from the hand because the hand imparts a velocity to the ball and then the hand stops moving.

CQ5.7 (a) force: The *Earth* attracts the *ball* <u>downward</u> with the force of gravity—reaction force: the *ball* attracts the *Earth* <u>upward</u> with the force of gravity; force: the *hand* pushes <u>up</u> on the *ball*—reaction force: the *ball* pushes <u>down</u> on the *hand*.

(b) force: The *Earth* attracts the *ball* <u>downward</u> with the force of gravity—reaction force: the *ball* attracts the *Earth* <u>upward</u> with the force of gravity.

CQ5.8 (a) The air inside pushes outward on each patch of rubber, exerting a force perpendicular to that section of area. The air outside pushes perpendicularly inward, but not quite so strongly. (b) As the balloon takes off, all of the sections of rubber feel essentially the same outward forces as before, but the now-open hole at the opening on the west side feels no force – except for a small amount of drag to the west from the escaping air. The vector sum of the forces on the rubber is to the east.

The small-mass balloon moves east with a large acceleration. (c) Hot combustion products in the combustion chamber push outward on all the walls of the chamber, but there is nothing for them to push on at the open rocket nozzle. The net force exerted by the gases on the chamber is up if the nozzle is pointing down. This force is larger than the gravitational force on the rocket body, and makes it accelerate upward.

CQ5.9 The molecules of the floor resist the ball on impact and push the ball back, upward. The actual force acting is due to the forces between molecules that allow the floor to keep its integrity and to prevent the ball from passing through. Notice that for a ball passing through a window, the molecular forces weren't strong enough.

CQ5.10 The tension in the rope when pulling the car is twice that in the tug-of-war. One could consider the car as behaving like another team of twenty more people.

CQ5.11 An object cannot exert a force on itself, so as to cause acceleration. If it could, then objects would be able to accelerate themselves, without interacting with the environment. You cannot lift yourself by tugging on your bootstraps.

CQ5.12 Yes. The table bends down more to exert a larger upward force. The deformation is easy to see for a block of foam plastic. The sag of a table can be displayed with, for example, an optical lever.

CQ5.13 As the barbell goes through the bottom of a cycle, the lifter exerts an upward force on it, and the scale reads the larger upward force that the floor exerts on them together. Around the top of the weight's motion, the scale reads less than average. If the weightlifter throws the barbell upward so that it loses contact with his hands, the reading on the scale will return to normal, reading just the weight of the weightlifter, until the barbell lands back in his hands, at which time the reading will jump upward.

CQ5.14 The sack of sand moves up with the athlete, regardless of how quickly the athlete climbs. Since the athlete and the sack of sand have the same weight, the acceleration of the system must be zero.

CQ5.15 If you slam on the brakes, your tires will skid on the road. The force of kinetic friction between the tires and the road is less than the maximum static friction force. Antilock brakes work by "pumping" the brakes (much more rapidly than you can) to minimize skidding of the tires on the road.

CQ5.16 (a) Larger: the tension in A must accelerate two blocks and not just one. (b) Equal. Whenever A moves by 1 cm, B moves by 1 cm. The two blocks have equal speeds at every instant and have equal accelerations. (c) Yes, backward, equal. The force of cord B on block 1 is the tension in the cord.

CQ5.17 As you pull away from a stoplight, friction exerted by the ground on the tires of the car accelerates the car forward. As you begin running forward from rest, friction exerted by the floor on your shoes causes your acceleration.

CQ5.18 It is impossible to string a horizontal cable without its sagging a bit. Since the cable has a mass, gravity pulls it downward. A vertical component of the tension must balance the weight for the cable to be in equilibrium. If the cable were completely horizontal, then there would be no vertical component of the tension to balance the weight. If a physicist would testify in court, the city employees would win.

CQ5.19 (a) Yes, as exerted by a vertical wall on a ladder leaning against it. (b) Yes, as exerted by a hammer driving a tent stake into the ground. (c) Yes, as the ball accelerates upward in bouncing from the floor. (d) No; the two forces describe the same interaction.

CQ5.20 The clever boy bends his knees to lower his body, then starts to straighten his knees to push his body up—that is when the branch breaks. In order to give himself an upward acceleration, he must push down on the branch with a force greater than his weight so that the branch pushes up on him with a force greater than his weight.

CQ5.21 (a) As a man takes a step, the action is the force his foot exerts on the Earth; the reaction is the force of the Earth on his foot. (b) The action is the force exerted on the girl's back by the snowball; the reaction is the force exerted on the snowball by the girl's back. (c) The action is the force of the glove on the ball; the reaction is the force of the ball on the glove. (d) The action is the force exerted on the window by the air molecules; the reaction is the force on the air molecules exerted by the window. We could in each case interchange the terms "action" and "reaction."

CQ5.22 (a) Both students slide toward each other. When student A pulls on the rope, the rope pulls back, causing her to slide toward Student B. The rope also pulls on the pulley, so Student B slides because he is gripping a rope attached to the pulley. (b) Both chairs slide because there is tension in the rope that pulls on both Student A and the pulley connected to Student B. (c) Both chairs slide because when Student B pulls on his rope, he pulls the pulley which puts tension into the rope passing over the pulley to Student A. (d) Both chairs slide because when Student A pulls on the rope, it pulls on her and also pulls on the pulley.

CQ5.23 If you have ever seen a car stuck on an icy road, with its wheels spinning wildly, you know the car has great difficulty moving forward until it "catches" on a rough patch. (a) Friction exerted by the road is the force making the car accelerate forward. Burning gasoline can provide energy for the motion, but only external forces—forces exerted by objects outside—can accelerate the car. (b) If the car moves forward slowly as it speeds up, then its tires do not slip on the surface. The rubber contacting the road moves toward the rear of the car, and static friction opposes relative sliding motion by exerting a force on the rubber toward the front of the car. If the car is under control (and not skidding), the relative speed is zero along the lines where the rubber meets the road, and static friction acts rather than kinetic friction.

SOLUTIONS TO END-OF-CHAPTER PROBLEMS

Section 5.1 The Concept of Force
Section 5.2 Newton's First Law and Inertial Frames
Section 5.3 Mass
Section 5.4 Newton's Second Law
Section 5.5 The Gravitational Force and Weight
Section 5.6 Newton's Third Law

***P5.1** (a) The woman's weight is the magnitude of the gravitational force acting on her, given by

$$F_g = mg = 120\text{ lb} = (4.448\text{ N/lb})(120\text{ lb}) = \boxed{534\text{ N}}$$

(b) Her mass is $m = \dfrac{F_g}{g} = \dfrac{534\text{ N}}{9.80\text{ m/s}^2} = \boxed{54.5\text{ kg}}$

***P5.2** We are given $F_g = mg = 900\text{ N}$, from which we can find the man's mass,

$$m = \frac{900\text{ N}}{9.80\text{ m/s}^2} = 91.8\text{ kg}$$

Then, his weight on Jupiter is given by

$$(F_g)_{\text{on Jupiter}} = 91.8\text{ kg}(25.9\text{ m/s}^2) = \boxed{2.38\text{ kN}}$$

P5.3 We use Newton's second law to find the force as a vector and then the Pythagorean theorem to find its magnitude. The givens are m = 3.00 kg and $\vec{\mathbf{a}} = \left(2.00\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}\right)$ m/s^2.

(a) The total vector force is

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}} = (3.00 \text{ kg})(2.00\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}) \text{ m/s}^2 = \boxed{(6.00\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}) \text{ N}}$$

(b) Its magnitude is

$$\left|\vec{\mathbf{F}}\right| = \sqrt{\left(F_x\right)^2 + \left(F_y\right)^2} = \sqrt{(6.00 \text{ N})^2 + (15.0 \text{ N})^2} = \boxed{16.2 \text{ N}}$$

P5.4 Using the reference axes shown in Figure P5.4, we see that

$$\sum F_x = T\cos 14.0° - T\cos 14.0° = 0$$

and

$$\sum F_y = -T\sin 14.0° - T\sin 14.0° = -2T\sin 14.0°$$

Thus, the magnitude of the resultant force exerted on the tooth by the wire brace is

$$R = \sqrt{\left(\sum F_x\right)^2 + \left(\sum F_y\right)^2} = \sqrt{0 + (-2T\sin 14.0°)^2} = 2T\sin 14.0°$$

or

$$R = 2(18.0 \text{ N})\sin 14.0° = \boxed{8.71 \text{ N}}$$

P5.5 We use the particle under constant acceleration and particle under a net force models. We first calculate the acceleration of the puck:

$$\vec{\mathbf{a}} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t} = \frac{\left(8.00\hat{\mathbf{i}} + 10.0\hat{\mathbf{j}}\right)\text{m/s} - 3.00\hat{\mathbf{i}} \text{ m/s}}{8.00 \text{ s}}$$
$$= 0.625\hat{\mathbf{i}} \text{ m/s}^2 + 1.25\hat{\mathbf{j}} \text{ m/s}^2$$

In $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$, the only horizontal force is the thrust $\vec{\mathbf{F}}$ of the rocket:

(a) $\vec{\mathbf{F}} = (4.00 \text{ kg})\left(0.625\hat{\mathbf{i}} \text{ m/s}^2 + 1.25\hat{\mathbf{j}} \text{ m/s}^2\right) = \boxed{\left(2.50\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}\right) \text{ N}}$

(b) Its magnitude is $\left|\vec{\mathbf{F}}\right| = \sqrt{(2.50 \text{ N})^2 + (5.00 \text{ N})^2} = \boxed{5.59 \text{ N}}$

P5.6 (a) Let the x axis be in the original direction of the molecule's motion. Then, from $v_f = v_i + at$, we have

$$a = \frac{v_f - v_i}{t} = \frac{-670 \text{ m/s} - 670 \text{ m/s}}{3.00 \times 10^{-13} \text{ s}} = \boxed{-4.47 \times 10^{15} \text{ m/s}^2}$$

(b) For the molecule, $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$. Its weight is negligible.

$$\vec{\mathbf{F}}_{\text{wall on molecule}} = \left(4.68 \times 10^{-26} \text{ kg}\right)\left(-4.47 \times 10^{15} \text{ m/s}^2\right)$$
$$= -2.09 \times 10^{-10} \text{ N}$$
$$\vec{\mathbf{F}}_{\text{molecule on wall}} = \boxed{+2.09 \times 10^{-10} \text{ N}}$$

***P5.7** Imagine a quick trip by jet, on which you do not visit the rest room and your perspiration is just canceled out by a glass of tomato juice. By subtraction, $\left(F_g\right)_p = mg_p$ and $\left(F_g\right)_C = mg_C$ give

$$\Delta F_g = m\left(g_p - g_C\right)$$

For a person whose mass is 90.0 kg, the change in weight is

$$\Delta F_g = 90.0 \text{ kg}\left(9.809\,5 - 9.780\,8\right) = \boxed{2.58 \text{ N}}$$

A precise balance scale, as in a doctor's office, reads the same in different locations because it compares you with the standard masses on its beams. A typical bathroom scale is not precise enough to reveal this difference.

P5.8 The force on the car is given by $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$, or, in one dimension, $\sum F = ma$. Whether the car is moving to the left or the right, since it's moving at constant speed, a = 0 and therefore $\sum F = \boxed{0}$ for both parts (a) and (b).

P5.9 We find the mass of the baseball from its weight: $w = mg$, so $m = w/g$ = 2.21 N/9.80 m/s^2 = 0.226 kg.

(a) We use $x_f = x_i + \frac{1}{2}(v_i + v_f)t$ and $x_f - x_i = \Delta x$, with $v_i = 0$, v_f = 18.0 m/s, and $\Delta t = t = 170 \text{ ms} = 0.170 \text{ s}$:

$$\Delta x = \frac{1}{2}(v_i + v_f)\Delta t$$
$$\Delta x = \frac{1}{2}(0 + 18.0 \text{ m/s})(0.170 \text{ s}) = \boxed{1.53 \text{ m}}$$

(b) We solve for acceleration using $v_{xf} = v_{xi} + a_x t$, which gives

$$a_x = \frac{v_{xf} - v_{xi}}{t}$$

where a is in m/s^2, v is in m/s, and t in s. Substituting gives

$$a_x = \frac{18.0 \text{ m/s} - 0}{0.170 \text{ s}} = 106 \text{ m/s}^2$$

Call $\vec{\mathbf{F}}_1$ = force of pitcher on ball, and $\vec{\mathbf{F}}_2$ = force of Earth on ball (weight). We know that

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \text{m}\vec{\mathbf{a}}$$

Writing this equation in terms of its components gives

$$\sum F_x = F_{1x} + F_{2x} = ma_x \qquad \sum F_y = F_{1y} + F_{2y} = ma_y$$

$$\sum F_x = F_{1x} + 0 = ma_x \qquad \sum F_y = F_{1y} - 2.21 \text{ N} = 0$$

Solving,

$$F_{1x} = (0.226 \text{ kg})(106 \text{ m/s}^2) = 23.9 \text{ N} \text{ and } F_{1y} = 2.21 \text{ N}$$

Then,

$$F_1 = \sqrt{(F_{1x})^2 + (F_{1y})^2}$$
$$= \sqrt{(23.9 \text{ N})^2 + (2.21 \text{ N})^2} = 24.0 \text{ N}$$

and $\theta = \tan^{-1}\left(\frac{2.21 \text{ N}}{23.9 \text{ N}}\right) = 5.29°$

The pitcher exerts a force of 24.0 N forward at 5.29° above the horizontal.

P5.10 (a) Use $\Delta x = \frac{1}{2}(v_i + v_f)\Delta t$, where $v_i = 0$, $v_f = v$, and $\Delta t = t$:

$$\Delta x = \frac{1}{2}(v_i + v_f)\Delta t = \boxed{\frac{1}{2} vt}$$

(b) Use $v_{xf} = v_{xi} + a_x t$:

$$v_{xf} = v_{xi} + a_x t \rightarrow a_x = \frac{v_{xf} - v_{xi}}{t} \rightarrow a_x = \frac{v - 0}{t} = \frac{v}{t}$$

Call $\vec{\mathbf{F}}_1$ = force of pitcher on ball, and $\vec{\mathbf{F}}_2 = -F_g = -mg =$ gravitational force on ball. We know that

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \mathrm{m}\vec{\mathbf{a}}$$

writing this equation in terms of its components gives

$$\sum F_x = F_{1x} + F_{2x} = ma_x \qquad \sum F_y = F_{1y} + F_{2y} = ma_y$$

$$\sum F_x = F_{1x} + 0 = ma_x \qquad \sum F_y = F_{1y} - mg = 0$$

Solving and substituting from above,

$$F_{1x} = mv/t \qquad F_{1y} = mg$$

then the magnitude of F_1 is

$$F_1 = \sqrt{(F_{1x})^2 + (F_{1y})^2}$$

$$= \sqrt{(mv/t)^2 + (mg)^2} = \boxed{m\sqrt{(v/t)^2 + g^2}}$$

and its direction is

$$\theta = \tan^{-1}\left(\frac{mg}{mv/t}\right) = \boxed{\tan^{-1}\left(\frac{gt}{v}\right)}$$

P5.11 Since this is a linear acceleration problem, we can use Newton's second law to find the force as long as the electron does not approach relativistic speeds (as long as its speed is much less than 3×10^8 m/s), which is certainly the case for this problem. We know the initial and final velocities, and the distance involved, so from these we can find the acceleration needed to determine the force.

(a) From $v_f^2 = v_i^2 + 2ax$ and $\sum F = ma$, we can solve for the acceleration and then the force: $a = \dfrac{v_f^2 - v_i^2}{2x}$

Substituting to eliminate a, $\sum F = \dfrac{m\left(v_f^2 - v_i^2\right)}{2x}$

Substituting the given information,

$$\sum F = \frac{\left(9.11 \times 10^{-31}\ \text{kg}\right)\left[\left(7.00 \times 10^5\ \text{m/s}\right)^2 - \left(3.00 \times 10^5\ \text{m/s}\right)^2\right]}{2(0.050\,0\ \text{m})}$$

$$\sum F = \boxed{3.64 \times 10^{-18}\ \text{N}}$$

(b) The Earth exerts on the electron the force called weight,

$$F_g = mg = (9.11 \times 10^{-31}\,\text{kg})(9.80\ \text{m/s}^2) = 8.93 \times 10^{-30}\,\text{N}$$

The accelerating force is

$$\boxed{4.08 \times 10^{11}\ \text{times the weight of the electron.}}$$

P5.12 We first find the acceleration of the object:

$$\vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i = \vec{\mathbf{v}}_i t + \frac{1}{2}\vec{\mathbf{a}}t^2$$

$$4.20\ \text{m}\hat{\mathbf{i}} - 3.30\ \text{m}\hat{\mathbf{j}} = 0 + \frac{1}{2}\vec{\mathbf{a}}(1.20\ \text{s})^2 = \left(0.720\ \text{s}^2\right)\vec{\mathbf{a}}$$

$$\vec{\mathbf{a}} = \left(5.83\hat{\mathbf{i}} - 4.58\hat{\mathbf{j}}\right)\ \text{m/s}^2$$

Now $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ becomes

$$\vec{\mathbf{F}}_g + \vec{\mathbf{F}}_2 = m\vec{\mathbf{a}}$$

$$\vec{\mathbf{F}}_2 = 2.80\ \text{kg}\left(5.83\hat{\mathbf{i}} - 4.58\hat{\mathbf{j}}\right)\ \text{m/s}^2 + \left(2.80\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)\hat{\mathbf{j}}$$

$$\vec{\mathbf{F}}_2 = \boxed{\left(16.3\hat{\mathbf{i}} + 14.6\hat{\mathbf{j}}\right)\ \text{N}}$$

P5.13 (a) Force exerted by spring on hand, to the left; force exerted by spring on wall, to the right.

(b) Force exerted by wagon on handle, downward to the left. Force exerted by wagon on planet, upward. Force exerted by wagon on ground, downward.

(c) Force exerted by football on player, downward to the right. Force exerted by football on planet, upward.

(d) Force exerted by small-mass object on large-mass object, to the left.

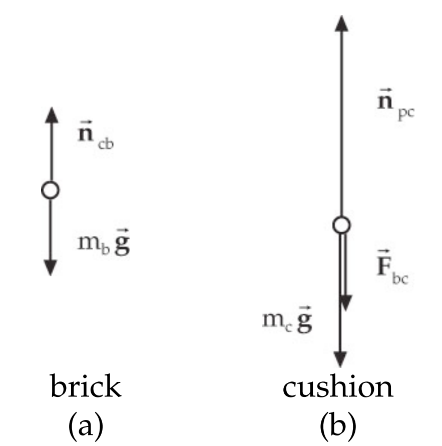
(e) Force exerted by negative charge on positive charge, to the left.

(f) Force exerted by iron on magnet, to the left.

P5.14 The free-body diagrams are shown in ANS. FIG. P5.14 below.

(a) $\vec{\mathbf{n}}_{cb}$ = normal force of cushion on brick
$m_b\vec{\mathbf{g}}$ = gravitational force on brick

(b) $\vec{\mathbf{n}}_{pc}$ = normal force of pavement on cushion
$m_b\vec{\mathbf{g}}$ = gravitational force on cushion
$\vec{\mathbf{F}}_{bc}$ = force of brick on cushion



ANS. FIG.P5.14

(c)

force: normal force of cushion on brick ($\vec{\mathbf{n}}_{cb}$) $\rightarrow$ reaction force: force of brick on cushion ($\vec{\mathbf{F}}_{bc}$) force: gravitational force of Earth on brick ($m_b\vec{\mathbf{g}}$) $\rightarrow$ reaction force: gravitational force of brick on Earth force: normal force of pavement on cushion ($\vec{\mathbf{n}}_{pc}$) $\rightarrow$ reaction force: force of cushion on pavement force: gravitational force of Earth on cushion ($m_c\vec{\mathbf{g}}$) $\rightarrow$ reaction force: gravitational force of cushion on Earth

***P5.15** (a) We start from the sum of the two forces:

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \left(-6.00\hat{\mathbf{i}} - 4.00\hat{\mathbf{j}}\right) + \left(-3.00\hat{\mathbf{i}} + 7.00\hat{\mathbf{j}}\right)$$
$$= \left(-9.00\hat{\mathbf{i}} + 3.00\hat{\mathbf{j}}\right)\text{ N}$$

The acceleration is then:

$$\vec{\mathbf{a}} = a_x\hat{\mathbf{i}} + a_y\hat{\mathbf{j}} = \frac{\sum \vec{\mathbf{F}}}{m} = \frac{\left(-9.00\hat{\mathbf{i}} + 3.00\hat{\mathbf{j}}\right)\text{ N}}{2.00\text{ kg}}$$
$$= \left(-4.50\hat{\mathbf{i}} + 1.50\hat{\mathbf{j}}\right)\text{ m/s}^2$$

and the velocity is found from

$$\vec{\mathbf{v}}_f = v_x\hat{\mathbf{i}} + v_y\hat{\mathbf{j}} = \vec{\mathbf{v}}_i + \vec{\mathbf{a}}t = \vec{\mathbf{a}}t$$

$$\vec{\mathbf{v}}_f = \left[\left(-4.50\hat{\mathbf{i}} + 1.50\hat{\mathbf{j}}\right)\text{ m/s}^2\right](10.0\text{ s})$$
$$= \boxed{\left(-45.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}\right)\text{ m/s}}$$

(b) The direction of motion makes angle θ with the x direction.

$$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(-\frac{15.0\text{ m/s}}{45.0\text{ m/s}}\right)$$

$$\theta = -18.4° + 180° = \boxed{162° \text{ from the } +x \text{ axis}}$$

(c) Displacement:

$$x\text{-displacement} = x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2$$

$$= \frac{1}{2}\left(-4.50\ \text{m/s}^2\right)(10.0\ \text{s})^2 = -225\ \text{m}$$

$$y\text{-displacement} = y_f - y_i = v_{yi}t + \frac{1}{2}a_y t^2$$

$$= \frac{1}{2}\left(+1.50\ \text{m/s}^2\right)(10.0\ \text{s})^2 = +75.0\ \text{m}$$

$$\Delta\vec{\mathbf{r}} = \boxed{\left(-225\hat{\mathbf{i}} + 75.0\hat{\mathbf{j}}\right)\ \text{m}}$$

(d) Position: $\vec{\mathbf{r}}_f = \vec{\mathbf{r}}_i + \Delta\vec{\mathbf{r}}$

$$\vec{\mathbf{r}}_f = \left(-2.00\hat{\mathbf{i}} + 4.00\hat{\mathbf{j}}\right) + \left(-225\hat{\mathbf{i}} + 75.0\hat{\mathbf{j}}\right) = \boxed{\left(-227\hat{\mathbf{i}} + 79.0\hat{\mathbf{j}}\right)\ \text{m}}$$

***P5.16** Since the two forces are perpendicular to each other, their resultant is

$$F_R = \sqrt{(180\ \text{N})^2 + (390\ \text{N})^2} = 430\ \text{N}$$

at an angle of

$$\theta = \tan^{-1}\left(\frac{390\ \text{N}}{180\ \text{N}}\right) = 65.2°\ \text{N of E}$$

From Newton's second law,

$$a = \frac{F_R}{m} = \frac{430\ \text{N}}{270\ \text{kg}} = 1.59\ \text{m/s}^2$$

or

$$\vec{\mathbf{a}} = \boxed{1.59\ \text{m/s}^2\ \text{at}\ 65.2°\ \text{N of E}}$$

P5.17 (a) With the wind force being horizontal, the only vertical force acting on the object is its own weight, mg. This gives the object a downward acceleration of

$$a_y = \frac{\sum F_y}{m} = \frac{-mg}{m} = -g$$

The time required to undergo a vertical displacement $\Delta y = -h$, starting with initial vertical velocity $v_{0y} = 0$, is found from $\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$ as

$$-h = 0 - \frac{g}{2}t^2 \qquad \text{or} \qquad \boxed{t = \sqrt{\frac{2h}{g}}}$$

(b) The only horizontal force acting on the object is that due to the wind, so $\sum F_x = F$ and the horizontal acceleration will be

$$a_x = \frac{\sum F_x}{m} = \boxed{\frac{F}{m}}$$

(c) With $v_{0x} = 0$, the horizontal displacement the object undergoes while falling a vertical distance h is given by $\Delta x = v_{ox}t + \frac{1}{2}a_x t^2$ as

$$\Delta x = 0 + \frac{1}{2}\left(\frac{F}{m}\right)\left(\sqrt{\frac{2h}{g}}\right)^2 = \boxed{\frac{Fh}{mg}}$$

(d) The total acceleration of this object while it is falling will be

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{(F/m)^2 + (-g)^2} = \boxed{\sqrt{(F/m)^2 + g^2}}$$

P5.18 For the same force F, acting on different masses $F = m_1a_1$ and $F = m_2a_2$. Setting these expressions for F equal to one another gives:

(a) $\frac{m_1}{m_2} = \frac{a_2}{a_1} = \boxed{\frac{1}{3}}$

(b) The acceleration of the combined object is found from

$$F = (m_1 + m_2)a = 4m_1a$$

or $$a = \frac{F}{4m_1} = \frac{1}{4}\left(3.00\ \text{m/s}^2\right) = \boxed{0.750\ \text{m/s}^2}$$

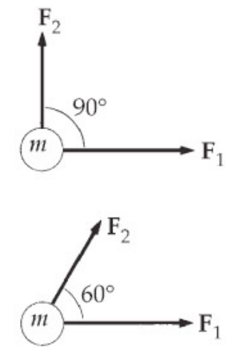
P5.19 We use the particle under a net force model and add the forces as vectors. Then Newton's second law tells us the acceleration.

(a) $\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = (20.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}})\text{ N}$

Newton's second law gives, with $m = 5.00$ kg,

$$\vec{\mathbf{a}} = \frac{\sum \vec{\mathbf{F}}}{m} = \left(4.00\hat{\mathbf{i}} + 3.00\hat{\mathbf{j}}\right)\text{ m/s}^2$$

or $\boxed{a = 5.00\text{ m/s}^2 \text{ at } \theta = 36.9°}$



ANS. FIG. P5.19

(b) In this configuration,

$$F_{2x} = 15.0\cos 60.0° = 7.50\text{ N}$$
$$F_{2y} = 15.0\sin 60.0° = 13.0\text{ N}$$
$$\vec{\mathbf{F}}_2 = \left(7.50\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\text{ N}$$

Then,

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \left[20.0\hat{\mathbf{i}} + \left(7.50\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\right]\text{ N}$$
$$= (27.5\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}})\text{ N}$$

and $\vec{\mathbf{a}} = \dfrac{\sum \vec{\mathbf{F}}}{m} = \left(5.50\hat{\mathbf{i}} + 2.60\hat{\mathbf{j}}\right)\text{ m/s}^2 = \boxed{6.08\text{ m/s}^2 \text{ at } 25.3°}$

P5.20 (a) You and the Earth exert equal forces on each other: $m_y g = M_E a_E$. If your mass is 70.0 kg,

$$a_E = \frac{(70.0\text{ kg})(9.80\text{ m/s}^2)}{5.98 \times 10^{24}\text{ kg}} = \boxed{\sim 10^{-22}\text{ m/s}^2} \qquad \textbf{[1]}$$

(b) You and the planet move for equal time intervals Δt according to $\Delta x = \frac{1}{2}a(\Delta t)^2$. If the seat is 50.0 cm high,

$$\sqrt{\frac{2\Delta x_y}{a_y}} = \sqrt{\frac{2\Delta x_E}{a_E}}$$

$$\Delta x_E = \frac{a_E}{a_y}\Delta x_y$$

We substitute for $\frac{a_E}{a_y}$ from [1] to obtain

$$\Delta x_E = \frac{70.0\ \text{kg}(0.500\ \text{m})}{5.98\times 10^{24}\ \text{kg}}$$

$$\boxed{\Delta x_E \sim 10^{-23}\ \text{m}}$$

P5.21 (a) $\boxed{15.0\ \text{lb up,}}$ to counterbalance the Earth's force on the block.

(b) $\boxed{5.00\ \text{lb up,}}$ the forces on the block are now the Earth pulling down with 15.0 lb and the rope pulling up with 10.0 lb. The forces from the floor and rope together balance the weight.

(c) $\boxed{0,}$ the block now accelerates up away from the floor.

P5.22 $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ reads

$$\left(-2.00\hat{\mathbf{i}} + 2.00\hat{\mathbf{j}} + 5.00\hat{\mathbf{i}} - 3.00\hat{\mathbf{j}} - 45.0\hat{\mathbf{i}}\right)\ \text{N} = m\left(3.75\ \text{m/s}^2\right)\hat{\mathbf{a}}$$

where $\hat{\mathbf{a}}$ represents the direction of $\vec{\mathbf{a}}$:

$$\left(-42.0\hat{\mathbf{i}} - 1.00\hat{\mathbf{j}}\right)\ \text{N} = m\left(3.75\ \text{m/s}^2\right)\hat{\mathbf{a}}$$

$$\sum \vec{\mathbf{F}} = \sqrt{(42.0)^2 + (1.00)^2}\ \text{N at } \tan^{-1}\left(\frac{1.00}{42.0}\right) \text{ below the } -x \text{ axis}$$

$$\sum \vec{\mathbf{F}} = 42.0\ \text{N at } 181° = m\left(3.75\ \text{m/s}^2\right)\hat{\mathbf{a}}$$

For the vectors to be equal, their magnitudes and their directions must be equal.

(a) Therefore $\boxed{\hat{\mathbf{a}} \text{ is at } 181°}$ counter-clockwise from the x axis

(b) $m = \frac{42.0\ \text{N}}{3.75\ \text{m/s}^2} = \boxed{11.2\ \text{kg}}$

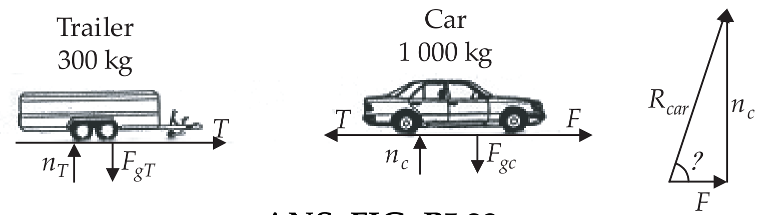
(c) $v = |\vec{\mathbf{v}}| = 0 + |\vec{\mathbf{a}}|t = (3.75\ \text{m/s}^2)(10.00\ \text{s}) = \boxed{37.5\ \text{m/s}}$

(d) $\vec{\mathbf{v}} = \vec{\mathbf{v}}_i + |\vec{\mathbf{a}}|\, t = 0 + \frac{\vec{\mathbf{F}}}{m} t$

$$\vec{\mathbf{v}} = \frac{\left(-42.0\hat{\mathbf{i}} - 1.00\hat{\mathbf{j}}\right)\text{ N}}{11.2\text{ kg}}(10.0\text{ s}) = \left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right)\text{ m/s}$$

So, $\vec{\mathbf{v}}_f = \boxed{\left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right)\text{ m/s}}$

* Choose the $+x$ direction to be horizontal and forward with the $+y$ vertical and upward. The common acceleration of the car and trailer then has components of $a_x = +2.15\text{ m/s}^2$ and $a_y = 0$.



ANS. FIG. P5.23

(a) The net force on the car is horizontal and given by

$$\left(\sum F_x\right)_{car} = F - T = m_{car}a_x = (1\,000\text{ kg})(2.15\text{ m/s}^2)$$
$$= \boxed{2.15 \times 10^3\text{ N forward}}$$

(b) The net force on the trailer is also horizontal and given by

$$\left(\sum F_x\right)_{trailer} = +T = m_{trailer}a_x = (300\text{ kg})(2.15\text{ m/s}^2)$$
$$= \boxed{645\text{ N forward}}$$

(c) Consider the free-body diagrams of the car and trailer. The only horizontal force acting on the trailer is T = 645 N forward, exerted on the trailer by the car. Newton's third law then states that the force the trailer exerts on the car is $\boxed{645\text{ N toward the rear}}$.

(d) The road exerts two forces on the car. These are F and n_c shown in the free-body diagram of the car. From part (a), $F = T + 2.15 \times 10^3\text{ N} = +2.80 \times 10^3\text{ N}$. Also, $\left(\sum F_y\right)_{car} = n_c - F_{gc} = m_{car}a_y = 0$, so $n_c = F_{gc} = m_{car}g = 9.80 \times 10^3\text{ N}$. The resultant force exerted on the car by the road is then

$$R_{car} = \sqrt{F^2 + n_c^2} = \sqrt{\left(2.80 \times 10^3\text{ N}\right)^2 + \left(9.80 \times 10^3\text{ N}\right)^2}$$
$$= 1.02 \times 10^4\text{ N}$$

at $\theta = \tan^{-1}\left(\frac{n_c}{F}\right) = \tan^{-1}(3.51) = 74.1°$ above the horizontal and forward. Newton's third law then states that the resultant force exerted on the road by the car is

$\boxed{1.02 \times 10^4 \text{ N at } 74.1° \text{ below the horizontal and rearward}}$.

P5.24 $v = v_i - kx$ implies the acceleration is given by

$$a = \frac{dv}{dt} = 0 - k\frac{dx}{dt} = -kv$$

Then the total force is

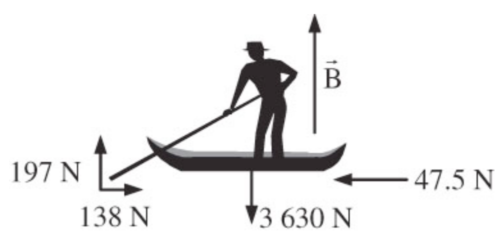
$$\sum F = ma = m(-kv)$$

The resistive force is opposite to the velocity:

$$\boxed{\sum \vec{\mathbf{F}} = -km\vec{\mathbf{v}}}$$

Section 5.7 Analysis Models Using Newton's Second Law

P5.25 As the worker through the pole exerts on the lake bottom a force of 240 N downward at 35° behind the vertical, the lake bottom through the pole exerts a force of 240 N upward at 35° ahead of the vertical. With the x axis horizontally forward, the pole force on the boat is



ANS. FIG. P5.25

$$\left(240\cos 35°\hat{\mathbf{j}} + 240\sin 35°\hat{\mathbf{i}}\right) \text{ N} = \left(138\hat{\mathbf{i}} + 197\hat{\mathbf{j}}\right) \text{ N}$$

The gravitational force of the whole Earth on boat and worker is $F_g = mg = 370 \text{ kg } (9.8 \text{ m/s}^2) = 3\ 630 \text{ N}$ down. The acceleration of the boat is purely horizontal, so

$$\sum F_y = ma_y \text{ gives } +B + 197 \text{ N} - 3\ 630 \text{ N} = 0$$

(a) The buoyant force is $B = \boxed{3.43 \times 10^3 \text{ N}}$.

(b) The acceleration is given by

$$\sum F_x = ma_x: \quad +138\text{ N} - 47.5\text{ N} = (370\text{ kg})a$$

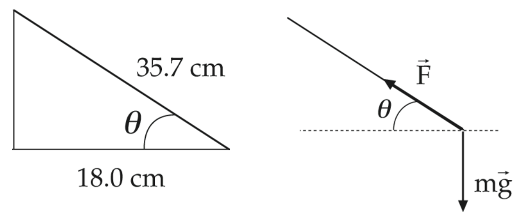
$$a = \frac{90.2\text{ N}}{370\text{ kg}} = 0.244\text{ m/s}^2$$

According to the constant-acceleration model,

$$\begin{aligned} v_{xf} &= v_{xi} + a_x t \\ &= 0.857\text{ m/s} + (0.244\text{ m/s}^2)(0.450\text{ s}) \\ &= 0.967\text{ m/s} \end{aligned}$$

$$\vec{\mathbf{v}}_f = \boxed{0.967\hat{\mathbf{i}}\text{ m/s}}$$

P5.26 (a) The left-hand diagram in ANS. FIG. P5.26(a) shows the geometry of the situation and lets us find the angle of the string with the horizontal:



ANS. FIG. P5.26(a)

$$\cos\theta = 28/35.7 = 0.784$$

or $\theta = 38.3°$

The right-hand diagram in ANS. FIG. P5.26(a) is the free-body diagram. The weight of the bolt is

$$w = mg = (0.065\text{ kg})(9.80\text{ m/s}^2) = 0.637\text{ N}$$

(b) To find the tension in the string, we apply Newton's second law in the x and y directions:

$$\sum F_x = ma_x: -T\cos 38.3° + F_{\text{magnetic}} = 0 \quad \textbf{[1]}$$

$$\sum F_y = ma_y: +T\sin 38.3° - 0.637\text{ N} = 0 \quad \textbf{[2]}$$

from equation [2],

$$T = \frac{0.637\text{ N}}{\sin 38.3°} = \boxed{1.03\text{ N}}$$

(c) Now, from equation [1],

$$F_{\text{magnetic}} = T\cos 38.3° = (1.03\text{ N})\cos 38.3° = \boxed{0.805\text{ N to the right}}$$

P5.27 (a) $P\cos 40.0° - n = 0$ and $P\sin 40.0° - 220\text{ N} = 0$
$P = 342\text{ N}$ and $n = 262\text{ N}$

(b) $P - n\cos 40.0° - 220\text{ N}\sin 40.0° = 0$
and $n\sin 40.0° - 220\text{ N}\cos 40.0° = 0$
$n = 262\text{ N}$ and $P = 342\text{ N}$.

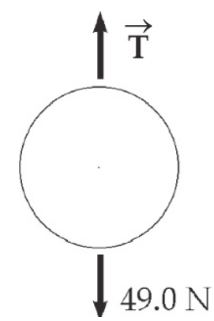
(c) The results agree. The methods are basically of the same level of difficulty. Each involves one equation in one unknown and one equation in two unknowns. If we are interested in n without finding P, method (b) is simpler.

P5.28 (a) Isolate either mass:

$$T + mg = ma = 0$$
$$|T| = |mg|$$

The scale reads the tension T, so

$$T = mg = (5.00\text{ kg})(9.80\text{ m/s}^2) = \boxed{49.0\text{ N}}$$

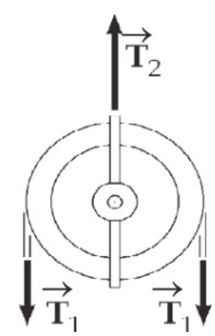


ANS. FIG. P5.28 (a) and (b)

(b) The solution to part (a) is also the solution to (b).

(c) Isolate the pulley:

$$\vec{\mathbf{T}}_2 + 2\vec{\mathbf{T}}_1 = 0$$
$$T_2 = 2|T_1| = 2mg = \boxed{98.0\text{ N}}$$



ANS. FIG. P5.28(c)

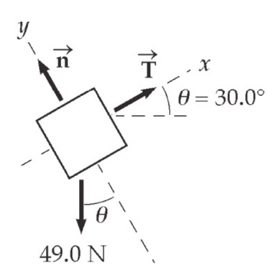
(d) $\sum \vec{\mathbf{F}} = \vec{\mathbf{n}} + \vec{\mathbf{T}} + m\vec{\mathbf{g}} = 0$

Take the component along the incline,

$$n_x + T_x + mg_x = 0$$

or $\quad 0 + T - mg\sin 30.0° = 0$

$$T = mg\sin 30.0° = \frac{mg}{2}$$
$$= \frac{(5.00\text{ kg})(9.80\text{ m/s}^2)}{2}$$
$$= \boxed{24.5\text{ N}}$$



ANS. FIG. P5.28(d)

***P5.29** (a) The resultant external force acting on this system, consisting of all three blocks having a total mass of 6.0 kg, is 42 N directed horizontally toward the right. Thus, the acceleration produced is

$$a = \frac{\sum F}{m} = \frac{42\ \text{N}}{6.0\ \text{kg}} = \boxed{7.0\ \text{m/s}^2\ \text{horizontally to the right}}$$

(b) Draw a free-body diagram of the 3.0-kg block and apply Newton's second law to the horizontal forces acting on this block:

$$\sum F_x = ma_x:$$

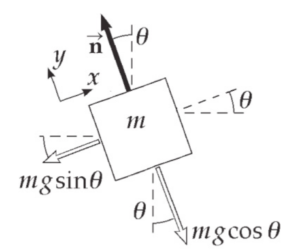
$$42\ \text{N} - T = (3.0\ \text{kg})(7.0\ \text{m/s}^2) \quad \rightarrow \quad T = \boxed{21\ \text{N}}$$

(c) The force accelerating the 2.0-kg block is the force exerted on it by the 1.0-kg block. Therefore, this force is given by

$$F = ma = (2.0\ \text{kg})(7.0\ \text{m/s}^2) = 14\ \text{N}$$

or $\vec{\mathbf{F}} = \boxed{14\ \text{N horizontally to the right}}$

P5.30 (a) ANS. FIG. P5.30 shows the forces on the object. The two forces acting on the block are the normal force, n, and the weight, mg. If the block is considered to be a point mass and the x axis is chosen to be parallel to the plane, then the free-body diagram will be as shown in the figure to the right. The angle θ is the angle of inclination of the plane. Applying Newton's second law for the accelerating system (and taking the direction up the plane as the positive x direction), we have



ANS. FIG. P5.30(a)

$$\sum F_y = n - mg\cos\theta = 0: \ n = mg\cos\theta$$

$$\sum F_x = -mg\sin\theta = ma: \ a = -g\sin\theta$$

(b) When $\theta = 15.0°$,

$$a = \boxed{-2.54\ \text{m/s}^2}$$

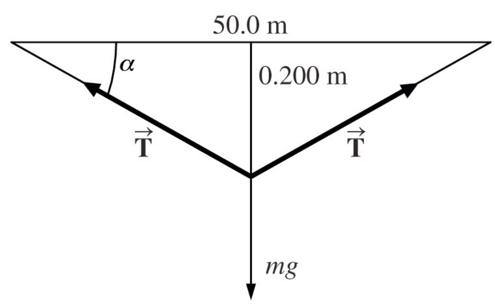
(c) Starting from rest,

$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) = 2a\Delta x$$

$$\left|v_f\right| = \sqrt{2|a|\Delta x} = \sqrt{2\left|-2.54 \text{ m/s}^2\right|(2.00 \text{ m})} = \boxed{3.19 \text{ m/s}}$$

P5.31 We use Newton's second law with the forces in the x and y directions in equilibrium.

(a) At the point where the bird is perched, the wire's midpoint, the forces acting on the wire are the tension forces and the force of gravity acting on the bird. These forces are shown in ANS. FIG. P5.31(a) below.



ANS. FIG. P5.31(a)

(b) The mass of the bird is m = 1.00 kg, so the force of gravity on the bird, its weight, is mg = (1.00 kg)(9.80 m/s^2) = 9.80 N. To calculate the angle α in the free-body diagram, we note that the base of the triangle is 25.0 m, so that

$$\tan\alpha = \frac{0.200 \text{ m}}{25.0 \text{ m}} \quad \rightarrow \quad \alpha = 0.458°$$

Each of the tension forces has x and y components given by

$$T_x = T\cos\alpha \quad \text{and} \quad T_y = T\sin\alpha$$

The x components of the two tension forces cancel out. In the y direction,

$$\sum F_y = 2T\sin\alpha - mg = 0$$

which gives

$$T = \frac{mg}{2\sin\alpha} = \frac{9.80 \text{ N}}{2\sin 0.458°} = \boxed{613 \text{ N}}$$

P5.32 To find the net force, we differentiate the equations for the position of the particle once with respect to time to obtain the velocity, and once again to obtain the acceleration:

$$v_x = \frac{dx}{dt} = \frac{d}{dt}\left(5t^2 - 1\right) = 10t, \quad v_y = \frac{dy}{dt} = \frac{d}{dt}\left(3t^3 + 2\right) = 9t^2$$

$$a_x = \frac{dv_x}{dt} = 10, \quad a_y = \frac{dv_y}{dt} = 18t$$

Then, at t = 2.00 s, a_x = 10.0 m/s^2, a_y = 36.0 m/s^2, and Newton's second law gives us

$$\sum F_x = ma_x: \;\; 3.00 \text{ kg}(10.0 \text{ m/s}^2) = 30.0 \text{ N}$$

$$\sum F_y = ma_y: \;\; 3.00 \text{ kg}(36.0 \text{ m/s}^2) = 108 \text{ N}$$

$$\sum F = \sqrt{F_x^2 + F_y^2} = \boxed{112 \text{ N}}$$

P5.33 From equilibrium of the sack:

$$T_3 = F_g \qquad \textbf{[1]}$$

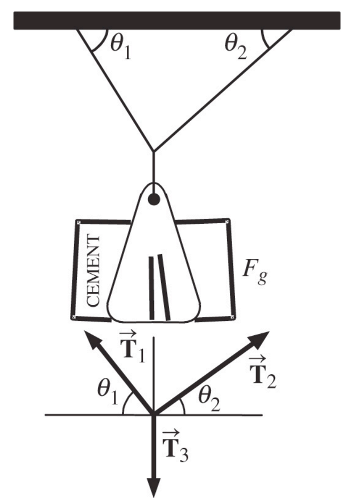
From $\sum F_y = 0$ for the knot:

$$T_1 \sin\theta_1 + T_2 \sin\theta_2 = F_g \qquad \textbf{[2]}$$

From $\sum F_x = 0$ for the knot:

$$T_1 \cos\theta_1 = T_2 \cos\theta_2 \qquad \textbf{[3]}$$

Eliminate T_2 by using $T_2 = T_1 \cos\theta_1 / \cos\theta_2$ and solve for T_1:



ANS. FIG. P5.33

$$T_1 = \frac{F_g \cos\theta_2}{\left(\sin\theta_1 \cos\theta_2 + \cos\theta_1 \sin\theta_2\right)} = \frac{F_g \cos\theta_2}{\sin\left(\theta_1 + \theta_2\right)}$$

$$T_3 = F_g = \boxed{325 \text{ N}}$$

$$T_1 = F_g\left(\frac{\cos 40.0°}{\sin 100.0°}\right) = \boxed{253 \text{ N}}$$

$$T_2 = T_1\left(\frac{\cos\theta_1}{\cos\theta_2}\right) = (253 \text{ N})\left(\frac{\cos 60.0°}{\cos 40.0°}\right) = \boxed{165 \text{ N}}$$

P5.34 See the solution for T_1 in Problem 5.33. The equations indicate that the tension is directly proportional to F_g.

***P5.35** Let us call the forces exerted by each person F_1 and F_2. Thus, for pulling in the same direction, Newton's second law becomes

$$F_1 + F_2 = (200\ \text{kg})(1.52\ \text{m/s}^2)$$

or $$F_1 + F_2 = 304\ \text{N} \qquad \textbf{[1]}$$

When pulling in opposite directions,

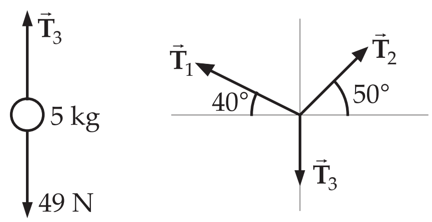
$$F_1 - F_2 = (200\ \text{kg})(-0.518\ \text{m/s}^2)$$

or $$F_1 - F_2 = -104\ \text{N} \qquad \textbf{[2]}$$

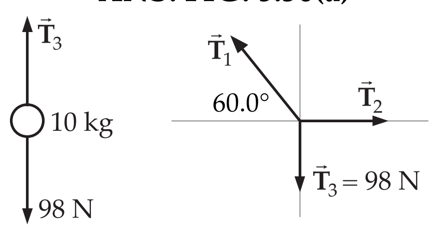
Solving [1] and [2] simultaneously, we find

$$F_1 = \boxed{100\ \text{N}} \text{ and } F_2 = \boxed{204\ \text{N}}$$

***P5.36** (a) First construct a free-body diagram for the 5.00-kg mass as shown in the Figure 5.36a. Since the mass is in equilibrium, we can require $T_3 - 49.0\ \text{N} = 0$ or $T_3 = 49.0\ \text{N}$. Next, construct a free-body diagram for the knot as shown in ANS. FIG. P5.36(a).



ANS. FIG. 5.36(a)



ANS. FIG. 5.36(b)

Again, since the system is moving at constant velocity, $a = 0$, and applying Newton's second law in component form gives

$$\sum F_x = T_2 \cos 50.0° - T_1 \cos 40.0° = 0$$
$$\sum F_y = T_2 \sin 50.0° + T_1 \sin 40.0° - 49.0\ \text{N} = 0$$

Solving the above equations simultaneously for T_1 and T_2 gives $\boxed{T_1 = 31.5\ \text{N}}$ and $\boxed{T_2 = 37.5\ \text{N}}$ and above we found $\boxed{T_3 = 49.0\ \text{N}}$.

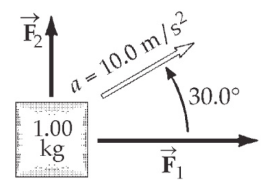
(b) Proceed as in part (a) and construct a free-body diagram for the mass and for the knot as shown in ANS. FIG. P5.36(b). Applying Newton's second law in each case (for a constant-velocity system), we find:

$$T_3 - 98.0\text{ N} = 0$$
$$T_2 - T_1 \cos 60.0° = 0$$
$$T_1 \sin 60.0° - T_3 = 0$$

Solving this set of equations we find:

$$\boxed{T_1 = 113\text{ N},}\ \boxed{T_2 = 56.6\text{ N},}\ \text{and}\ \boxed{T_3 = 98.0\text{ N}}$$

P5.37 Choose a coordinate system with $\hat{\mathbf{i}}$ East and $\hat{\mathbf{j}}$ North. The acceleration is



ANS. FIG. P5.37

$$\vec{\mathbf{a}} = [(10.0\cos 30.0°)\hat{\mathbf{i}} + (10.0\sin 30.0°)\hat{\mathbf{j}}]\text{ m/s}^2$$
$$= (8.66\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}})\text{ m/s}^2$$

From Newton's second law,

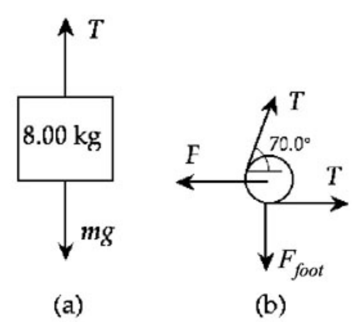
$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}} = (1.00\text{ kg})(8.66\hat{\mathbf{i}}\text{ m/s}^2 + 5.00\hat{\mathbf{j}}\text{ m/s}^2)$$
$$= (8.66\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}})\text{ N}$$

and $\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2$

So the force we want is

$$\vec{\mathbf{F}}_1 = \sum \vec{\mathbf{F}} - \vec{\mathbf{F}}_2 = (8.66\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}} - 5.00\hat{\mathbf{j}})\text{ N}$$
$$= 8.66\hat{\mathbf{i}}\text{ N} = \boxed{8.66\text{ N east}}$$

P5.38 (a) Assuming frictionless pulleys, the tension is uniform through the entire length of the rope. Thus, the tension at the point where the rope attaches to the leg is the same as that at the 8.00-kg block. ANS. FIG. P5.38(a) gives a free-body diagram of the suspended block. Recognizing that the block has zero acceleration, Newton's second law gives



ANS. FIG. P5.38

$$\sum F_y = T - mg = 0$$

or

$$T = mg = (8.00\text{ kg})(9.80\text{ m/s}^2) = \boxed{78.4\text{ N}}$$

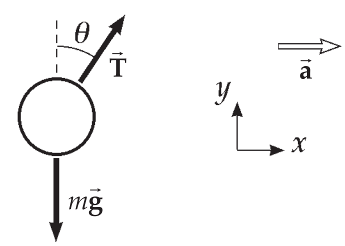
(b) ANS. FIG. P5.38(b) gives a free-body diagram of the pulley near the foot. Here, F is the magnitude of the force the foot exerts on the pulley. By Newton's third law, this is the same as the magnitude of the force the pulley exerts on the foot. Applying the second law gives

$$\sum F_x = T + T\cos 70.0° - F = ma_x = 0$$

or

$$F = T(1+\cos 70.0°) = (78.4\text{ N})(1+\cos 70.0°) = \boxed{105\text{ N}}$$

***P5.39** (a) Assume the car and mass accelerate horizontally. We consider the forces on the suspended object.



ANS. FIG. P5.39

$$\sum F_y = ma_y\text{: } +T\cos\theta - mg = 0$$

$$\sum F_x = ma_x\text{: } +T\sin\theta = ma$$

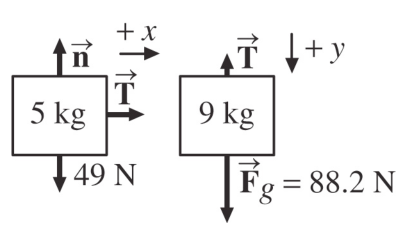
Substitute $T = \dfrac{mg}{\cos\theta}$ from the first equation into the second,

$$\frac{mg\sin\theta}{\cos\theta} = mg\tan\theta = ma$$

$$\boxed{a = g\tan\theta}$$

(b) $a = (9.80\text{ m/s}^2)\tan 23.0° = \boxed{4.16\text{ m/s}^2}$

P5.40 (a) The forces on the objects are shown in ANS. FIG. P5.40.



ANS. FIG. P5.40

(b) and (c) First, consider m_1, the block moving along the horizontal. The only force in the direction of movement is T. Thus,

$$\sum F_x = ma$$

or $T = (5.00 \text{ kg})a$ **[1]**

Next consider m_2, the block that moves vertically. The forces on it are the tension T and its weight, 88.2 N.

We have $\sum F_y = ma$:

$$88.2 \text{ N} - T = (9.00 \text{ kg})a \quad \textbf{[2]}$$

Note that both blocks must have the same magnitude of acceleration. Equations [1] and [2] can be added to give 88.2 N = (14.0 kg)a. Then

$$\boxed{a = 6.30 \text{ m/s}^2 \text{ and } T = 31.5 \text{ N}}$$

P5.41 (a) and (b) The slope of the graph of upward velocity versus time is the acceleration of the person's body. At both time 0 and time 0.5 s, this slope is (18 cm/s)/0.6 s = 30 cm/s^2.

For the person's body,

$$\sum F_y = ma_y:$$
$$+F_{\text{bar}} - (64.0 \text{ kg})(9.80 \text{ m/s}^2) = (64.0 \text{ kg})(0.3 \text{ m/s}^2)$$

Note that there is no floor touching the person to exert a normal force, and that he does not exert any extra force "on himself." Solving, $F_{\text{bar}} = \boxed{646 \text{ N up}}$.

(c) a_y = slope of v_y versus t graph = 0 at t = 1.1 s. The person is moving with maximum speed and is momentarily in equilibrium:

$$\sum F_y = ma_y:$$
$$+F_{\text{bar}} - (64.0 \text{ kg})(9.80 \text{ m/s}^2) = 0$$

$$F_{\text{bar}} = \boxed{627 \text{ N up}}$$

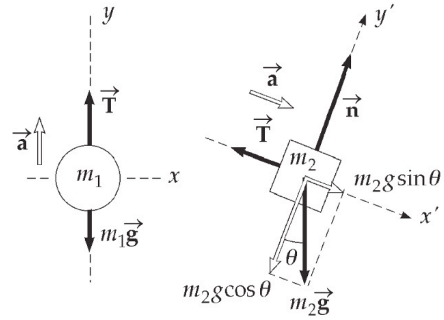
(d) a_y = slope of v_y versus t graph = (0 – 24 cm/s)/(1.7 s – 1.3 s) = –60 cm/s^2

$$\sum F_y = ma_y:$$
$$+F_{\text{bar}} - (64.0 \text{ kg})(9.80 \text{ m/s}^2) = (64.0 \text{ kg})(-0.6 \text{ m/s}^2)$$

$$F_{\text{bar}} = \boxed{589 \text{ N up}}$$

P5.42 $m_1 = 2.00\text{ kg}$, $m_2 = 6.00\text{ kg}$, $\theta = 55.0°$

(a) The forces on the objects are shown in ANS. FIG. P5.42.



ANS. FIG. P5.42

(b) $\sum F_x = m_2 g\sin\theta - T = m_2 a$ and

$$T - m_1 g = m_1 a$$

$$a = \frac{m_2 g\sin\theta - m_1 g}{m_1 + m_2}$$

$$= \frac{(6.00\text{ kg})(9.80\text{ m/s}^2)\sin 55.0° - (2.00\text{ kg})(9.80\text{ m/s}^2)}{2.00\text{ kg} + 6.00\text{ kg}}$$

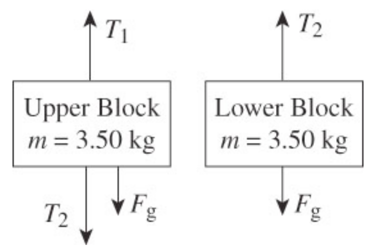
$$= \boxed{3.57\text{ m/s}^2}$$

(c) $T = m_1(a+g) = (2.00\text{ kg})(3.57\text{ m/s}^2 + 9.80\text{ m/s}^2) = \boxed{26.7\text{ N}}$

(d) Since $v_i = 0$, $v_f = at = (3.57\text{ m/s}^2)(2.00\text{ s}) = \boxed{7.14\text{ m/s}}$.

P5.43 (a) Free-body diagrams of the two blocks are shown in ANS. FIG. P5.43. Note that each block experiences a downward gravitational force

$$F_g = (3.50\text{ kg})(9.80\text{ m/s}^2) = 34.3\text{ N}$$



ANS. FIG. P5.43

Also, each has the same upward acceleration as the elevator, in this case $a_y = +1.60\text{ m/s}^2$.

Applying Newton's second law to the lower block:

$$\sum F_y = ma_y \quad \Rightarrow \quad T_2 - F_g = ma_y$$

or

$$T_2 = F_g + ma_y = 34.3\text{ N} + (3.50\text{ kg})(1.60\text{ m/s}^2) = \boxed{39.9\text{ N}}$$

Next, applying Newton's second law to the upper block:

$$\sum F_y = ma_y \quad \Rightarrow \quad T_1 - T_2 - F_g = ma_y$$

or

$$T_1 = T_2 + F_g + ma_y = 39.9\text{ N} + 34.3\text{ N} + (3.50\text{ kg})(1.60\text{ m/s}^2)$$

$$= \boxed{79.8\text{ N}}$$

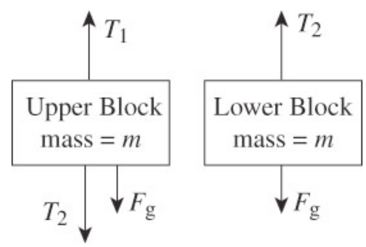
(b) Note that the tension is greater in the upper string, and this string will break first as the acceleration of the system increases. Thus, we wish to find the value of a_y when $T_1 = 85.0$. Making use of the general relationships derived in (a) above gives:

$$T_1 = T_2 + F_g + ma_y = \left(F_g + ma_y\right) + F_g + ma_y = 2F_g + 2ma_y$$

or

$$a_y = \frac{T_1 - 2F_g}{2m} = \frac{85.0\ \text{N} - 2(34.3\ \text{N})}{2(3.50\ \text{kg})} = \boxed{2.34\ \text{m/s}^2}$$

P5.44 (a) Free-body diagrams of the two blocks are shown in ANS. FIG. P5.44. Note that each block experiences a downward gravitational force $F_g = mg$.



ANS. FIG. P5.44

Also, each has the same upward acceleration as the elevator, $a_y = +a$.

Applying Newton's second law to the lower block:

$$\sum F_y = ma_y \qquad \Rightarrow \qquad T_2 - F_g = ma_y$$

or $T_2 = mg + ma = \boxed{m(g + a)}$

Next, applying Newton's second law to the upper block:

$$\sum F_y = ma_y \qquad \Rightarrow \qquad T_1 - T_2 - F_g = ma_y$$

or

$$T_1 = T_2 + F_g + ma_y = (mg + ma) + mg + ma = 2(mg + ma)$$
$$= \boxed{2m(g + a)} = 2T_2$$

(b) Note that $\boxed{T_1 = 2T_2\text{, so the upper string breaks first}}$ as the acceleration of the system increases.

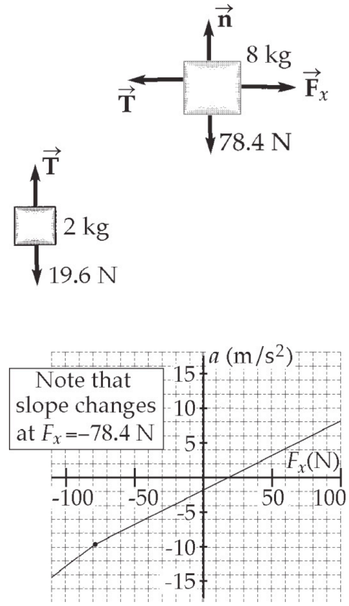
(c) When the upper string breaks, both blocks will be in free fall with $a = -g$. Then, using the results of part (a), $T_2 = m(g + a) = m(g - g) = \boxed{0}$ and $T_1 = 2T_2 = \boxed{0}$.

P5.45 Forces acting on $m_1 = 2.00$-kg block:

$$T - m_1 g = m_1 a \qquad \textbf{[1]}$$

Forces acting on $m_2 = 8.00$-kg block:

$$F_x - T = m_2 a \qquad \textbf{[2]}$$



ANS. FIG. P5.45

(a) Eliminate T and solve for a:

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

$$\boxed{a > 0 \text{ for } F_x > m_1 g = 19.6 \text{ N}}$$

(b) Eliminate a and solve for T:

$$T = \frac{m_1}{m_1 + m_2}\left(F_x + m_2 g\right)$$

$$\boxed{T = 0 \text{ for } F_x \le -m_2 g = -78.4 \text{ N}}$$

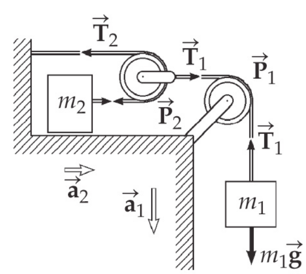
Note that if $F_x < -m_2 g$, the cord is loose, so mass m_2 is in free fall and mass m_1 accelerates under the action of F_x only.

(c) See ANS. FIG. P5.45.

F_x, N	–100	–78.4	–50.0	0	50.0	100
a_x, m/s^2	–12.5	–9.80	–6.96	–1.96	3.04	8.04

P5.46 (a) Pulley P_2 has acceleration a_1.

Since m_2 moves *twice* the distance P_2 moves in the same time, m_2 has twice the acceleration of P_2, i.e., $\boxed{a_2 = 2a_1}$.



ANS. FIG. P5.46

(b) From the figure, and using

$$\sum F = ma: \quad m_1 g - T_1 = m_1 a_1 \qquad \textbf{[1]}$$

$$T_2 = m_2 a_2 = 2m_2 a_1 \qquad \textbf{[2]}$$

$$T_1 - 2T_2 = 0 \qquad \textbf{[3]}$$

Equation [1] becomes $m_1 g - 2T_2 = m_1 a_1$. This equation combined with equation [2] yields

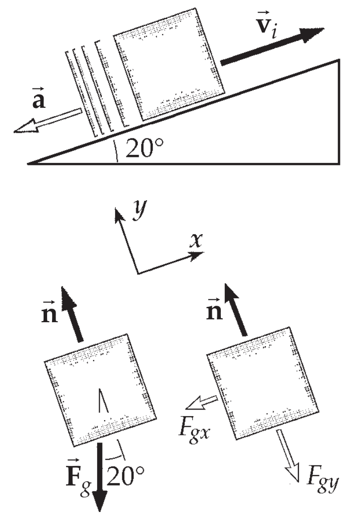
$$\frac{T_2}{m_2}\left(2m_2 + \frac{m_2}{2}\right) = m_1 g$$

$$\boxed{T_2 = \frac{m_1 m_2}{2m_2 + \frac{1}{2}m_1}g} \quad \text{and} \quad \boxed{T_2 = \frac{m_1 m_2}{m_2 + \frac{1}{4}m_1}g}$$

(c) From the values of T_2 and T_1, we find that

$$a_2 = \frac{T_2}{m_2} = \boxed{\frac{m_1 g}{2m_2 + \frac{1}{2}m_1}} \quad \text{and } a_1 = \frac{1}{2}a_2 = \boxed{\frac{m_1 g}{4m_2 + m_1}}$$

***P5.47** We use the particle under constant acceleration and particle under a net force models. Newton's law applies for each axis. After it leaves your hand, the block's speed changes only because of one component of its weight:



ANS. FIG. P5.47

$$\sum F_x = ma_x$$
$$-mg\sin 20.0° = ma$$

$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right)$$

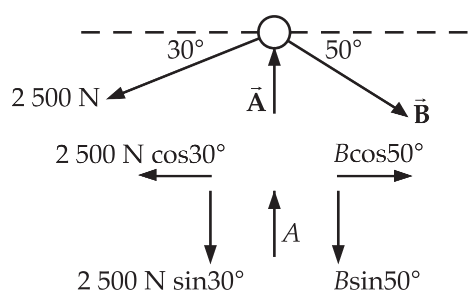
Taking $v_f = 0$, $v_i = 5.00$ m/s, and $a = -g\sin(20.0°)$ gives, suppressing units,

$$0 = (5.00)^2 - 2(9.80)\sin(20.0°)\left(x_f - 0\right)$$

or

$$x_f = \frac{25.0}{2(9.80)\sin(20.0°)} = \boxed{3.73 \text{ m}}$$

***P5.48** We assume the vertical bar is in compression, pushing up on the pin with force A, and the tilted bar is in tension, exerting force B on the pin at –50.0°.



ANS. FIG. P5.48

$$\sum F_x = 0:$$

$$-2\ 500\ \text{N}\cos 30° + B\cos 50° = 0$$

$$\boxed{B = 3.37\times 10^3\ \text{N}}$$

$$\sum F_y = 0:$$

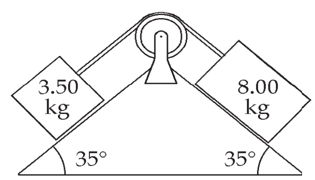
$$-2\ 500\ \text{N}\sin 30° + A - 3.37\times 10^3\ \text{N}\ \sin 50° = 0$$

$$\boxed{A = 3.83\times 10^3\ \text{N}}$$

Positive answers confirm that

$$\boxed{B \text{ is in tension and } A \text{ is in compression.}}$$

P5.49 Since it has a larger mass, we expect the 8.00-kg block to move down the plane. The acceleration for both blocks should have the same magnitude since they are joined together by a non-stretching string. Define up the left-hand plane as positive for the 3.50-kg object and down the right-hand plane as positive for the 8.00-kg object.



ANS. FIG. P5.49

$$\sum F_1 = m_1 a_1: \quad -m_1 g\sin 35.0° + T = m_1 a$$
$$\sum F_2 = m_2 a_2: \quad m_2 g\sin 35.0° - T = m_2 a$$

and, suppressing units,

$$-(3.50)(9.80)\sin 35.0° + T = 3.50a$$
$$(8.00)(9.80)\sin 35.0° - T = 8.00a.$$

Adding, we obtain $+45.0\ \text{N} - 19.7\ \text{N} = (11.5\ \text{kg})a$.

(a) Thus the acceleration is $\boxed{a = 2.20\ \text{m/s}^2}$. By substitution,

$$-19.7\ \text{N} + T = (3.50\ \text{kg})(2.20\ \text{m/s}^2) = 7.70\ \text{N}$$

(b) The tension is $\boxed{T = 27.4\ \text{N}}$

P5.50 Both blocks move with acceleration $a = \left(\dfrac{m_2 - m_1}{m_2 + m_1}\right)g$:

$$a = \left(\frac{7\text{ kg} - 2\text{ kg}}{7\text{ kg} + 2\text{ kg}}\right)(9.80\text{ m/s}^2) = 5.44\text{ m/s}^2$$

(a) Take the upward direction as positive for m_1.

$$v_{yf}^2 = v_{yi}^2 + 2a_x\left(y_f - y_i\right)$$

$$0 = (-2.4\text{ m/s})^2 + 2(5.44\text{ m/s}^2)(y_f - 0)$$

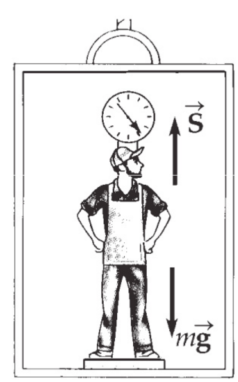
$$y_f = -\frac{5.76\text{ m}^2/\text{s}^2}{2(5.44\text{ m/s}^2)} = -0.529\text{ m}$$

$$y_f = \boxed{0.529\text{ m below its initial level}}$$

(b) $v_{yf} = v_{yi} + a_y t$: $v_{yf} = -2.40\text{ m/s} + (5.44\text{ m/s}^2)(1.80\text{ s})$

$$v_{yf} = \boxed{7.40\text{ m/s upward}}$$

P5.51 We draw a force diagram and apply Newton's second law for each part of the elevator trip to find the scale force. The acceleration can be found from the change in speed divided by the elapsed time.



ANS. FIG. P5.51

Consider the force diagram of the man shown as two arrows. The force F is the upward force exerted on the man by the scale, and his weight is

$$F_g = mg = (72.0\text{ kg})(9.80\text{ m/s}^2) = 706\text{ N}$$

With $+y$ defined to be upwards, Newton's second law gives

$$\sum F_y = +F_s - F_g = ma$$

Thus, we calculate the upward scale force to be

$$F_s = 706\text{ N} + (72.0\text{ kg})a \qquad \textbf{[1]}$$

where a is the acceleration the man experiences as the elevator changes speed.

(a) Before the elevator starts moving, the elevator's acceleration is zero ($a = 0$). Therefore, equation [1] gives the force exerted by the scale on the man as 706 N upward, and the man exerts a downward force of $\boxed{706\text{ N}}$ on the scale.

(b) During the first 0.800 s of motion, the man accelerates at a rate of

$$a_x = \frac{\Delta v}{\Delta t} = \frac{1.20\text{ m/s} - 0}{0.800\text{ s}} = 1.50\text{ m/s}^2$$

Substituting a into equation [1] then gives

$$F = 706\text{ N} + (72.0\text{ kg})(1.50\text{ m/s}^2) = \boxed{814\text{ N}}$$

(c) While the elevator is traveling upward at constant speed, the acceleration is zero and equation [1] again gives a scale force $F = \boxed{706\text{ N}}$.

(d) During the last 1.50 s, the elevator first has an upward velocity of 1.20 m/s, and then comes to rest with an acceleration of

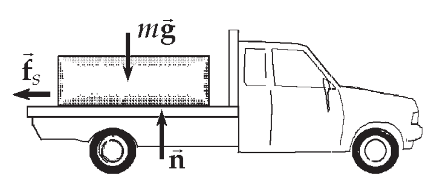
$$a = \frac{\Delta v}{\Delta t} = \frac{0 - 1.20\text{ m/s}}{1.50\text{ s}} = -0.800\text{ m/s}^2$$

Thus, the force of the man on the scale is

$$F = 706\text{ N} + (72.0\text{ kg})(-0.800\text{ m/s}^2) = \boxed{648\text{ N}}$$

Section 5.8 Forces of Friction

***P5.52** If the load is on the point of sliding forward on the bed of the slowing truck, static friction acts backward on the load with its maximum value, to give it the same acceleration as the truck:



ANS. FIG. P5.52

$$\Sigma F_x = ma_x: \qquad -f_s = m_{\text{load}}a_x$$

$$\Sigma F_y = ma_y: \qquad n - m_{\text{load}}g = 0$$

Solving for the normal force and substituting into the x equation gives:

$$-\mu_s m_{\text{load}} g = m_{\text{load}} a_x \qquad \text{or} \qquad a_x = -\mu_s g$$

We can then use

$$v_{xf}^2 = v_{xi}^2 + 2a_x\left(x_f - x_i\right)$$

Which becomes

$$0 = v_{xi}^2 + 2(-\mu_s g)\left(x_f - 0\right)$$

(a) $$x_f = \frac{v_{xi}^2}{2\mu_s g} = \frac{(12.0\ \text{m/s})^2}{2(0.500)\left(9.80\ \text{m/s}^2\right)} = \boxed{14.7\ \text{m}}$$

(b) From the expression $x_f = \dfrac{v_{xi}^2}{2\mu_s g}$,

$\boxed{\text{neither mass affects the answer}}$

P5.53 Using $m = 12.0 \times 10^{-3}$ kg, $v_i = 260$ m/s, $v_f = 0$, $\Delta x = (x_f - x_i) = 0.230$ m, and $v_f^2 = v_i^2 + 2a(x_f - x_i)$, we find the acceleration of the bullet: $a = -1.47 \times 10^5\ \text{m/s}^2$. Newton's second law then gives

$$\sum F_x = ma_x$$

$$f_k = ma = -1.76 \times 10^5\ \text{N}$$

The (kinetic) friction force is $\boxed{1.76 \times 10^5\ \text{N in the negative } x \text{ direction}}$.

P5.54 We apply Newton's second law to the car to determine the maximum static friction force acting on the car:

$$\sum F_y = ma_y: \quad +n - mg = 0$$

$$f_s \le \mu_s n = \mu_s mg$$

This maximum magnitude of static friction acts so long as the tires roll without skidding.

$$\sum F_x = ma_x \rightarrow -f_s = ma$$

The maximum acceleration is

$$a = -\mu_s g$$

The initial and final conditions are: $x_i = 0$, $v_i = 50.0$ mi/h = 22.4 m/s, and $v_f = 0$. Then,

$$v_f^2 = v_i^2 + 2a(x_f - x_i) \rightarrow v_i^2 = 2\mu_s g x_f$$

(a) $x_f = \dfrac{v_i^2}{2\mu_s g}$

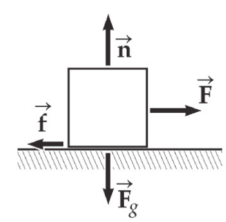
$$x_f = \frac{(22.4 \text{ m/s})^2}{2(0.100)(9.80 \text{ m/s}^2)} = \boxed{256 \text{ m}}$$

(b) $x_f = \dfrac{v_i^2}{2\mu_s g}$

$$x_f = \frac{(22.4 \text{ m/s})^2}{2(0.600)(9.80 \text{ m/s}^2)} = \boxed{42.7 \text{ m}}$$

P5.55 For equilibrium: $f = F$ and $n = F_g$. Also, $f = \mu n$, i.e.,

$$\mu = \frac{f}{n} = \frac{F}{F_g}$$



ANS. FIG. P5.55

In parts (a) and (b), we replace F with the magnitude of the applied force and μ with the appropriate coefficient of friction.

(a) The coefficient of static friction is found from

$$\mu_s = \frac{F}{F_g} = \frac{75.0 \text{ N}}{(25.0 \text{ kg})(9.80 \text{ m/s}^2)} = \boxed{0.306}$$

(b) The coefficient of kinetic friction is found from

$$\mu_k = \frac{F}{F_g} = \frac{60.0 \text{ N}}{(25.0 \text{ kg})(9.80 \text{ m/s}^2)} = \boxed{0.245}$$

P5.56 Find the acceleration of the car, which is the same as the acceleration of the book because the book does not slide.

For the car: $v_i = 72.0$ km/h = 20.0 m/s, $v_f = 0$, $\Delta x = (x_f - x_i) = 30.0$ m. Using $v_f^2 = v_i^2 + 2a(x_f - x_i)$, we find the acceleration of the car:

$$a = -6.67 \text{ m/s}^2$$

Now, find the maximum acceleration that friction can provide. Because the book does not slide, static friction provides the force that slows down the book. We have the coefficient of static friction, $\mu_s = 0.550$, and we know $f_s \le \mu_s n$. The book is on a horizontal seat, so friction acts in the horizontal direction, and the vertical normal force that the seat exerts on the book is equal in magnitude to the force of gravity on the book: $n = F_g = mg$. For maximum acceleration, the static friction force will be a maximum, so $f_s = \mu_s n = \mu_s mg$. Applying Newton's second law, we find the acceleration that friction can provide for the book:

$$\sum F_x = ma_x:$$

$$-f_s = ma$$

$$-\mu_s mg = ma$$

which gives $a = -\mu_s g = -(0.550)(9.80 \text{ m/s}^2) = -5.39 \text{ m/s}^2$, which is too small for the stated conditions.

The situation is impossible because maximum static friction cannot provide the acceleration necessary to keep the book stationary on the seat.

P5.57 The x and y components of Newton's second law as the eraser begins to slip are

$$-f + mg\sin\theta = 0 \text{ and } +n - mg\cos\theta = 0$$

with $f = \mu_s n$ or $\mu_k n$, these equations yield

$$\mu_s = \tan\theta_c = \tan 36.0° = \boxed{0.727}$$

$$\mu_k = \tan\theta_c = \tan 30.0° = \boxed{0.577}$$

P5.58 We assume that all the weight is on the rear wheels of the car.

(a) We find the record time from

$$F = ma: \quad \mu_s mg = ma \quad \text{or} \quad a = \mu_s g$$

But

$$\Delta x = \frac{at^2}{2} = \frac{\mu_s g t^2}{2}$$

so $\mu_s = \dfrac{2\Delta x}{gt^2}$

$$\mu_s = \frac{2(0.250\ \text{mi})(1\,609\ \text{m/mi})}{(9.80\ \text{m/s}^2)(4.43\ \text{s})^2} = \boxed{4.18}$$

(b) Time would increase, as the wheels would skid and only kinetic friction would act; or perhaps the car would flip over.

P5.59 Maximum static friction provides the force that produces maximum acceleration, resulting in a minimum time interval to accelerate through Δx = 3.00 m. We know that the maximum force of static friction is $f_s = \mu_s n$. If the shoe is on a horizontal surface, friction acts in the horizontal direction. Assuming that the vertical normal force is maximal, equal in magnitude to the force of gravity on the person, we have $n = F_g = mg$; therefore, the maximum static friction force is

$$f_s = \mu_s n = \mu_s mg$$

Applying Newton's second law:

$$\sum F_x = ma_x:$$

$$f_s = ma$$

$$\mu_s mg = ma \quad \rightarrow \quad a = \mu_s g$$

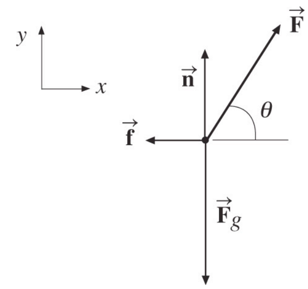
We find the time interval $\Delta t = t$ to accelerate from rest through Δx = 3.00 m using $x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$:

$$\Delta x = \frac{1}{2}a_x(\Delta t)^2 \rightarrow \Delta t = \sqrt{\frac{2\Delta x}{a_x}} = \sqrt{\frac{2\Delta x}{\mu_s g}}$$

(a) For $\mu_s = 0.500$, $\Delta t = \boxed{1.11\text{ s}}$

(b) For $\mu_s = 0.800$, $\Delta t = \boxed{0.875\text{ s}}$

P5.60 (a) See the free-body diagram of the suitcase in ANS. FIG. P5.60(a).



ANS. FIG. P5.60(a)

(b) $m_{\text{suitcase}} = 20.0$ kg, $F = 35.0$ N

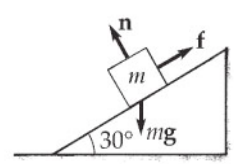
$$\sum F_x = ma_x: \quad -20.0\text{ N} + F\cos\theta = 0$$
$$\sum F_y = ma_y: \quad +n + F\sin\theta - F_g = 0$$

$$F\cos\theta = 20.0\text{ N}$$
$$\cos\theta = \frac{20.0\text{ N}}{35.0\text{ N}} = 0.571$$
$$\boxed{\theta = 55.2^\circ}$$

(c) With $F_g = (20.0\text{ kg})(9.80\text{ m/s}^2)$,

$$n = F_g - F\sin\theta = [196\text{ N} - (35.0\text{ N})(0.821)]$$
$$\boxed{n = 167\text{ N}}$$

P5.61 We are given: $m = 3.00$ kg, $\theta = 30.0^\circ$, $x = 2.00$ m, $t = 1.50$ s



ANS. FIG. P5.61

(a) At constant acceleration,

$$x_f = v_i t + \tfrac{1}{2}at^2$$

Solving,

$$a = \frac{2(x_f - v_i t)}{t^2} = \frac{2(2.00\text{ m} - 0)}{(1.50\text{ s})^2} = \boxed{1.78\text{ m/s}^2}$$

From the acceleration, we can calculate the friction force, answer (c), next.

(c) Take the positive x axis down parallel to the incline, in the direction of the acceleration. We apply Newton's second law:

$$\sum F_x = mg\sin\theta - f = ma$$

Solving, $f = m(g\sin\theta - a)$

Substituting,

$$f = (3.00\text{ kg})[(9.80\text{ m/s}^2)\sin 30.0° - 1.78\text{ m/s}^2] = \boxed{9.37\text{ N}}$$

(b) Applying Newton's law in the y direction (perpendicular to the incline), we have no burrowing-in or taking-off motion. Then the y component of acceleration is zero:

$$\sum F_y = n - mg\cos\theta = 0$$

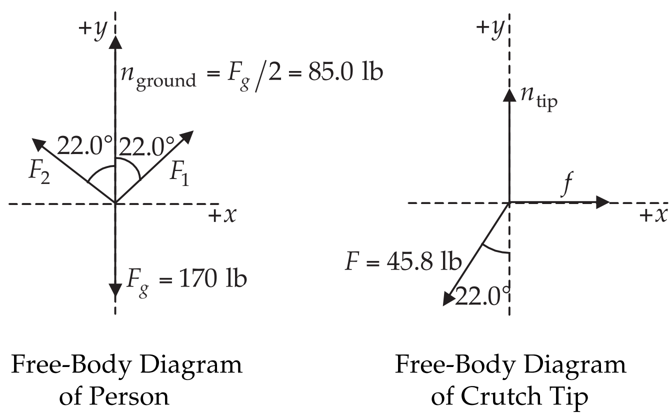
Thus $n = mg\cos\theta$

Because $f = \mu_k n$

we have $\mu_k = \dfrac{f}{mg\cos\theta} = \dfrac{9.37\text{ N}}{(3.00\text{ kg})(9.80\text{ m/s}^2)\cos 30.0°} = \boxed{0.368}$

(d) $v_f = v_i + at$ so $v_f = 0 + (1.78\text{ m/s}^2)(1.50\text{ s}) = \boxed{2.67\text{ m/s}}$

***P5.62** The free-body diagrams for this problem are shown in ANS. FIG. P5.62.



ANS. FIG. P5.62

From the free-body diagram for the person,

$$\sum F_x = F_1\sin(22.0°) - F_2\sin(22.0°) = 0$$

which gives $F_1 = F_2 = F$. Then, $\sum F_y = 2F\cos 22.0° + 85.0\text{ lbs} - 170\text{ lbs} = 0$ yields $F = 45.8$ lb.

(a) Now consider the free-body diagram of a crutch tip.

$$\sum F_x = f - (45.8\ \text{lb})\sin 22.0° = 0$$

or $f = 17.2$ lb.

$$\sum F_y = n_{\text{tip}} - (45.8\ \text{lb})\cos 22.0° = 0$$

which gives $n_{\text{tip}} = 42.5$ lb.

For minimum coefficient of friction, the crutch tip will be on the verge of slipping, so $f = (f_s)_{\max} = \mu_s n_{\text{tip}}$ and

$$\mu_s = \frac{f}{n_{\text{tip}}} = \frac{17.2\ \text{lb}}{42.5\ \text{lb}} = \boxed{0.404}$$

(b) As found above, the compression force in each crutch is

$$F_1 = F_2 = F = \boxed{45.8\ \text{lb}}$$

P5.63 Newton's second law for the 5.00-kg mass gives

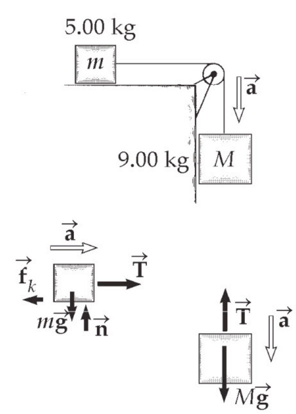
$$T - f_k = (5.00\ \text{kg})a$$

Similarly, for the 9.00-kg mass,

$$(9.00\ \text{kg})g - T = (9.00\ \text{kg})a$$

Adding these two equations gives:

$$(9.00\ \text{kg})(9.80\ \text{m/s}^2) - 0.200(5.00\ \text{kg})(9.80\ \text{m/s}^2) = (14.0\ \text{kg})a$$

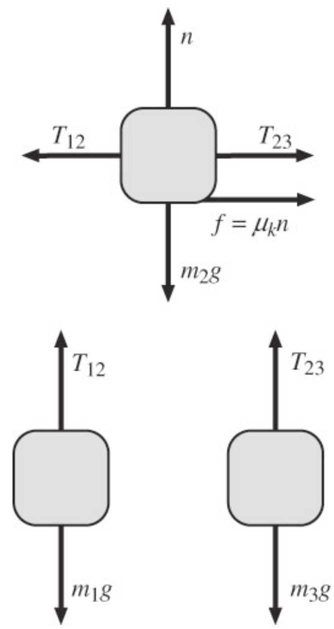


ANS. FIG. P5.63

Which yields $a = 5.60\ \text{m/s}^2$. Plugging this into the first equation above gives

$$T = (5.00\ \text{kg})(5.60\ \text{m/s}^2) + 0.200(5.00\ \text{kg})(9.80\ \text{m/s}^2) = \boxed{37.8\ \text{N}}$$

P5.64 (a) The free-body diagrams for each object appear on the right.



ANS. FIG. P5.64(a)

(b) Let a represent the positive magnitude of the acceleration $-a\hat{\mathbf{j}}$ of m_1, of the acceleration $-a\hat{\mathbf{i}}$ of m_2, and of the acceleration $+a\hat{\mathbf{j}}$ of m_3. Call T_{12} the tension in the left cord and T_{23} the tension in the cord on the right.

For m_1, $\sum F_y = ma_y$:

$$+T_{12} - m_1 g = -m_1 a$$

For m_2, $\sum F_x = ma_x$:

$$-T_{12} + \mu_k n + T_{23} = -m_2 a$$

and $\sum F_y = ma_y$, giving $n - m_2 g = 0$.

For m_3, $\sum F_y = ma_y$, giving $T_{23} - m_3 g = +m_3 a$.

We have three simultaneous equations:

$$-T_{12} + 39.2 \text{ N} = (4.00 \text{ kg})a$$
$$+T_{12} - 0.350(9.80 \text{ N}) - T_{23} = (1.00 \text{ kg})a$$
$$+T_{23} - 19.6 \text{ N} = (2.00 \text{ kg})a$$

Add them up (this cancels out the tensions):

$$+39.2 \text{ N} - 3.43 \text{ N} - 19.6 \text{ N} = (7.00 \text{ kg})a$$

$$a = \boxed{2.31 \text{ m/s}^2\text{, down for } m_1\text{, left for } m_2\text{, and up for } m_3}$$

(c) Now $-T_{12} + 39.2 \text{ N} = (4.00 \text{ kg})(2.31 \text{ m/s}^2)$

$$\boxed{T_{12} = 30.0 \text{ N}}$$

and $T_{23} - 19.6 \text{ N} = (2.00 \text{ kg})(2.31 \text{ m/s}^2)$

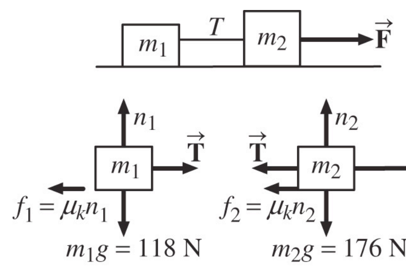
$$\boxed{T_{23} = 24.2 \text{ N}}$$

(d) If the tabletop were smooth, friction disappears ($\mu_k = 0$), and so the acceleration would become larger. For a larger acceleration, according to the equations above, the tensions change:

$$T_{12} = m_1 g - m_1 a \rightarrow \boxed{T_{12} \text{ decreases}}$$

$$T_{23} = m_3 g + m_3 a \rightarrow \boxed{T_{23} \text{ increases}}$$

P5.65 Because the cord has constant length, both blocks move the same number of centimeters in each second and so move with the same acceleration. To find just this acceleration, we could model the 30-kg system as a particle under a net force. That method would not help to finding the tension, so we treat the two blocks as separate accelerating particles.



ANS. FIG. P5.65

(a) ANS. FIG. P5.65 shows the free-body diagrams for the two blocks. The tension force exerted by block 1 on block 2 is the same size as the tension force exerted by object 2 on object 1. The tension in a light string is a constant along its length, and tells how strongly the string pulls on objects at both ends.

(b) We use the free-body diagrams to apply Newton's second law.

For m_1: $\sum F_x = T - f_1 = m_1 a$ or $T = m_1 a + f_1$ **[1]**

And also $\sum F_y = n_1 - m_1 g = 0$ or $n_1 = m_1 g$

Also, the definition of the coefficient of friction gives

$$f_1 = \mu n_1 = (0.100)(12.0 \text{ kg})(9.80 \text{ m/s}^2) = 11.8 \text{ N}$$

For m_2: $\sum F_x = F - T - f_2 = ma$ **[2]**

Also from the y component, $n_2 - m_2 g = 0$ or $n_2 = m_2 g$

And again $f_2 = \mu n_2 = (0.100)(18.0 \text{ kg})(9.80 \text{ m/s}^2) = 17.6 \text{ N}$

Substituting T from equation [1] into [2], we get

$$F - m_1 a - f_1 - f_2 = m_2 a \quad \text{or} \quad F - f_1 - f_2 = m_2 a + m_1 a$$

Solving for a,

$$a = \frac{F - f_1 - f_2}{m_1 + m_2} = \frac{(68.0\text{ N} - 11.8\text{ N} - 17.6\text{ N})}{(12.0\text{ kg} + 18.0\text{ kg})} = \boxed{1.29\text{ m/s}^2}$$

(c) From equation [1],

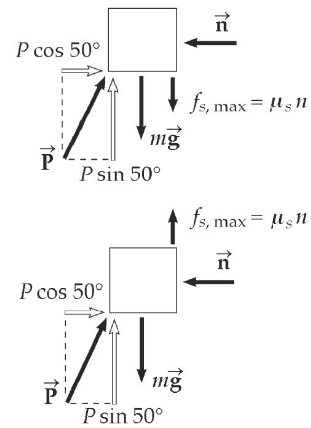
$$T = m_1 a + f_1 = (12.0\text{ kg})(1.29\text{ m/s}^2) + 11.8\text{ N} = \boxed{27.2\text{ N}}$$

P5.66 (a) To find the maximum possible value of P, imagine impending upward motion as case 1. Setting $\sum F_x = 0$:

$$P\cos 50.0° - n = 0$$

with $f_{s,\max} = \mu_s n$:

$$f_{s,\max} = \mu_s P\cos 50.0°$$
$$= 0.250(0.643)P = 0.161P$$



ANS. FIG. P5.66

Setting $\sum F_y = 0$:

$$P\sin 50.0° - 0.161P - (3.00\text{ kg})(9.80\text{ m/s}^2) = 0$$

$$P_{\max} = \boxed{48.6\text{ N}}$$

To find the minimum possible value of P, consider impending downward motion. As in case 1,

$$f_{s,\max} = 0.161P$$

Setting $\sum F_y = 0$:

$$P\sin 50.0° + 0.161P - (3.00\text{ kg})(9.80\text{ m/s}^2) = 0$$

$$P_{\min} = \boxed{31.7\text{ N}}$$

(b) If $P > 48.6$ N, the block slides up the wall. If $P < 31.7$ N, the block slides down the wall.

(c) We repeat the calculation as in part (a) with the new angle.

Consider impending upward motion as case 1. Setting

$$\sum F_x = 0: \qquad P\cos 13° - n = 0$$
$$f_{s,\,\max} = \mu_s n: \quad f_{s,\,\max} = \mu_s P\cos 13°$$
$$= 0.250(0.974)P = 0.244P$$

Setting

$$\sum F_y = 0: \quad P\sin 13° - 0.244P - (3.00\text{ kg})(9.80\text{ m/s}^2) = 0$$
$$P_{\max} = -1\,580\text{ N}$$

The push cannot really be negative. However large or small it is, it cannot produce upward motion. To find the minimum possible value of P, consider impending downward motion. As in case 1,

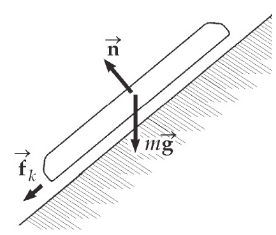
$$f_{s,\,\max} = 0.244P$$

Setting

$$\sum F_y = 0: \quad P\sin 13° + 0.244P - (3.00\text{ kg})(9.80\text{ m/s}^2) = 0$$
$$P_{\min} = \boxed{62.7\text{ N}}$$

$P \geq 62.7$ N. The block cannot slide up the wall. If $P < 62.7$ N, the block slides down the wall.

P5.67 We must consider separately the rock when it is in contact with the roof and when it has gone over the top into free fall. In the first case, we take x and y as parallel and perpendicular to the surface of the roof:



ANS. FIG. P5.67

$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$
$$n = mg\cos\theta$$

then friction is $f_k = \mu_k n = \mu_k mg\cos\theta$

$$\sum F_x = ma_x: \quad -f_k - mg\sin\theta = ma_x$$

$$a_x = -\mu_k g\cos\theta - g\sin\theta = (-0.400\cos 37.0° - \sin 37.0°)(9.80 \text{ m/s}^2)$$
$$= -9.03 \text{ m/s}^2$$

The rock goes ballistic with speed given by

$$v_{xf}^2 = v_{xi}^2 + 2a_x\left(x_f - x_i\right) = (15 \text{ m/s})^2 + 2\left(-9.03 \text{ m/s}^2\right)(10 \text{ m} - 0)$$
$$= 44.4 \text{ m}^2/\text{s}^2$$
$$v_{xf} = 6.67 \text{ m/s}$$

For the free fall, we take x and y horizontal and vertical:

$$v_{yf}^2 = v_{yi}^2 + 2a_y\left(y_f - y_i\right)$$
$$y_f = \frac{v_{yf}^2 - v_{yi}^2}{2a_y}$$
$$= \frac{0 - (6.67 \text{ m/s } \sin 37°)^2}{2\left(-9.8 \text{ m/s}^2\right)} = 0.822 \text{ m above the top of the roof}$$

Then $y_{\text{tot}} = 10.0 \text{ m } \sin 37.0° + 0.822 \text{ m} = \boxed{6.84 \text{ m}}$.

P5.68 The motion of the salmon as it breaks the surface of the water and eventually leaves must be modeled in two steps. The first is over a distance of 0.750 m, until half of the salmon is above the surface, while a constant force, P, is applied upward. In this motion, the initial velocity of the salmon as it nears the surface is 3.58 m/s and ends with the salmon having a velocity, $v_{½}$, when it is half out of the water. This is then the initial velocity for the second motion, where gravity is a second force to be considered acting on the fish. This motion is again over a distance of 0.750 m, and results with the salmon having a final velocity of 6.26 m/s.

The vertical motion equations, in each case, would be

$$a_{1y} = \frac{v_{1yf}^2 - v_{1yi}^2}{2\ \Delta y} = \frac{v_{1/2}^2 - (3.58 \text{ m/s})^2}{2\ (0.750 \text{ m})} = \frac{v_{1/2}^2 - \left(12.8 \text{ m}^2/\text{s}^2\right)}{1.50 \text{ m}}$$

and

$$a_{2y} = \frac{v_{2yf}^2 - v_{2yi}^2}{2\ \Delta y} = \frac{(6.26 \text{ m/s})^2 - v_{1/2}^2}{2\ (0.750 \text{ m})} = \frac{\left(39.2 \text{ m}^2/\text{s}^2\right) - v_{1/2}^2}{1.50 \text{ m}}$$

Solving for the square of the velocity in each case and equating the expressions, we find

$$v_{1/2}^2 = (1.50\text{ m})a_{1y} + (12.8\text{ m}^2/\text{s}^2)$$

$$v_{1/2}^2 = (39.2\text{ m}^2/\text{s}^2) - (1.50\text{ m})a_{2y}$$

$$(1.50\text{ m})a_{1y} + (12.8\text{ m}^2/\text{s}^2) = (39.2\text{ m}^2/\text{s}^2) - (1.50\text{ m})a_{2y}$$
$$a_{1y} = (17.6\text{ m/s}^2) - a_{2y}$$

In the first motion, the relationship between the net acceleration and the net force can be written as

$$\sum F_y = P = ma_{1y}$$
$$P = (61.0\text{ kg})a_{1y}$$

Substituting from above,

$$P = (61.0\text{ kg})\left[(17.6\text{ m/s}^2) - a_{2y}\right]$$
$$P = 1\ 070\text{ N} - (61.0\text{ kg})a_{2y}$$

In the second motion, the relationship between the net acceleration and the net force can be written as

$$\sum F_y = P - mg = ma_{2y}$$
$$P = mg + ma_{2y} = (61.0\text{ kg})(9.80\text{ m/s}^2) + (61.0\text{ kg})a_{2y}$$
$$P = 598\text{ N} + (61.0\text{ kg})a_{2y}$$

Equating these two equations for, P,

$$1\ 070\text{ N} - (61.0\text{ kg})a_{2y} = 598\text{ N} + (61.0\text{ kg})a_{2y}$$
$$-(122.0\text{ kg})a_{2y} = -472\text{ N}$$
$$a_{2y} = 3.87\text{ m/s}^2$$

Plugging into either of the above,

$$P = 598\text{ N} + (61.0\text{ kg})(3.87\text{ m/s}^2)$$
$$P = \boxed{834\text{ N}}$$

P5.69 Take $+x$ in the direction of motion of the tablecloth. For the mug:

$$\sum F_x = ma_x: \quad 0.1 \text{ N} = 0.2 \text{ kg } a_x$$
$$a_x = 0.5 \text{ m/s}^2$$

Relative to the tablecloth, the acceleration of the mug is $0.500 \text{ m/s}^2 - 3.00 \text{ m/s}^2 = -2.50 \text{ m/s}^2$. The mug reaches the edge of the tablecloth after time given by

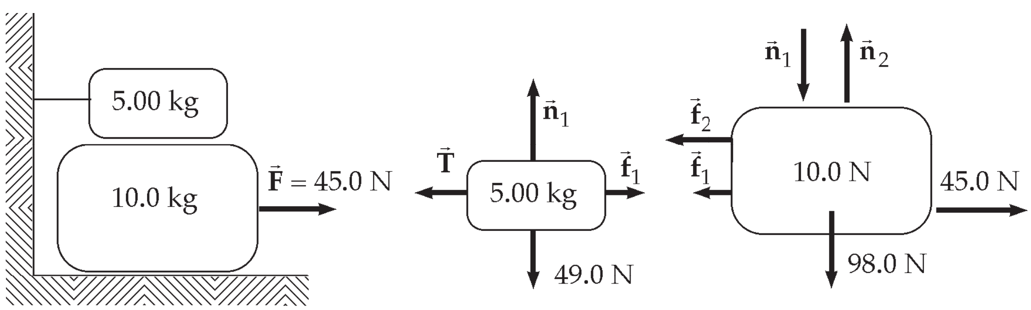
$$\Delta x = v_{xi}t + \frac{1}{2}a_x t^2$$
$$-0.300 \text{ m} = 0 + \frac{1}{2}\left(-2.50 \text{ m/s}^2\right)t^2$$
$$t = 0.490 \text{ s}$$

The motion of the mug relative to tabletop is over distance

$$\frac{1}{2}a_x t^2 = \frac{1}{2}\left(0.500 \text{ m/s}^2\right)\left(0.490 \text{ s}\right)^2 = \boxed{0.060\,0 \text{ m}}$$

The tablecloth slides 36 cm over the table in this process.

***P5.70** (a) The free-body diagrams are shown in the figure below.



ANS. FIG. P5.70(a)

f_1 and n_1 appear in both diagrams as action-reaction pairs.

(b) For the 5.00-kg mass, Newton's second law in the y direction gives:

$$n_1 = m_1 g = (5.00 \text{ kg})(9.80 \text{ m/s}^2) = 49.0 \text{ N}$$

In the x direction,

$$f_1 - T = 0$$

$$T = f_1 = \mu mg = 0.200(5.00 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{9.80 \text{ N}}$$

For the 10.0-kg mass, Newton's second law in the *x* direction gives:

$$45.0 \text{ N} - f_1 - f_2 = (10.0 \text{ kg})a$$

In the *y* direction,

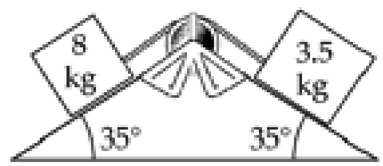
$$n_2 - n_1 - 98.0 \text{ N} = 0$$

$$f_2 = \mu n_2 = \mu(n_1 + 98.0 \text{ N}) = 0.20(49.0 \text{ N} + 98.0 \text{ N}) = 29.4 \text{ N}$$

$$45.0 \text{ N} - 9.80 \text{ N} - 29.4 \text{ N} = (10.0 \text{ kg})a$$

$$a = \boxed{0.580 \text{ m/s}^2}$$

***P5.71** For the right-hand block (m_1), $\sum F_1 = m_1 a$ gives



ANS. FIG. P5.71

$$-m_1 g \sin 35.0° - f_{k,1} + T = m_1 a$$

or

$$-(3.50 \text{ kg})(9.80 \text{ m/s}^2)\sin 35.0° - \mu_s(3.50 \text{ kg})(9.80 \text{ m/s}^2)\cos 35.0° + T = (3.50 \text{ kg})(1.50 \text{ m/s}^2) \quad \textbf{[1]}$$

For the left-hand block (m_2), $\sum F_2 = m_2 a$ gives

$$+m_2 g \sin 35.0° - f_{k,2} - T = m_2 a$$

$$+(8.00 \text{ kg})(9.80 \text{ m/s}^2)\sin 35.0° - \mu_s(8.00 \text{ kg})(9.80 \text{ m/s}^2)\cos 35.0° - T = (8.00 \text{ kg})(1.50 \text{ m/s}^2) \quad \textbf{[2]}$$

Solving equations [1] and [2] simultaneously gives

(a) $\boxed{\mu_k = 0.087\ 1}$

(b) $\boxed{T = 27.4 \text{ N}}$

Additional Problems

P5.72 (a) Choose the black glider plus magnet as the system.

$$\sum F_x = ma_x \to +0.823\text{ N} = (0.24\text{ kg})a$$

$$a = \boxed{3.43\text{ m/s}^2\text{ toward the scrap iron}}$$

(b) The force of attraction the magnet exerts on the scrap iron is the same as in (a):

$$a_{\text{black}} = \boxed{3.43\text{ m/s}^2\text{ toward the scrap iron}}$$

By Newton's third law, the force the black glider exerts on the magnet is equal and opposite to the force exerted on the scrap iron:

$$\sum F_x = ma_x \to -0.823\text{ N} = -(0.12\text{ kg})\ a$$

$$a = \boxed{-6.86\text{ m/s}^2\text{ toward the magnet}}$$

P5.73 Let situation 1 be the original situation, with $\sum F_1 = m_1 a_1 = m_1(8.40\text{ mi/h}\cdot\text{s})$. Let situation 2 be the case with larger force $\sum F_2 = (1+0.24)\sum F_1 = m_1 a_2 = 1.24 m_1 a_1$, so $a_2 = 1.24 a_1$. Let situation 3 be the case with the original force but with smaller mass:

$$\sum F_3 = \sum F_1 = m_3 a_3 = (1-0.24) m_1 a_3$$

$$a_3 = \frac{\sum F_1}{0.76 m_1} = 1.32 a_1$$

(a) With $1.32a$ greater than $1.24a_1$, $\boxed{\text{reducing the mass}}$ gives a larger increase in acceleration.

(b) Now with both changes,

$$\sum F_4 = m_4 a_4$$

$$1.24 \sum F_1 = 0.76 m_1 a_4$$

$$a_4 = \frac{1.24}{0.76}\frac{\sum F_1}{m_1} = \frac{1.24}{0.76}(8.40\text{ mi/h}\cdot\text{s}) = \boxed{13.7\text{ mi/h}\cdot\text{s}}$$

P5.74 Find the acceleration of the block according to the kinematic equations. The book travels through a displacement of 1.00 m in a time interval of 0.483 s. Use the equation $x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$, where $\Delta x = x_f - x_i = 1.00$ m, $\Delta t = t = 0.483$ s, and $v_i = 0$:

$$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2 \rightarrow a = \frac{2\Delta x}{t^2} = 8.57 \text{ m/s}^2$$

Now, find the acceleration of the block caused by the forces. See the free-body diagram below. We take the positive y axis is perpendicular to the incline; the positive x axis is parallel and down the incline.

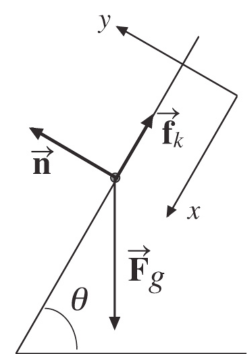
$$\sum F_y = ma_y:$$

$$n - mg\cos\theta = 0 \rightarrow n = mg\cos\theta$$

$$\sum F_x = ma_x:$$

$$mg\sin\theta - f_k = ma$$

where $f_k = \mu_k n = \mu_k mg\cos\theta$



ANS. FIG. P5.74

Substituting the express for kinetic friction into the x-component equation gives

$$mg\sin\theta - \mu_k mg\cos\theta = ma \rightarrow a = g(\sin\theta - \mu_k\cos\theta)$$

For $\mu_k = 0.300$, and $\theta = 60.0°$, $a = 7.02 \text{ m/s}^2$.

The situation is impossible because these forces on the book cannot produce the acceleration described.

P5.75 (a) Since the puck is on a horizontal surface, the normal force is vertical. With $a_y = 0$, we see that

$$\sum F_y = ma_y \rightarrow n - mg = 0 \quad \text{or} \quad n = mg$$

Once the puck leaves the stick, the only horizontal force is a friction force in the negative x direction (to oppose the motion of the puck). The acceleration of the puck is

$$a_x = \frac{\Sigma F_x}{m} = \frac{-f_k}{m} = \frac{-\mu_k n}{m} = \frac{-\mu_k(mg)}{m} = \boxed{-\mu_k g}$$

(b) Then $v_{xf}^2 = v_{xi}^2 + 2a\Delta x$ gives the horizontal displacement of the puck before coming to rest as

$$\Delta x = \frac{v_{xf}^2 - v_{xi}^2}{2a_x} = \frac{0 - v_i^2}{2(-\mu_k g)} = \boxed{\frac{v_i^2}{2\mu_k g}}$$

***P5.76** (a) Let x represent the position of the glider along the air track. Then $z^2 = x^2 + h_0^2$, $x = (z^2 - h_0^2)^{1/2}$, and $v_x = \frac{dx}{dt} = \frac{1}{2}(z^2 - h_0^2)^{-1/2}(2z)\frac{dz}{dt}$.

Now $\frac{dz}{dt}$ is the rate at which the string passes over the pulley, so it is equal to v_y of the counterweight.

$$v_x = z(z^2 - h_0^2)^{-1/2} v_y = uv_y$$

(b) $a_x = \frac{dv_x}{dt} = \frac{d}{dt}uv_y = u\frac{dv_y}{dt} + v_y\frac{du}{dt}$

At release from rest, $v_y = 0$ and $a_x = ua_y$.

(c) $\sin 30.0° = \frac{80.0\text{ cm}}{z}$, $z = 1.60$ m,

$$u = (z^2 - h_0^2)^{-1/2} z = \left[(1.6\text{ m})^2 - (0.8\text{ m})^2\right]^{-1/2}(1.6\text{ m}) = 1.15\text{ m}$$

For the counterweight, $\sum F_y = ma_y$:

$$T - (0.5\text{ kg})(9.80\text{ m/s}^2) = -(0.5\text{ kg})a_y$$

$$a_y = (-2\text{ kg}^{-1})T + (9.80\text{ m/s}^2)$$

For the glider, $\sum F_x = ma_x$:

$$\begin{aligned} T\cos 30° &= (1.00\text{ kg})\ a_x = (1.15\text{ kg})a_y \\ &= (1.15\text{ kg})\left[(-2\text{ kg}^{-1})T + 9.80\text{ m/s}^2\right] \\ &= -2.31T + 11.3\text{ N} \end{aligned}$$

$$3.18T = 11.3\text{ N}$$

$$T = \boxed{3.56\text{ N}}$$

***P5.77** When an object of mass m is on this frictionless incline, the only force acting parallel to the incline is the parallel component of weight, $mg\sin\theta$, directed down the incline. The acceleration is then

$$a = \frac{mg\sin\theta}{m} = g\sin\theta = \left(9.80\ \text{m/s}^2\right)\sin 35.0° = 5.62\ \text{m/s}^2$$

directed down the incline.

(a) Taking up the incline as positive, the time for the sled projected up the incline to come to rest is given by

$$t = \frac{v_f - v_i}{a} = \frac{0 - 5.00\ \text{m/s}}{-5.62\ \text{m/s}^2} = 0.890\ \text{s}$$

The distance the sled travels up the incline in this time is

$$\Delta x = v_{\text{avg}}t = \left(\frac{v_f + v_i}{2}\right) = \left(\frac{0 + 5.00\ \text{m/s}}{2}\right)(0.890\ \text{s}) = \boxed{2.23\ \text{m}}$$

(b) The time required for the first sled to return to the bottom of the incline is the same as the time needed to go up, that is, t = 0.890 s. In this time, the second sled must travel down the entire 10.0-m length of the incline. The needed initial velocity is found from

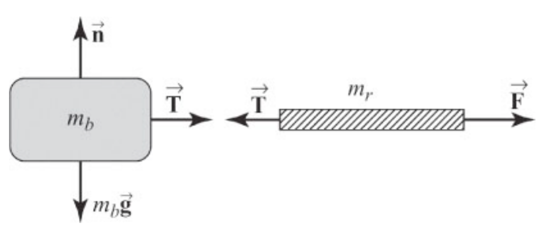
$$\Delta x = v_i t + \frac{1}{2}at^2$$

which gives

$$v_i = \frac{\Delta x}{t} - \frac{at}{2} = \frac{-10.0\ \text{m}}{0.890\ \text{s}} - \frac{\left(-5.62\ \text{m/s}^2\right)(0.890\ \text{s})}{2} = -8.74\ \text{m/s}$$

or $\boxed{8.74\ \text{m/s down the incline}}$

P5.78 (a) free-body diagrams of block and rope are shown in ANS. FIG. P5.78(a):



ANS. FIG. P5.78(a)

(b) Applying Newton's second law to the rope yields

$$\sum F_x = ma_x \quad \Rightarrow \quad F - T = m_r a \quad \text{or} \quad T = F - m_r a \qquad \textbf{[1]}$$

Then, applying Newton's second law to the block, we find

$$\sum F_x = ma_x \quad \Rightarrow T = m_b a \quad \text{or} \quad F - m_r a = m_b a$$

which gives

$$\boxed{a = \frac{F}{m_b + m_r}}$$

(c) Substituting the acceleration found above back into equation [1] gives the tension at the left end of the rope as

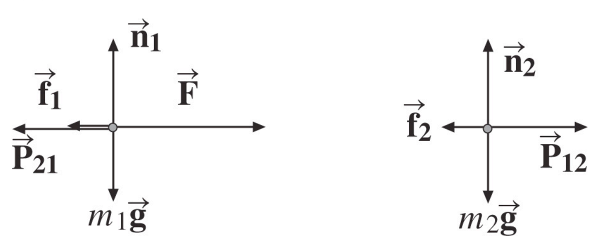
$$T = F - m_r a = F - m_r\left(\frac{F}{m_b + m_r}\right) = F\left(\frac{m_b + \cancel{m_r} - \cancel{m_r}}{m_b + m_r}\right)$$

or $$\boxed{T = \left(\frac{m_b}{m_b + m_r}\right)F}$$

(d) From the result of (c) above, we see that as m_r approaches zero, T approaches F. Thus,

the tension in a cord of negligible mass is constant along its length.

P5.79 (a) The free-body diagrams of the two blocks shown in ANS. FIG. P5.79(a):



ANS. FIG. P5.79(a)

Vertical forces sum to zero because the blocks move on a horizontal surface; therefore, $a_y = 0$ for each block.

$\sum F_{1y} = m_1 a_y$: $\sum F_{2y} = m_2 a_y$:

$-m_1 g + n_1 = 0 \rightarrow n_1 = m_1 g$ $-m_2 g + n_2 = 0 \rightarrow n_2 = m_2 g$

Kinetic friction is: Kinetic friction is:

$f_1 = \mu_1 n_1 = \mu_1 m_1 g$ $f_2 = \mu_2 n_2 = \mu_2 m_2 g$

(b) The net force on the system of the blocks would be equal to the magnitude of the force, F, minus the friction force on each block. The blocks will have the same acceleration.

(c) The net force on the mass, m_1, would be equal to the force, F, minus the friction force on m_1 and the force P_{21}, as identified in the free-body diagram.

(d) The net force on the mass, m_2, would be equal to the force, P_{12}, minus the friction force on m_2, as identified in the free-body diagram.

(e) The blocks are pushed to the right by force $\vec{\mathbf{F}}$, so kinetic friction $\vec{\mathbf{f}}$ acts on each block to the left. Each block has the same horizontal acceleration, $a_x = a$. Each block exerts an equal and opposite force on the other, so those forces have the same magnitude: $P_{12} = P_{21} = P$.

$\sum F_{1x} = m_1 a_x$: $\sum F_{2x} = m_2 a_x$:

$F - P - f_1 = m_1 a$ $P - f_2 = m_2 a$

$\boxed{F - P - \mu_1 m_1 g = m_1 a}$ $\boxed{P - \mu_2 m_2 g = m_2 a}$

(f) Adding the above two equations of x components, we find

$$F - P - \mu_1 m_1 g + P - \mu_2 m_2 g = m_1 a + m_2 a$$
$$F - \mu_1 m_1 g - \mu_2 m_2 g = (m_1 + m_2)a \rightarrow$$
$$\boxed{a = \frac{F - \mu_1 m_1 g - \mu_2 m_2 g}{m_1 + m_2}}$$

(g) From the x component equation for block 2, we have

$$P - \mu_2 m_2 g = m_2 a \rightarrow P = \mu_2 m_2 g + m_2 a$$

$$\boxed{P = \left(\frac{m_2}{m_1 + m_2}\right)\left[F + (\mu_2 - \mu_1) m_1 g\right]}$$

We see that when the coefficients of friction are equal, $\mu_1 = \mu_2$, the magnitude P is independent of friction.

P5.80 (a) The cable does not stretch: Whenever one car moves 1 cm, the other moves 1 cm.

> At any instant they have the same velocity and at all instants they have the same acceleration.

(b) Consider the BMW as the object.

$$\sum F_y = ma_y:$$

$$+T - mg = ma$$

$$+T - (1\ 461\ \text{kg})(9.80\ \text{m/s}^2) = (1\ 461\ \text{kg})(1.25\ \text{m/s}^2)$$

$$T = \boxed{1.61 \times 10^4\ \text{N}}$$

(c) Consider both cars as the object.

$$\sum F_y = ma_y:$$

$$+T - (m + M)g = (m + M)a$$

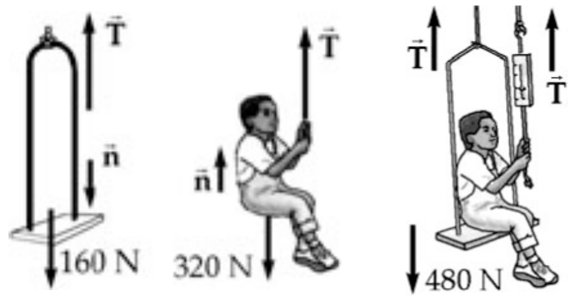
$$+T - (1\ 461\ \text{kg} + 1\ 207\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= (1\ 461\ \text{kg} + 1\ 207\ \text{kg})(1.25\ \text{m/s}^2)$$

$$T_{\text{above}} = \boxed{2.95 \times 10^4\ \text{N}}$$

P5.81 (a) ANS. FIG. P5.81(a) shows the free-body diagrams for this problem.

Note that the same-size force n acts up on Nick and down on chair, and cancels out in the diagram. The same-size force T = 250 N acts up on Nick and up on chair, and appears twice in the diagram.



ANS. FIG. P5.81(a)

(b) First consider Nick and the chair together as the system. Note that **two** ropes support the system, and $T = 250$ N in each rope.

Applying $\sum F = ma$, $$2T - (160\text{ N} + 320\text{ N}) = ma$$

where $$m = \frac{480\text{ N}}{9.80\text{ m/s}^2} = 49.0\text{ kg}$$

Solving for a gives $$a = \frac{(500 - 480)\text{ N}}{49.0\text{ kg}} = \boxed{0.408\text{ m/s}^2}$$

(c) On Nick, we apply

$\sum F = ma$: $$n + T - 320\text{ N} = ma$$

where $$m = \frac{320\text{ N}}{9.80\text{ m/s}^2} = 32.7\text{ kg}$$

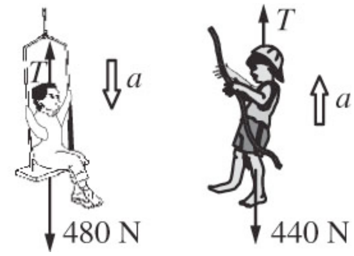
The normal force is the one remaining unknown:

$$n = ma + 320\text{ N} - T$$

Substituting, $$n = (32.7\text{ kg})\left(0.408\text{ m/s}^2\right) + 320\text{ N} - 250\text{ N}$$

gives $$n = \boxed{83.3\text{ N}}$$

P5.82 See ANS. FIG. P5.82 showing the free-body diagrams. The rope has tension T.



ANS. FIG. P5.82

(a) As soon as Nick passes the rope to the other child,

Nick and the seat, with total weight 480 N, will accelerate down and the child, with smaller weight 440 N, will accelerate up.

On Nick and the seat,

$$\sum F_y = +480 \text{ N} - T = \frac{480 \text{ N}}{9.80 \text{ m/s}^2}a$$

On the child,

$$\sum F_y = +T - 440 \text{ N} = \frac{440 \text{ N}}{9.80 \text{ m/s}^2}a$$

Adding,

$$+480 \text{ N} - T + T - 440 \text{ N} = (49.0 \text{ kg} + 44.9 \text{ kg})a$$

$$a = \frac{40 \text{ N}}{93.9 \text{ kg}} = \boxed{0.426 \text{ m/s}^2 = a}$$

The rope tension is T = 440 N + (44.9 kg)(0.426 m/s^2) = 459 N.

(b) The rope must support Nick and the seat, so the rope tension is 480 N.

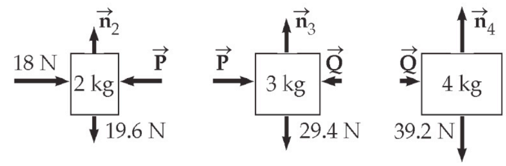
In problem 81, a rope tension of 250 N does not make the rope break. In part (a), the rope is strong enough to support tension 459 N. But now the tension everywhere in the rope is 480 N, so it can exceed the breaking strength of the rope.

The tension in the chain supporting the pulley is 480 N + 480 N = 960 N, so the chain may break first.

P5.83 (a) See free-body diagrams in ANS. FIG. P5.83.

(b) We write $\sum F_x = ma_x$ for each object.

$$18\text{ N} - P = (2\text{ kg})a$$
$$P - Q = (3\text{ kg})a$$
$$Q = (4\text{ kg})a$$



ANS. FIG. P5.83

Adding gives

$$18\text{ N} = (9\text{ kg})a \rightarrow a = \boxed{2.00\text{ m/s}^2}$$

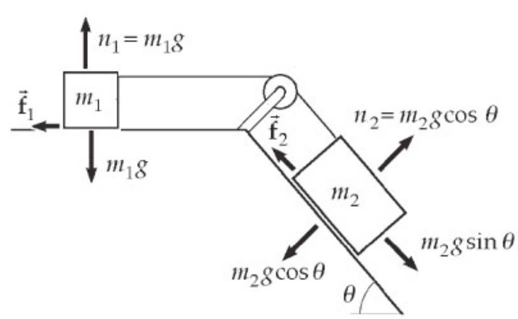
(c) The resultant force on any object is $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$: All have the same acceleration:

$$\sum \vec{\mathbf{F}} = (4\text{ kg})(2\text{ m/s}^2) = \boxed{8.00\text{ N on the 4-kg object}}$$
$$\sum \vec{\mathbf{F}} = (3\text{ kg})(2\text{ m/s}^2) = \boxed{6.00\text{ N on the 3-kg object}}$$
$$\sum \vec{\mathbf{F}} = (2\text{ kg})(2\text{ m/s}^2) = \boxed{2.00\text{ N on the 2-kg object}}$$

(d) From above, $P = 18\text{ N} - (2\text{ kg})a \rightarrow \boxed{P = 14.0\text{ N}}$, and $Q = (4\text{ kg})a \rightarrow \boxed{Q = 8.00\text{ N}}$.

(e) Introducing the heavy block reduces the acceleration because the mass of the system (plasterboard-heavy block-you) is greater. The 3-kg block models the heavy block of wood. The contact force on your back is represented by Q, which is much less than the force F. The difference between F and Q is the net force causing acceleration of the 5-kg pair of objects.

P5.84 (a) For the system to start to move when released, the force tending to move m_2 down the incline, $m_2 g \sin \theta$, must exceed the maximum friction force which can retard the motion:



ANS. FIG. P5.84

$$f_{\max} = f_{1,\max} + f_{2,\max} = \mu_{s,1} n_1 + \mu_{s,2} n_2$$
$$f_{\max} = \mu_{s,1} m_1 g + \mu_{s,2} m_2 g \cos\theta$$

From the table of coefficients of friction in the text, we take $\mu_{s,1} = 0.610$ (aluminum on steel) and $\mu_{s,2} = 0.530$ (copper on steel). With

$$m_1 = 2.00 \text{ kg}, m_2 = 6.00 \text{ kg}, \theta = 30.0°$$

the maximum friction force is found to be $f_{\max} = 38.9$ N. This exceeds the force tending to cause the system to move, $m_2 g \sin\theta = 6.00 \text{ kg}\left(9.80 \text{ m/s}^2\right)\sin 30° = 29.4 \text{ N}$. Hence,

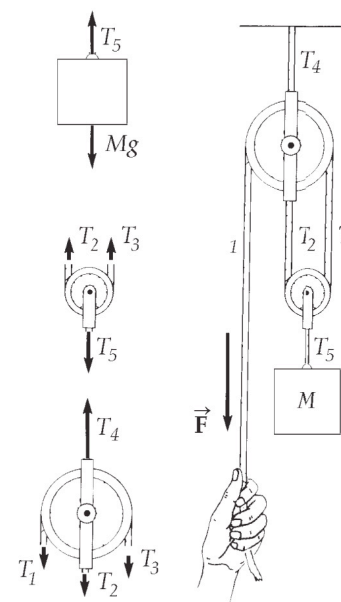
$$\boxed{\text{the system will not start to move when released}}$$

(b) and (c) $\boxed{\text{No answer because the blocks do not move.}}$

(d) The friction forces increase in magnitude until the total friction force retarding the motion, $f = f_1 + f_2$, equals the force tending to set the system in motion. That is, until

$$\boxed{f = m_2 g \sin\theta = 29.4 \text{ N}}$$

P5.85 (a) See ANS. FIG. P5.85 showing the forces. All forces are in the vertical direction. The lifting can be done at constant speed, with zero acceleration and total force zero on each object.



ANS. FIG. 5.85

(b) For M, $\sum F = 0 = T_5 - Mg$

so $T_5 = Mg$

Assume frictionless pulleys. The tension is constant throughout a light, continuous rope. Therefore, $T_1 = T_2 = T_3$.

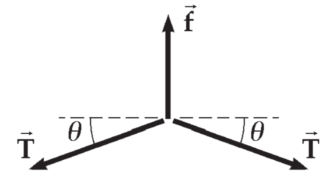
For the bottom pulley,

$$\sum F = 0 = T_2 + T_3 - T_5$$

so $2T_2 = T_5$. Then $\boxed{T_1 = T_2 = T_3 = \dfrac{Mg}{2}}$, $\boxed{T_4 = \dfrac{3Mg}{2}}$, and $\boxed{T_5 = Mg}$.

(c) Since $F = T_1$, we have $\boxed{F = \dfrac{Mg}{2}}$.

***P5.86** (a) Consider forces on the midpoint of the rope. It is nearly in equilibrium just before the car begins to move. Take the y axis in the direction of the force you exert:



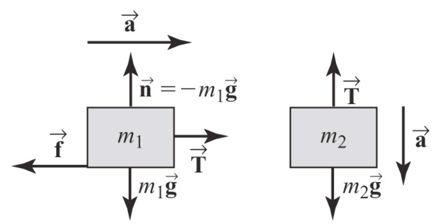
ANS. FIG. P5.86

$$\sum F_y = ma_y: \qquad -T\sin\theta + f - T\sin\theta = 0$$

$$\boxed{T = \frac{f}{2\sin\theta}}$$

(b) $T = \dfrac{100\text{ N}}{2\sin 7°} = \boxed{410\text{ N}}$

***P5.87** The acceleration of the system is found from



ANS. FIG. 5.87

$$\Delta y = v_{yi}t + \frac{1}{2}a_y t^2$$

since $v_{yi} = 0$, we obtain

$$a = \frac{2\Delta y}{t^2} = \frac{2(1.00\text{ m})}{(1.20\text{ s})^2} = 1.39\text{ m/s}^2$$

Using the free-body diagram for m_2, Newton's second law gives

$$\sum F_{y2} = m_2 a:$$
$$m_2 g - T = m_2 a$$
$$T = m_2(g - a)$$
$$= (5.00\text{ kg})(9.80\text{ m/s}^2 - 1.39\text{ m/s}^2)$$
$$= 42.1\text{ N}$$

Then, applying Newton's second law to the horizontal motion of m_1,

$$\sum F_{x1} = m_1 a:$$
$$T - f = m_1 a$$
$$f = T - m_1 a$$
$$= 42.1\text{ N} - (10.0\text{ kg})(1.39\text{ m/s}^2) = 28.2\text{ N}$$

Since $n = m_1 g = 98.0$ N, we have

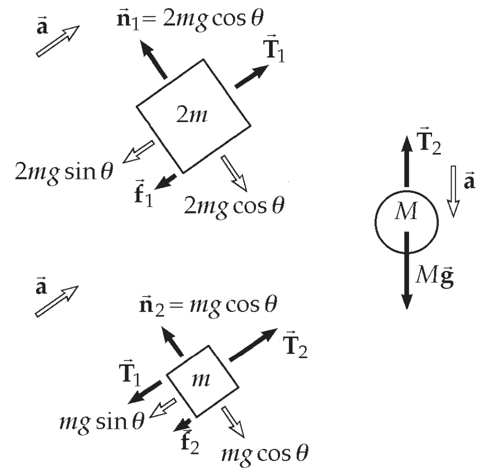
$$\mu_k = \frac{f}{n} = \frac{28.2 \text{ N}}{98.0 \text{ N}} = \boxed{0.288}$$

***P5.88** Applying Newton's second law to each object gives:

$$T_1 = f_1 + 2m(g\sin\theta + a) \quad \textbf{[1]}$$

$$T_2 - T_1 = f_2 + m(g\sin\theta + a) \quad \textbf{[2]}$$

$$T_2 = M(g - a) \quad \textbf{[3]}$$



ANS. FIG. P5.88

(a), (b) Assuming that the system is in equilibrium ($a = 0$) and that the incline is frictionless, ($f_1 = f_2 = 0$), the equations reduce to

$$\boxed{T_1 = 2mg\sin\theta} \quad \textbf{[1']}$$

$$T_2 - T_1 = mg\sin\theta \quad \textbf{[2']}$$

$$T_2 = Mg \quad \textbf{[3']}$$

Substituting [1′] and [3′] into equation [2′] then gives

$$\boxed{M = 3m\sin\theta}$$

so equation [3′] becomes $\boxed{T_2 = 3mg\sin\theta}$

(c), (d) $M = 6m\sin\theta$ (double the value found above), and $f_1 = f_2 = 0$. With these conditions present, the equations become $T_1 = 2m(g\sin\theta + a)$, $T_2 - T_1 = m(g\sin\theta + a)$ and $T_2 = 6m\sin\theta(g - a)$. Solved simultaneously, these yield

$$\boxed{a = \frac{g\sin\theta}{1 + 2\sin\theta}}, \quad \boxed{T_1 = 4mg\sin\theta\left(\frac{1+\sin\theta}{1+2\sin\theta}\right)} \text{ and}$$

$$\boxed{T_2 = 6mg\sin\theta\left(\frac{1+\sin\theta}{1+2\sin\theta}\right)}$$

(e) Equilibrium ($a = 0$) and impending motion **up** the incline, so $M = M_{\max}$ while $f_1 = 2\mu_s mg\cos\theta$ and $f_2 = \mu_s mg\cos\theta$, both directed **down** the incline. Under these conditions, the equations become $T_1 = 2mg(\sin\theta + \mu_s\cos\theta)$, $T_2 - T_1 = mg(\sin\theta + \mu_s\cos\theta)$, and $T_2 = M_{\max}g$, which yield $\boxed{M_{\max} = 3m(\sin\theta + \mu_s\cos\theta)}$.

(f) Equilibrium ($a = 0$) and impending motion **down** the incline, so $M = M_{\min}$, while $f_1 = 2\mu_s mg\cos\theta$ and $f_2 = \mu_s mg\cos\theta$, both directed **up** the incline. Under these conditions, the equations are $T_1 = 2mg(\sin\theta - \mu_s\cos\theta)$, $T_2 - T_1 = mg(\sin\theta - \mu_s\cos\theta)$, and $T_2 = M_{\min}g$, which yield $\boxed{M_{\min} = 3m(\sin\theta - \mu_s\cos\theta)}$. When this expression gives a negative value, it corresponds physically to a mass M hanging from a cord over a pulley at the bottom end of the incline.

(g) $\boxed{T_{2,\max} - T_{2,\min} = M_{\max}g - M_{\min}g = 6\mu_s mg\cos\theta}$

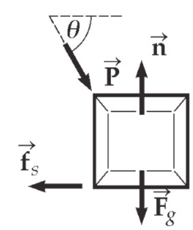
P5.89 (a) The crate is in equilibrium, just before it starts to move. Let the normal force acting on it be n and the friction force, f_s.

Resolving vertically: $\sum F_y = ma_y$ gives

$$n = F_g + P\sin\theta$$

Horizontally, $\sum F_x = ma_x$ gives

$$P\cos\theta = f$$



ANS. FIG. P5.89

But,

$$f_s \le \mu_s n$$

i.e.,

$$P\cos\theta \le \mu_s\left(F_g + P\sin\theta\right)$$

or

$$P(\cos\theta - \mu_s\sin\theta) \le \mu_s F_g$$

Divide by $\cos\theta$:

$$P(1 - \mu_s\tan\theta) \le \mu_s F_g\sec\theta$$

Then

$$P_{\text{minimum}} = \frac{\mu_s F_g \sec\theta}{1 - \mu_s \tan\theta}$$

(b) To set the crate into motion, the x component ($P\cos\theta$) must overcome friction $f_s = \mu_s n$:

$$P\cos\theta \geq \mu_s n = \mu_s\,(F_g + P\sin\theta)$$

$$P(\cos\theta - \mu_s \sin\theta) \geq \mu_s\, F_g$$

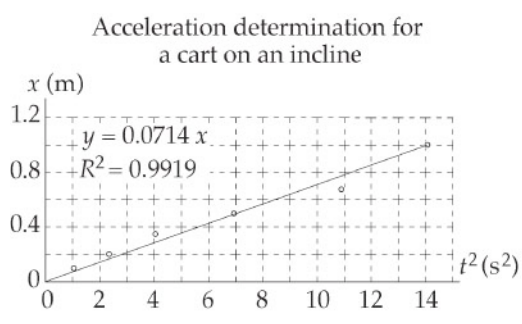
For this condition to be satisfied, it must be true that

$$(\cos\theta - \mu_s\,\sin\theta) > 0 \rightarrow \mu_s \tan\theta < 1 \rightarrow \tan\theta < \frac{1}{\mu_s}$$

If this condition is not met, no value of P can move the crate.

P5.90 (a) See table below and graph in ANS. FIG. P5.90(a).

t(s)	t^2(s^2)	x(m)
0	0	0
1.02	1.04 0	0.100
1.53	2.34 1	0.200
2.01	4.04 0	0.350
2.64	6.97 0	0.500
3.30	10.89	0.750
3.75	14.06	1.00



ANS. FIG. P5.90(a)

(b) From $x = \frac{1}{2}at^2$ the slope of a graph of x versus t^2 is $\frac{1}{2}a$, and

$$a = 2 \times \text{slope} = 2\left(0.071\,4 \text{ m/s}^2\right) = \boxed{0.143 \text{ m/s}^2}$$

(c) From $a' = g\sin\theta$,

$$a' = 9.80 \text{ m/s}^2\left(\frac{1.77\,4}{127.1}\right) = 0.137 \text{ m/s}^2 \text{, different by 4\%.}$$

The difference is accounted for by the uncertainty in the data, which we may estimate from the third point as

$$\frac{0.350 - (0.071\,4)(4.04)}{0.350} = 18\%$$

Thus the acceleration values agree.

P5.91 (a) The net force on the cushion is in a fixed direction, downward and forward making angle $\theta = \tan^{-1}(F/mg)$ with the vertical.

Because the cushion starts from rest, the direction of its line of motion will be the same as that of the net force.

We show the path is a straight line another way. In terms of a standard coordinate system, the x and y coordinates of the cushion are

$$y = h - \frac{1}{2}gt^2$$

$$x = \frac{1}{2}(F/m)t^2 \rightarrow t^2 = (2m/F)x$$

Substitution of t^2 into the equation for y gives

$$y = h - (mg/f)x$$

which is an equation for a straight line.

(b) Because the cushion starts from rest, it will move in the direction of the net force which is the direction of its acceleration; therefore, it will move with increasing speed and its velocity changes in magnitude.

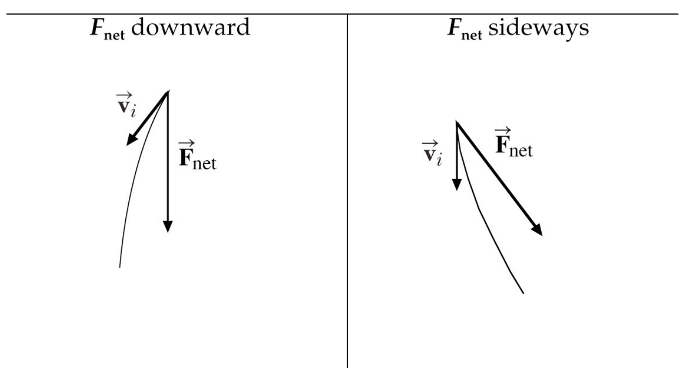
(c) Since the line of motion is in the direction of the net force, they both make the same angle with the vertical. Refer to Figure P5.91 in the textbook: in terms of a right triangle with angle θ, height h, and base x,

$$\tan\theta = x/h = F/mg \to x = hF/mg$$
$$x = \frac{(8.00\text{ m})(2.40\text{ N})}{(1.20\text{ kg})(9.80\text{ m/s}^2)}$$

and the cushion will land a distance

$x = \boxed{1.63\text{ m from the base of the building}}$.

(d) The cushion will move along a tilted parabola. If the cushion were experiencing a constant net force directed vertically downward (as is normal with gravity), and if its initial velocity were down and somewhat to the left, the trajectory would have the shape of a parabola that we would expect for projectile motion. Because the constant net force is "sideways"—at an angle θ counterclockwise from the vertical—the cushion would travel a similar trajectory as described above, but rotated counterclockwise by the angle θ so that the initial velocity is directed downward. See the figures.



ANS. FIG. P5.91(d)

P5.92 (a) When block 2 moves down 1 cm, block 1 moves 2 cm forward, so block 1 always has twice the speed of block 2, and $\boxed{a_1 = 2a_2}$ relates the magnitudes of the accelerations.

(b) Let T represent the uniform tension in the cord.

For block 1 as object,

$$\sum F_x = m_1 a_1: \quad T = m_1 a_1 = m_1(2a_2)$$
$$T = 2m_1 a_2 \qquad \textbf{[1]}$$

For block 2 as object,

$$\sum F_y = m_2 a_2: \quad T + T - m_2 g = m_2(-a_2)$$
$$2T - m_2 g = -m_2 a_2 \qquad [2]$$

To solve simultaneously we substitute equation [1] into equation [2]:

$$2(2m_1 a_2) - m_2 g = -m_2 a_2 \rightarrow 4m_1 a_2 + m_2 a_2 = m_2 g$$
$$a_2 = \frac{m_2 g}{4m_1 + m_2}$$

for m_2 = 1.30 kg: $\boxed{a_2 = 12.7\text{ N }(1.30\text{ kg} + 4\ m_1)^{-1}\text{ down}}$

(c) If m_1 is very much less than 1.30 kg, a_2 approaches

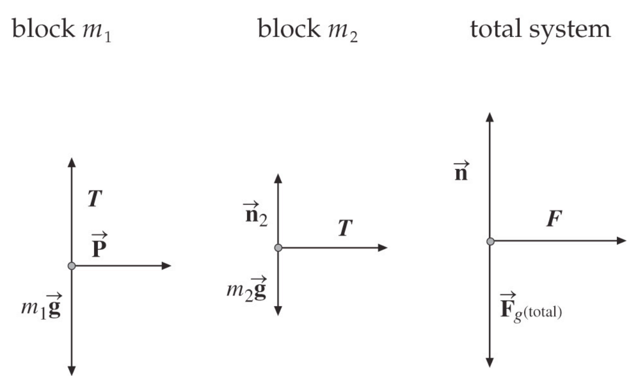
$$12.7\text{ N}/1.30\text{ kg} = \boxed{9.80\text{ m/s}^2\text{ down}}$$

(d) If m_1 approaches infinity, $\boxed{a_2 \text{ approaches zero}}$.

(e) From equation (2) above, $2T = m_2 g + m_2 a_2 = 12.74\text{ N} + 0$,
$\boxed{T = 6.37\text{ N}}$

(f) Yes. As m_1 approaches zero, block 2 is essentially in free fall. As m_2 becomes negligible compared to m_1, m_2 has very little weight, so the system is nearly in equilibrium.

P5.93 We will use $\sum F = ma$ on each object, so we draw force diagrams for the $M + m_1 + m_2$ system, and also for blocks m_1 and m_2. Remembering that normal forces are always perpendicular to the contacting surface, and always **push** on a body, draw n_1 and n_2 as shown.



ANS. FIG. P5.93

Note that m_1 is in contact with the cart, and therefore feels a normal force exerted by the cart. Remembering that ropes always **pull** on bodies toward the center of the rope, draw the tension force $\vec{\mathbf{T}}$. Finally, draw the gravitational force on each block, which always points downwards.

Applying $\sum F = ma$,

For m_1: $T - m_1 g = 0$

For m_2: $T = m_2 a$

Eliminating T,

$$a = \frac{m_1 g}{m_2}$$

For all three blocks:

$$\boxed{F = (M + m_1 + m_2)\frac{m_1 g}{m_2}}$$

P5.94 (a) $\sum F_y = ma_y$:

$n - mg\cos\theta = 0$

or $n = (8.40 \text{ kg})(9.80 \text{ m/s}^2)\cos\theta$

$$\boxed{n = (82.3 \text{ N})\cos\theta}$$

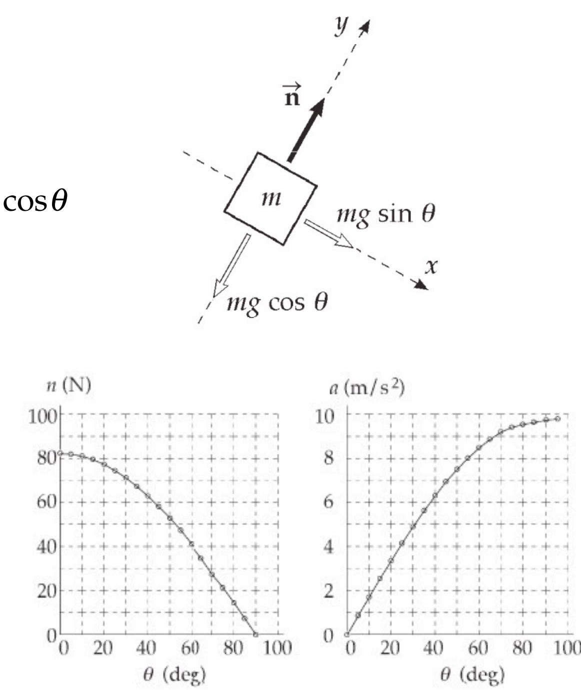
(b) $\sum F_x = ma_x$:

$mg\sin\theta = ma$

or

$a = g\sin\theta$

$$\boxed{a = (9.80 \text{ m/s}^2)\sin\theta}$$



ANS. FIG. P5.94

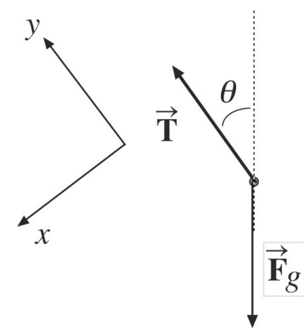
(c)

θ, deg	n, N	a, m/s^2
0.00	82.3	0.00
5.00	82.0	0.854
10.0	81.1	1.70
15.0	79.5	2.54
20.0	77.4	3.35
25.0	74.6	4.14
30.0	71.3	4.90
35.0	67.4	5.62
40.0	63.1	6.30
45.0	58.2	6.93
50.0	52.9	7.51
55.0	47.2	8.03
60.0	41.2	8.49
65.0	34.8	8.88
70.0	28.2	9.21
75.0	21.3	9.47
80.0	14.3	9.65
85.0	7.17	9.76
90.0	0.00	9.80

(d) At 0°, the normal force is the full weight and the acceleration is zero. At 90°, the mass is in free fall next to the vertical incline.

P5.95 Refer to the free-body diagram in ANS. FIG. P5.95. Choose the x axis pointing down the slope so that the string makes the angle θ with the vertical. The acceleration is obtained from $v_f = v_i + at$:

$$a = (v_f - v_i)/t = (30.0 \text{ m/s}^2 - 0)/6.00 \text{ s}$$
$$a = 5.00 \text{ m/s}^2$$



ANS. FIG. P5.95

Because the string stays perpendicular to the ceiling, we know that the toy moves with the same acceleration as the van, 5.00 m/s^2 parallel to the hill. We take the x axis in this direction, so

$$a_x = 5.00 \text{ m/s}^2 \quad \text{and} \quad a_y = 0$$

The only forces on the toy are the string tension in the y direction and the planet's gravitational force, as shown in the force diagram. The size of the latter is mg = (0.100 kg)(9.80 m/s^2) = 0.980 N

(a) Using $\sum F_x = ma_x$ gives (0.980 N) $\sin\theta$ = (0.100 kg)(5.00 m/s^2)

Then $\sin\theta$ = 0.510 and $\theta = \boxed{30.7°}$

(b) Using $\sum F_y = ma_y$ gives $+T$ – (0.980 N) $\cos\theta$ = 0

T = (0.980 N) cos 30.7° = $\boxed{0.843 \text{ N}}$

Challenge Problems

P5.96 $\sum \vec{F} = m\vec{a}$ gives the object's acceleration:

$$\vec{\mathbf{a}} = \frac{\sum \vec{\mathbf{F}}}{m} = \frac{\left(8.00\hat{\mathbf{i}} - 4.00t\hat{\mathbf{j}}\right) \text{ N}}{2.00 \text{ kg}}$$
$$\vec{\mathbf{a}} = \left(4.00 \text{ m/s}^2\right)\hat{\mathbf{i}} - \left(2.00 \text{ m/s}^3\right)t\hat{\mathbf{j}} = \frac{d\vec{\mathbf{v}}}{dt}$$

(a) To arrive at an equation for the instantaneous velocity of object, we must integrate the above equation.

$$d\vec{\mathbf{v}} = \left(4.00\ \text{m/s}^2\right)dt\hat{\mathbf{i}} - \left(2.00\ \text{m/s}^3\right)tdt\hat{\mathbf{j}}$$
$$\int d\vec{\mathbf{v}} = \int\left(4.00\ \text{m/s}^2\right)dt\hat{\mathbf{i}} - \int\left(2.00\ \text{m/s}^3\right)t\,dt\hat{\mathbf{j}}$$
$$\vec{\mathbf{v}} = \left[\left(4.00\ \text{m/s}^2\right)t + c_1\right]\hat{\mathbf{i}} - \left[\left(1.00\ \text{m/s}^3\right)t^2 + c_2\right]\hat{\mathbf{j}}$$

In order to evaluate the constants of integration, we observe that the object is at rest when $t = 0$ s.

$$\vec{\mathbf{v}}(t=0) = 0 = \left[\left(4.00\ \text{m/s}^2\right)0 + c_1\right]\hat{\mathbf{i}} - \left[\left(1.00\ \text{m/s}^3\right)0^2 + c_2\right]\hat{\mathbf{j}}$$

or $\quad c_1 = c_2 = 0$

and

$$\vec{\mathbf{v}} = \left[\left(4.00\ \text{m/s}^2\right)t\right]\hat{\mathbf{i}} - \left[\left(1.00\ \text{m/s}^3\right)t^2\right]\hat{\mathbf{j}}$$

Thus, when $v = 15.0$ m/s,

$$|\vec{\mathbf{v}}| = 15.0\ \text{m/s} = \sqrt{\left[\left(4.00\ \text{m/s}^2\right)t\right]^2 + \left[\left(1.00\ \text{m/s}^3\right)t^2\right]^2}$$
$$15.0\ \text{m/s} = \sqrt{\left[\left(16.0\ \text{m}^2/\text{s}^4\right)t^2\right] + \left[\left(1.00\ \text{m}^2/\text{s}^6\right)t^4\right]}$$
$$225\ \text{m}^2/\text{s}^2 = \left[\left(16.0\ \text{m}^2/\text{s}^4\right)t^2\right] + \left[\left(1.00\ \text{m}^2/\text{s}^6\right)t^4\right]$$
$$0 = \left(1.00\ \text{m}^2/\text{s}^6\right)t^4 + \left(16.0\ \text{m}^2/\text{s}^4\right)t^2 - 225\ \text{m}^2/\text{s}^2$$

We now need a solution to the above equation, in order to find t. The equation can be factored as,

$$0 = \left(t^2 - 9\right)\left(t^2 + 25\right)$$

The solution for t, here, comes from the first factor:

$$t^2 - 9.00 = 0$$
$$t = \pm 3.00\ \text{s} = \boxed{3.00\ \text{s}}$$

(b) In order to find the object's position at this time, we need to integrate the velocity equation, using the assumption that the objects starts at the origin (the constants of integration will again be equal to 0, as before).

$$d\vec{\mathbf{r}} = \left(4.00\ \text{m/s}^2\right)tdt\hat{\mathbf{i}} - \left(1.00\ \text{m/s}^3\right)t^2dt\hat{\mathbf{j}}$$
$$\int d\vec{\mathbf{r}} = \int\left(4.00\ \text{m/s}^2\right)t\,dt\hat{\mathbf{i}} - \int\left(1.00\ \text{m/s}^3\right)t^2\,dt\hat{\mathbf{j}}$$
$$\vec{\mathbf{r}} = \left[\left(2.00\ \text{m/s}^2\right)t^2\right]\hat{\mathbf{i}} - \left[\left(0.333\ \text{m/s}^3\right)t^3\right]\hat{\mathbf{j}}$$

Now, using the time above and finding the magnitude of this displacement vector,

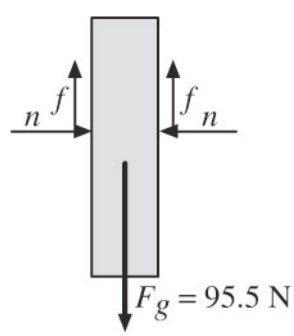
$$|\vec{\mathbf{r}}| = \sqrt{\left[\left(2.00\ \text{m/s}^2\right)(3.00\ \text{s})^2\right]^2 + \left[\left(0.333\ \text{m/s}^3\right)(3.00\ \text{s})^3\right]^2}$$
$$|\vec{\mathbf{r}}| = \boxed{20.1\ \text{m}}$$

(c) Using the displacement vector found in part (b),

$$\vec{\mathbf{r}} = \left[\left(2.00\ \text{m/s}^2\right)t^2\right]\hat{\mathbf{i}} - \left[\left(0.333\ \text{m/s}^3\right)t^3\right]\hat{\mathbf{j}}$$
$$\vec{\mathbf{r}} = \left[\left(2.00\ \text{m/s}^2\right)(3.00\ \text{s})^2\right]\hat{\mathbf{i}} - \left[\left(0.333\ \text{m/s}^3\right)(3.00\ \text{s})^3\right]\hat{\mathbf{j}}$$
$$\vec{\mathbf{r}} = \boxed{(18.0\ \text{m})\hat{\mathbf{i}} - (9.00\ \text{m})\hat{\mathbf{j}}}$$

P5.97 Since the board is in equilibrium, $\sum F_x = 0$ and we see that the normal forces must be the same on both sides of the board. Also, if the minimum normal forces (compression forces) are being applied, the board is on the verge of slipping and the friction force on each side is

$$f = \left(f_s\right)_{\text{max}} = \mu_s n$$



ANS. FIG. P5.97

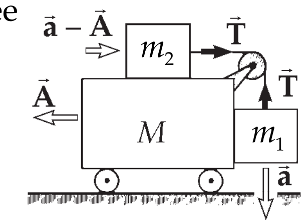
The board is also in equilibrium in the vertical direction, so

$$\sum F_y = 2f - F_g = 0\text{, or } f = \frac{F_g}{2}$$

The minimum compression force needed is then

$$n = \frac{f}{\mu_s} = \frac{F_g}{2\mu_s} = \frac{95.5\text{ N}}{2(0.663)} = \boxed{72.0\text{ N}}$$

***P5.98** We apply Newton's second law to each of the three masses, reading the forces from ANS. FIG. P5.98:



ANS. FIG. P5.98

$$m_2(a - A) = T \Rightarrow \quad a = \frac{T}{m_2} + A \qquad \textbf{[1]}$$

$$MA = R_x = T \Rightarrow \quad A = \frac{T}{M} \qquad \textbf{[2]}$$

$$m_1 a = m_1 g - T \Rightarrow \quad T = m_1(g - a) \qquad \textbf{[3]}$$

(a) Substitute the value for a from [1] into [3] and solve for T:

$$T = m_1\left[g - \left(\frac{T}{m_2} + A\right)\right]$$

Substitute for A from [2]:

$$T = m_1\left[g - \left(\frac{T}{m_2} + \frac{T}{M}\right)\right] \Rightarrow T = \boxed{m_2 g\left[\frac{m_1 M}{m_2 M + m_1(m_2 + M)}\right]}$$

(b) Solve [3] for a and substitute value of T:

$$a = g - \frac{T}{m_1} = g - m_2 g\left[\frac{M}{m_2 M + m_1(m_2 + M)}\right]$$

$$= g\left[1 - \frac{m_2 M}{m_2 M + m_1(m_2 + M)}\right]$$

$$= \boxed{\left[\frac{g m_1(m_2 + M)}{m_2 M + m_1(m_2 + M)}\right]}$$

(c) From [2], $A = \frac{T}{M}$. Substitute the value of T:

$$A = \frac{T}{M} = \boxed{\left[\frac{m_1 m_2 g}{m_2 M + m_1(m_2 + M)}\right]}$$

(d) The acceleration of m_1 is given by

$$a - A = \boxed{\left[\frac{m_1 M g}{m_2 M + m_1(m_2 + M)}\right]}$$

P5.99 (a) The cord makes angle θ with the horizontal where

$$\theta = \tan^{-1}\left(\frac{0.100\text{ m}}{0.400\text{ m}}\right) = 14.0°$$

Applying Newton's second law in the y direction gives

$$\sum F_y = ma_y:$$

$$T\sin\theta - mg + n = 0$$

$$(+10\text{ N})\sin 14.0° - (2.20\text{ kg})(9.80\text{ m/s}^2) + n = 0$$

which gives n = 19.1 N. Applying Newton's second law in the x direction then gives

$$\sum F_x = ma_x:$$

$$T\cos\theta - f_k = ma$$

$$T\cos\theta - \mu_k n = ma$$

$$(+10\text{ N})\cos 14.0° - 0.400(19.1\text{ N}) = (2.20\text{ kg})\ a$$

which gives

$$a = \boxed{0.931\text{ m/s}^2}$$

(b) When x is large we have $n = 21.6$ N, $f_k = 8.62$ N, and $a = (10\text{ N} - 8.62\text{ N})/2.2\text{ kg} = 0.625\text{ m/s}^2$.

As x decreases, the acceleration increases gradually, passes through a maximum, and then drops more rapidly, becoming negative. At $x = 0$ it reaches the value $a = [0 - 0.4(21.6\text{ N} - 10\text{ N})]/2.2\text{ kg} = -2.10\text{ m/s}^2$.

(c) We carry through the same calculations as in part (a) for a variable angle, for which $\cos\theta = x[x^2 + (0.100\text{ m})^2]^{-1/2}$ and $\sin\theta = (0.100\text{ m})[x^2 + (0.100\text{ m})^2]^{-1/2}$. We find

$$a = \left(\frac{1}{2.20\text{ kg}}\right)(10\text{ N})x\left[x^2 + 0.100^2\right]^{-1/2} - 0.400\left(21.6\text{ N} - (10\text{ N})(0.100)\left[x^2 + 0.100^2\right]^{-1/2}\right)$$

$$a = 4.55x\left[x^2 + 0.100^2\right]^{-1/2} - 3.92 + 0.182\left[x^2 + 0.100^2\right]^{-1/2}$$

Now to maximize a we take its derivative with respect to x and set it equal to zero:

$$\frac{da}{dx} = 4.55\left(x^2 + 0.100^2\right)^{-1/2} + 4.55x\left(-\frac{1}{2}\right)2x\left(x^2 + 0.100^2\right)^{-3/2} + 0.182\left(-\frac{1}{2}\right)2x\left(x^2 + 0.100^2\right)^{-3/2} = 0$$

Solving,

$$4.55\left(x^2 + 0.1^2\right) - 4.55x^2 - 0.182x = 0$$

or $\quad x = \boxed{0.250\text{ m}}$

At this point, suppressing units,

$$a = (4.55)(0.250)\left[0.250^2 + 0.100^2\right]^{-1/2} - 3.92 + 0.182\left[0.250^2 + 0.100^2\right]^{-1/2}$$

$$= \boxed{0.976\text{ m/s}^2}$$

(d) We solve, suppressing units,

$$0 = 4.55x\left[x^2 + 0.100^2\right]^{-1/2} - 3.92 + 0.182\left[x^2 + 0.100^2\right]^{-1/2}$$
$$3.92\left[x^2 + 0.100^2\right]^{1/2} = 4.55x + 0.182$$
$$15.4\left[x^2 + 0.100^2\right] = 20.7x^2 + 1.65x + 0.033\ 1$$

which gives the quadratic equation

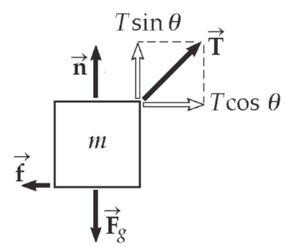
$$5.29x^2 + 1.65x - 0.121 = 0$$

Only the positive root is directly meaningful, so

$$x = \boxed{0.0610\ \text{m}}$$

P5.100 The force diagram is shown on the right. With motion impending,

$$n + T\sin\theta - mg = 0$$
$$f = \mu_s\left(mg - T\sin\theta\right)$$



ANS. FIG. P5.100

and

$$T\cos\theta - \mu_s mg + \mu_s T\sin\theta = 0$$

so $$T = \frac{\mu_s mg}{\cos\theta + \mu_s \sin\theta}$$

To minimize T, we maximize $\cos\theta + \mu_s \sin\theta$:

$$\frac{d}{d\theta}\left(\cos\theta + \mu_s\sin\theta\right) = 0 = -\sin\theta + \mu_s\cos\theta$$

Therefore, the angle where tension T is a minimum is

$$\theta = \tan^{-1}\left(\mu_s\right) = \tan^{-1}(0.350) = 19.3°$$

What is the tension at this angle? From above,

$$T = \frac{0.350(1.30\ \text{kg})(9.80\ \text{m/s}^2)}{\cos 19.3° + 0.350\sin 19.3°} = 4.21\ \text{N}$$

The situation is impossible because at the angle of minimum tension, the tension exceeds 4.00 N.

P5.101 (a) Following the in-chapter example about a block on a frictionless incline, we have

$$a = g\sin\theta = \left(9.80\ \text{m/s}^2\right)\sin 30.0°$$

$$\boxed{a = 4.90\ \text{m/s}^2}$$

(b) The block slides distance x on the incline, with $\sin 30.0° = \dfrac{0.500\ \text{m}}{x}$.

$$x = 1.00\ \text{m:}\ v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) = 0 + 2\left(4.90\ \text{m/s}^2\right)(1.00\ \text{m})$$

$$v_f = \boxed{3.13\ \text{m/s}}\ \text{after time}\ t_s = \frac{2x_f}{v_f} = \frac{2(1.00\ \text{m})}{3.13\ \text{m/s}} = 0.639\ \text{s}$$

(c) To calculate the horizontal range of the block, we need to first determine the time interval during which it is in free fall. We use $y_f - y_i = v_{yi}t + \frac{1}{2}a_y t^2$, and substitute, noting that v_{yi} = (–3.13 m/s) sin 30.0°.

$$-2.00 = (-3.13\ \text{m/s})\sin 30.0° t - \frac{1}{2}\left(9.80\ \text{m/s}^2\right)t^2$$

$$\left(4.90\ \text{m/s}^2\right)t^2 + (1.56\ \text{m/s})t - 2.00\ \text{m} = 0$$

Solving for t gives

$$t = \frac{-1.56\ \text{m/s} \pm \sqrt{(1.56\ \text{m/s})^2 - 4\left(4.90\ \text{m/s}^2\right)(-2.00\ \text{m})}}{9.80\ \text{m/s}^2}$$

Only the positive root is physical, with t = 0.499 s. The horizontal range of the block is then

$$x_f = v_x t = \left[(3.13\ \text{m/s})\cos 30.0°\right](0.499\ \text{s}) = \boxed{1.35\ \text{m}}$$

(d) The total time from release to impact is then

$$\text{total time} = t_s + t = 0.639\ \text{s} + 0.499\ \text{s} = \boxed{1.14\ \text{s}}$$

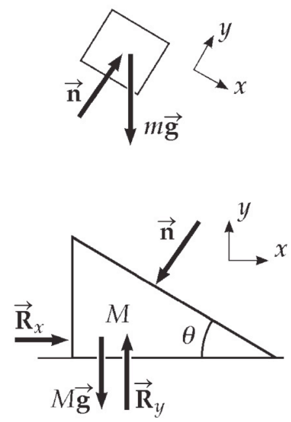
(e) The mass of the block makes no difference, as acceleration due to gravity, whether an object is in free fall or on a frictionless incline, is independent of the mass of the object.

P5.102 Throughout its up and down motion after release the block has

$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$
$$n = mg\cos\theta$$

Let $\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$ represent the force of table on incline. We have

$$\sum F_x = ma_x: \quad +R_x - n\sin\theta = 0$$
$$R_x = mg\cos\theta\sin\theta$$
$$\sum F_y = ma_y: \quad -Mg - n\cos\theta + R_y = 0$$
$$R_y = Mg + mg\cos^2\theta$$



ANS. FIG. P5.102

$$\boxed{\vec{\mathbf{R}} = mg\cos\theta\sin\theta \text{ to the right} + \left(M + m\cos^2\theta\right)g \text{ upward}}$$

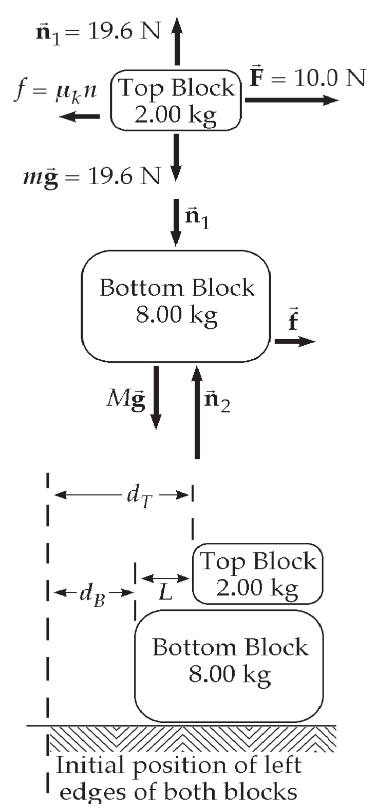
***P5.103** (a) First, draw a free-body diagram of the top block (top panel in ANS. FIG. P5.103). Since $a_y = 0$, $n_1 = 19.6$ N, and

$$f_k = \mu_k n_1 = 0.300(19.6 \text{ N})$$
$$= 5.88 \text{ N}$$

From $\sum F_x = ma_T$,

$$10.0 \text{ N} - 5.88 \text{ N} = (2.00 \text{ kg})a_T$$

or $a_T = 2.06 \text{ m/s}^2$ (for top block). Now draw a free-body diagram (middle figure) of the bottom block and observe that $\sum F_x = Ma_B$ gives $f = 5.88 \text{ N} = (8.00 \text{ kg})a_B$ or $a_B = 0.735 \text{ m/s}^2$ (for the bottom block). In time t, the distance each block moves (starting from rest) is



ANS. FIG. P5.103

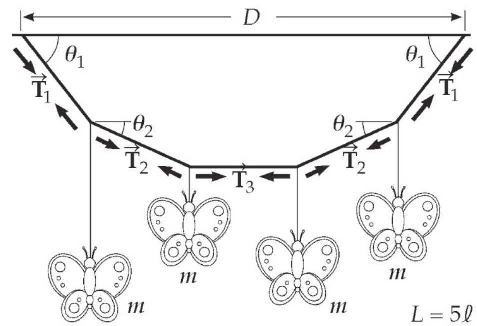
$d_T = \frac{1}{2}a_T t^2$ and $d_B = \frac{1}{2}a_B t^2$. For the top block to reach the right edge of the bottom block (see bottom figure), it is necessary that $d_T = d_B + L$ or

$$\frac{1}{2}(2.06\ \text{m/s}^2)t^2 = \frac{1}{2}(0.735\ \text{m/s}^2)t^2 + 3.00\ \text{m}$$

which gives $t = \boxed{2.13\ \text{s}}$.

(b) From above, $d_B = \frac{1}{2}(0.735\ \text{m/s}^2)(2.13\ \text{s})^2 = \boxed{1.67\ \text{m}}$.

P5.104 (a) Apply Newton's second law to two points where butterflies are attached on either half of mobile (the other half is the same, by symmetry).



ANS. FIG. P5.104

$T_2 \cos\theta_2 - T_1 \cos\theta_1 = 0$ **[1]**

$T_1 \sin\theta_1 - T_2 \sin\theta_2 - mg = 0$ **[2]**

$T_2 \cos\theta_2 - T_3 = 0$ **[3]**

$T_2 \sin\theta_2 - mg = 0$ **[4]**

Substituting [4] into [2] for $T_2 \sin\theta_2$,

$$T_1 \sin\theta_1 - mg - mg = 0$$

Then

$$\boxed{T_1 = \frac{2mg}{\sin\theta_1}}$$

Substitute [3] into [1] for $T_2 \cos\theta_2$:

$$T_3 - T_1 \cos\theta_1 = 0,\ T_3 = T_1 \cos\theta_1$$

Substitute value of T_1:

$$T_3 = 2mg\frac{\cos\theta_1}{\sin\theta_1} = \boxed{\frac{2mg}{\tan\theta_1} = T_3}$$

From equation [4],

$$T_2 = \frac{mg}{\sin\theta_2}$$

(b) Divide [4] by [3]:

$$\frac{T_2 \sin\theta_2}{T_2 \cos\theta_2} = \frac{mg}{T_3}$$

Substitute value of T_3:

$$\tan\theta_2 = \frac{mg\tan\theta_1}{2mg}, \quad \boxed{\theta_2 = \tan^{-1}\left(\frac{\tan\theta_1}{2}\right)}$$

Then we can finish answering part (a):

$$\boxed{T_2 = \frac{mg}{\sin\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right]}}$$

(c) D is the horizontal distance between the points at which the two ends of the string are attached to the ceiling.

$$\boxed{\begin{aligned}&D = 2\ell\cos\theta_1 + 2\ell\cos\theta_2 + \ell \text{ and } L = 5\ell\\ &D = \frac{L}{5}\left\{2\cos\theta_1 + 2\cos\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right] + 1\right\}\end{aligned}}$$

ANSWERS TO EVEN-NUMBERED PROBLEMS

P5.2 2.38 kN

P5.4 8.71 N

P5.6 (a) -4.47×10^{15} m/s^2; (b) $+2.09 \times 10^{-10}$ N

P5.8 (a) zero; (b) zero

P5.10 (a) $\frac{1}{2}vt$; (b) magnitude: $m\sqrt{(v/t)^2 + g^2}$, direction: $\tan^{-1}\left(\frac{gt}{v}\right)$

P5.12 $\left(16.3\hat{\mathbf{i}} + 14.6\hat{\mathbf{j}}\right)$ N

P5.14 (a–c) See free-body diagrams and corresponding forces in P5.14.

P5.16 1.59 m/s^2 at 65.2° N of E

P5.18 (a) $\frac{1}{3}$; (b) 0.750 m/s^2

P5.20 (a) $\sim 10^{-22}$ m/s^2; (b) $\Delta x \sim 10^{-23}$ m

P5.22 (a) $\hat{\mathbf{a}}$ is at 181°; (b) 11.2 kg; (c) 37.5 m/s; (d) $\left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right)$ m/s

P5.24 $\sum \vec{\mathbf{F}} = -km\vec{\mathbf{v}}$

P5.26 (a) See ANS. FIG. P5.26; (b) 1.03 N; (c) 0.805 N to the right

P5.28 (a) 49.0 N; (b) 49.0 N; (c) 98.0 N; (d) 24.5 N

P5.30 (a) See ANS. FIG. P5.30(a); (b) –2.54 m/s^2; (c) 3.19 m/s

P5.32 112 N

P5.34 See P5.33 for complete derivation.

P5.36 (a) T_1 = 31.5 N, T_2 = 37.5 N, T_3 = 49.0 N; (b) T_1 = 113 N, T_2 = 56.6 N, T_3 = 98.0 N

P5.38 (a) 78.4 N; (b) 105 N

P5.40 a = 6.30 m/s^2 and T = 31.5 N

P5.42 (a) See ANS FIG P5.42; (b) 3.57 m/s^2; (c) 26.7 N; (d) 7.14 m/s

P5.44 (a) $2m(g + a)$; (b) $T_1 = 2T_2$, so the upper string breaks first; (c) 0, 0

P5.46 (a) $a_2 = 2a_1$; (b) $T_2 = \dfrac{m_1 m_2}{2m_2 + \frac{1}{2}m_1} g$ and $T_2 = \dfrac{m_1 m_2}{m_2 + \frac{1}{4}m_1} g$; (c) $\dfrac{m_1 g}{2m_2 + \frac{1}{2}m_1}$ and $\dfrac{m_1 g}{4m_2 + m_1}$

P5.48 $B = 3.37 \times 10^3$ N, $A = 3.83 \times 10^3$ N, B is in tension and A is in compression.

P5.50 (a) 0.529 m below its initial level; (b) 7.40 m/s upward

P5.52 (a) 14.7 m; (b) neither mass is necessary

P5.54 (a) 256 m; (b) 42.7 m

P5.56 The situation is impossible because maximum static friction cannot provide the acceleration necessary to keep the book stationary on the seat.

P5.58 (a) 4.18; (b) Time would increase, as the wheels would skid and only kinetic friction would act; or perhaps the car would flip over.

P5.60 (a) See ANS. FIG. P5.60; (b) $\theta = 55.2°$; (c) n = 167 N

P5.62 (a) 0.404; (b) 45.8 lb

P5.64 (a) See ANS. FIG. P5.64; (b) 2.31 m/s^2, down for m_1, left for m_2, and up for m_3; (c) T_{12} = 30.0 N and T_{23} = 24.2 N; (d) T_{12} decreases and T_{23} increases

P5.66 (a) 48.6 N, 31. 7 N; (b) If P > 48.6 N, the block slides up the wall. If P < 31.7 N, the block slides down the wall; (c) 62.7 N, $P \geq$ 62.7 N, the block cannot slide up the wall. If P < 62.7 N, the block slides down the wall

P5.68 834 N

P5.70 (a) See P5.70 for complete solution; (b) 9.80 N, 0.580 m/s^2

P5.72 (a) 3.43 m/s^2 toward the scrap iron; (b) 3.43 m/s^2 toward the scrap iron; (c) –6.86 m/s^2 toward the magnet

P5.74 The situation is impossible because these forces on the book cannot produce the acceleration described.

P4.76 (a) and (b) See P5.76 for complete derivation; (c) 3.56 N

P5.78 (a) See ANS. FIG. P5.78(a); (b) $a = \dfrac{F}{m_b + m_r}$; (c) $T = \left(\dfrac{m_b}{m_b + m_r}\right)F$; (d) the tension in a cord of negligible mass is constant along its length

P5.80 (a) At any instant they have the same velocity and at all instants they have the same acceleration; (b) 1.61×10^4 N; (c) 2.95×10^4 N

P5.82 (a) Nick and the seat, with total weight 480 N, will accelerate down and the child, with smaller weight 440 N, will accelerate up; (b) In P5.81, a rope tension of 250 N does not make the rope break. In part (a), the rope is strong enough to support tension 459 N. But now the tension everywhere in the rope is 480 N, so it can exceed the breaking strength of the rope.

P5.84 (a) The system will not start to move when released; (b and c) no answer; (d) $f = m_2 g \sin\theta = 29.4$ N

P5.86 (a) $T = \dfrac{f}{2\sin\theta}$; (b) 410 N

P5.88 (a) $M = 3m\sin\theta$; (b) $T_1 = 2mg\sin\theta,\ T_2 = 3mg\sin\theta$; (c) $a = \dfrac{g\sin\theta}{1+2\sin\theta}$;

(d) $T_1 = 4mg\sin\theta\left(\dfrac{1+\sin\theta}{1+2\sin\theta}\right),\ T_2 = 6mg\sin\theta\left(\dfrac{1+\sin\theta}{1+2\sin\theta}\right)$;

(e) $M_{\text{max}} = 3m(\sin\theta + \mu_s\cos\theta)$; (f) $M_{\text{min}} = 3m(\sin\theta - \mu_s\cos\theta)$;

(g) $T_{2,\text{max}} - T_{2,\text{min}} = M_{\text{max}}g - M_{\text{min}}g = 6\mu_s mg\cos\theta$

P5.90 See table in P5.90 and ANS. FIG P5.90; (b) 0.143 m/s^2; (c) The acceleration values agree.

P5.92 (a) $a_1 = 2a_2$; (b) $a_2 = 12.7\text{ N }(1.30\text{ kg} + 4m_1)^{-1}$ down; (c) 9.80 m/s^2 down; (d) a_2 approaches zero; (e) $T = 6.37$ N; (f) yes

P5.94 (a) $n = (8.23\text{ N})\cos\theta$; (b) $a = (9.80\text{ m/s}^2)\sin\theta$; (c) See ANS. FIG P5.94; (d) At 0°, the normal force is the full weight, and the acceleration is zero. At 90° the mass is in free fall next to the vertical incline.

P5.96 (a) 3.00 s; (b) 20.1 m; (c) $(18.0\text{m})\hat{\mathbf{i}} - (9.00\text{m})\hat{\mathbf{j}}$

P5.98 (a) $m_2 g\left[\dfrac{m_1 M}{m_2 M + m_1(m_2+M)}\right]$; (b) $\left[\dfrac{g m_1(m_2+M)}{m_2 M + m_1(m_2+M)}\right]$;
(c) $\left[\dfrac{m_1 m_2 g}{m_2 M + m_1(m_2+M)}\right]$; (d) $\left[\dfrac{m_1 M g}{m_2 M + m_1(m_2+M)}\right]$

P5.100 The situation is impossible because at the angle of minimum tension, the tension exceeds 4.00 N

P5.102 $\vec{\mathbf{R}} = mg\cos\theta\sin\theta$ to the right $+\left(M + m\cos^2\theta\right)g$ upward

P5.104 (a) $T_1 = \dfrac{2mg}{\sin\theta_1}$, $\dfrac{2mg}{\tan\theta_1} = T_3$; (b) $\theta_2 = \tan^{-1}\left(\dfrac{\tan\theta_1}{2}\right)$,
$T_2 = -\dfrac{mg}{\sin\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right]}$; (c) See P5.104 for complete explanation.