5

The Laws of Motion

CHAPTER OUTLINE

ANSWERS TO QUESTIONS

Q5.1 (a) The force due to gravity of the earth pulling down on the ball—the reaction force is the force due to gravity of the ball pulling up on the earth. The force of the hand pushing up on the ball—reaction force is ball pushing down on the hand.

(b) The only force acting on the ball in free-fall is the gravity due to the earth -the reaction force is the gravity due to the ball pulling on the earth.

Q5.2 The resultant force is zero, as the acceleration is zero.

Q5.3 Mistake one: The car might be momentarily at rest, in the process of (suddenly) reversing forward into backward motion. In this case, the forces on it add to a (large) backward resultant.

Mistake two: There are no cars in interstellar space. If the car is remaining at rest, there are some large forces on it, including its weight and some force or forces of support.

Mistake three: The statement reverses cause and effect, like a politician who thinks that his getting elected was the reason for people to vote for him.

Q5.4 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. (Both performers won Academy Awards.)

Q5.5 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.

Q5.6 It would be smart for the explorer to gently push the rock back into the storage compartment. Newton's 3rd law states that the rock will apply the same size force on her that she applies on it. The harder she pushes on the rock, the larger her resulting acceleration.

Q5.7 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.

Q5.8 While a football is in flight, the force of gravity and air resistance act on it. When a football is in the process of being kicked, the foot pushes forward on the ball and the ball pushes backward on the foot. At this time and while the ball is in flight, the Earth pulls down on the ball (gravity) and the ball pulls up on the Earth. The moving ball pushes forward on the air and the air backward on the ball.

Q5.9 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.

Some physics teachers demonstrate this by asking a beefy student to pull on the ends of a cord supporting a can of soup at its center. Some get two burly young men to pull on opposite ends of a strong rope, while the smallest person in class gleefully mashes the center of the rope down to the table. Point out the beauty of sagging suspension-bridge cables. With a laser and an optical lever, demonstrate that the mayor makes the courtroom table sag when he sits on it, and the judge bends the bench. Give them "I make the floor sag" buttons, available to instructors using this manual. Estimate the cost of an infinitely strong cable, and the truth will always win.

Q5.10 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 iron is moving upward, the lifter can declare that she has thrown it, just by letting go of it for a moment, so our answer applies also to this case.

Q5.11 As the sand leaks out, the acceleration increases. With the same driving force, a decrease in the mass causes an increase in the acceleration.

Q5.12 As the rocket takes off, it burns fuel, pushing the gases from the combustion out the back of the rocket. Since the gases have mass, the total remaining mass of the rocket, fuel, and oxidizer decreases. With a constant thrust, a decrease in the mass results in an increasing acceleration.

Q5.13 The friction of the road pushing on the tires of a car causes an automobile to move. The push of the air on the propeller moves the airplane. The push of the water on the oars causes the rowboat to move.

Q5.14 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. In the second case, 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. The third action is the force of the glove on the ball; the reaction is the force of the ball on the glove. The fourth 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.'

Q5.15 The tension in the rope must be 9 200 N. Since the rope is moving at a constant speed, then the resultant force on it must be zero. The 49ers are pulling with a force of 9 200 N. If the 49ers were winning with the rope steadily moving in their direction or if the contest was even, then the tension would still be 9 200 N. In all of these case, the acceleration is zero, and so must be the resultant force on the rope. To win the tug-of-war, a team must exert a larger force on the ground than their opponents do.

Q5.16 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.

Q5.17 This statement contradicts Newton's 3rd law. The force that the locomotive exerted on the wall is the same as that exerted by the wall on the locomotive. The wall temporarily exerted on the locomotive a force greater than the force that the wall could exert without breaking.

Q5.18 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.

Q5.19 The resultant force doesn't always add to zero. If it did, nothing could ever accelerate. If we choose a single object as our system, action and reaction forces can never add to zero, as they act on different objects.

Q5.20 An object cannot exert a force on itself. 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.

Q5.21 To get the box to slide, you must push harder than the maximum static frictional force. Once the box is moving, you need to push with a force equal to the kinetic frictional force to maintain the box's motion.

Q5.22 The stopping distance will be the same if the mass of the truck is doubled. The stopping distance will decrease by a factor of four if the initial speed is cut in half.

Q5.23 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. Anti-lock brakes work by "pumping" the brakes (much more rapidly that you can) to minimize skidding of the tires on the road.

Q5.24 With friction, it takes longer to come down than to go up. On the way up, the frictional force and the component of the weight down the plane are in the same direction, giving a large acceleration. On the way down, the forces are in opposite directions, giving a relatively smaller acceleration. If the incline is frictionless, it takes the same amount of time to go up as it does to come down.

Q5.25 (a) The force of static friction between the crate and the bed of the truck causes the crate to accelerate. Note that the friction force on the crate is in the direction of its motion relative to the ground (but opposite to the direction of possible sliding motion of the crate relative to the truck bed).

(b) It is most likely that the crate would slide forward relative to the bed of the truck.

Q5.26 In Question 25, part (a) is an example of such a situation. Any situation in which friction is the force that accelerates an object from rest is an example. As you pull away from a stop light, friction is the force that accelerates forward a box of tissues on the level floor of the car. At the same time, friction of the ground on the tires of the car accelerates the car forward.

SOLUTIONS TO PROBLEMS

The following problems cover Sections 5.1–5.6.

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 For the same force F, acting on different masses

$$F = m_1 a_1$$

and

$$F = m_2 a_2$$

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

(b) $F = (m_1 + m_2)a = 4m_1 a = m_1 (3.00\ \text{m/s}^2)$

$a = \boxed{0.750\ \text{m/s}^2}$

***P5.2** $v_f = 880\ \text{m/s},\ m = 25.8\ \text{kg},\ x_f = 6\ \text{m}$

$v_f^2 = 2ax_f = 2x_f\left(\frac{F}{m}\right)$

$F = \frac{mv_f^2}{2x_f} = \boxed{1.66 \times 10^6\ \text{N forward}}$

P5.3 $m = 3.00\ \text{kg}$

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

$\sum \mathbf{F} = m\mathbf{a} = \boxed{\left(6.00\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}\right)\ \text{N}}$

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

P5.4 $F_g = \text{weight of ball} = mg$

$v_{\text{release}} = v$ and time to accelerate $= t$:

$$\mathbf{a} = \frac{\Delta v}{\Delta t} = \frac{v}{t} = \frac{v}{t}\hat{\mathbf{i}}$$

(a) Distance $x = \bar{v}t$:

$$x = \left(\frac{v}{2}\right)t = \boxed{\frac{vt}{2}}$$

(b) $\mathbf{F}_p - F_g\hat{\mathbf{j}} = \frac{F_g v}{gt}\hat{\mathbf{i}}$

$$\mathbf{F}_p = \boxed{\frac{F_g v}{gt}\hat{\mathbf{i}} + F_g\hat{\mathbf{j}}}$$

P5.5 $m = 4.00\text{ kg}$, $\mathbf{v}_i = 3.00\hat{\mathbf{i}}\text{ m/s}$, $\mathbf{v}_8 = \left(8.00\hat{\mathbf{i}} + 10.0\hat{\mathbf{j}}\right)\text{ m/s}$, $t = 8.00\text{ s}$

$$\mathbf{a} = \frac{\Delta\mathbf{v}}{t} = \frac{5.00\hat{\mathbf{i}} + 10.0\hat{\mathbf{j}}}{8.00}\text{ m/s}^2$$

$$\mathbf{F} = m\mathbf{a} = \boxed{\left(2.50\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}\right)\text{ N}}$$

$$F = \sqrt{(2.50)^2 + (5.00)^2} = \boxed{5.59\text{ N}}$$

P5.6 (a) Let the x-axis be in the original direction of the molecule's motion.

$$v_f = v_i + at: \quad -670\text{ m/s} = 670\text{ m/s} + a\left(3.00 \times 10^{-13}\text{ s}\right)$$

$$a = \boxed{-4.47 \times 10^{15}\text{ m/s}^2}$$

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

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

$$\vec{\mathbf{F}}_{\text{molecule on wall}} = \boxed{+2.09 \times 10^{-10}\text{ N}}$$

P5.7 (a) $\sum F = ma$ and $v_f^2 = v_i^2 + 2ax_f$ or $a = \dfrac{v_f^2 - v_i^2}{2x_f}$.

Therefore,

$$\sum F = m\frac{\left(v_f^2 - v_i^2\right)}{2x_f}$$

$$\sum F = 9.11\times10^{-31}\ \text{kg}\frac{\left[\left(7.00\times10^5\ \text{m/s}^2\right)^2 - \left(3.00\times10^5\ \text{m/s}^2\right)^2\right]}{2(0.050\,0\ \text{m})} = \boxed{3.64\times10^{-18}\ \text{N}}.$$

(b) The weight of the electron is

$$F_g = mg = \left(9.11\times10^{-31}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right) = 8.93\times10^{-30}\ \text{N}$$

The accelerating force is $\boxed{4.08\times10^{11}\ \text{times the weight of the electron.}}$

P5.8 (a) $F_g = mg = 120\ \text{lb} = (4.448\ \text{N/lb})(120\ \text{lb}) = \boxed{534\ \text{N}}$

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

P5.9 $F_g = mg = 900\ \text{N}$, $m = \dfrac{900\ \text{N}}{9.80\ \text{m/s}^2} = 91.8\ \text{kg}$

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

P5.10 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 88.7 kg, the change in weight is

$$\Delta F_g = 88.7\ \text{kg}(9.809\,5 - 9.780\,8) = \boxed{2.55\ \text{N}}.$$

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.

P5.11 (a) $\sum \mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 = \left(20.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}\right)\text{ N}$

$$\sum \mathbf{F} = m\mathbf{a}: \quad 20.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}} = 5.00\mathbf{a}$$

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

or

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

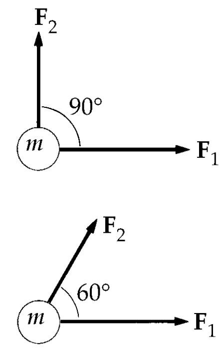


FIG. P5.11

(b)

$$F_{2x} = 15.0\cos 60.0° = 7.50\text{ N}$$

$$F_{2y} = 15.0\sin 60.0° = 13.0\text{ N}$$

$$\mathbf{F}_2 = \left(7.50\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\text{ N}$$

$$\sum \mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 = \left(27.5\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\text{ N} = m\mathbf{a} = 5.00\mathbf{a}$$

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

P5.12 We find acceleration:

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

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

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

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

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

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

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

P5.13 (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,

$$a_e = \frac{(70.0\text{ kg})\left(9.80\text{ m/s}^2\right)}{5.98\times 10^{24}\text{ kg}} = \boxed{\sim 10^{-22}\text{ m/s}^2}.$$

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

$$\sqrt{\frac{2x_y}{a_y}} = \sqrt{\frac{2x_e}{a_e}}$$

$$x_e = \frac{a_e}{a_y}x_y = \frac{m_y}{m_e}x_y = \frac{70.0\text{ kg}(0.500\text{ m})}{5.98\times 10^{24}\text{ kg}}\boxed{\sim 10^{-23}\text{ m}}.$$

P5.14 $\sum \mathbf{F} = m\mathbf{a}$ 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 $\mathbf{a}$

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

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

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

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

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

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

(d) $\mathbf{v}_f = \mathbf{v}_i + \mathbf{a}t = 0 + \left(3.75 \text{ m/s}^2 \text{ at } 181°\right)10.0 \text{ s}$ so $\mathbf{v}_f = 37.5 \text{ m/s at } 181°$

$\mathbf{v}_f = 37.5 \text{ m/s } \cos 181° \,\hat{\mathbf{i}} + 37.5 \text{ m/s } \sin 181° \,\hat{\mathbf{j}}$ so $\mathbf{v}_f = \boxed{\left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right) \text{ m/s}}$

(c) $\left|\mathbf{v}_f\right| = \sqrt{37.5^2 + 0.893^2} \text{ m/s} = \boxed{37.5 \text{ m/s}}$

P5.15 (a) $\boxed{15.0 \text{ lb up}}$

(b) $\boxed{5.00 \text{ lb up}}$

(c) $\boxed{0}$

Section 5.7 **Some Applications of Newton's Laws**

P5.16 $v_x = \dfrac{dx}{dt} = 10t$, $v_y = \dfrac{dy}{dt} = 9t^2$

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

At $t = 2.00$ s, $a_x = 10.0 \text{ m/s}^2$, $a_y = 36.0 \text{ m/s}^2$

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

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

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

P5.17

$$m = 1.00 \text{ kg}$$
$$mg = 9.80 \text{ N}$$
$$\tan\alpha = \frac{0.200 \text{ m}}{25.0 \text{ m}}$$
$$\alpha = 0.458°$$

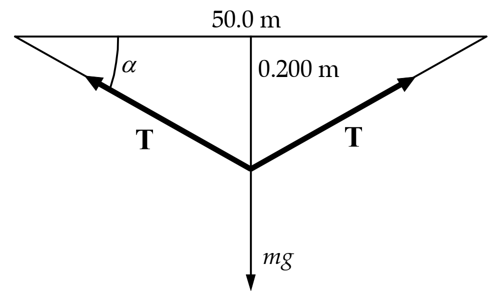


FIG. P5.17

Balance forces,

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

P5.18

$$T_3 = F_g \qquad (1)$$

$$T_1\sin\theta_1 + T_2\sin\theta_2 = F_g \qquad (2)$$

$$T_1\cos\theta_1 = T_2\cos\theta_2 \qquad (3)$$

Eliminate T_2 and solve for T_1

$$T_1 = \frac{F_g\cos\theta_2}{(\sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2)} = \frac{F_g\cos\theta_2}{\sin(\theta_1+\theta_2)}$$
$$T_3 = F_g = \boxed{325 \text{ N}}$$
$$T_1 = F_g\left(\frac{\cos 25.0°}{\sin 85.0°}\right) = \boxed{296 \text{ N}}$$
$$T_2 = T_1\left(\frac{\cos\theta_1}{\cos\theta_2}\right) = 296 \text{ N}\left(\frac{\cos 60.0°}{\cos 25.0°}\right) = \boxed{163 \text{ N}}$$

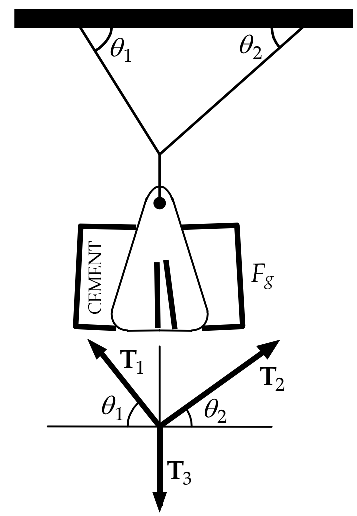


FIG. P5.18

P5.19 See the solution for T_1 in Problem 5.18.

P5.20 (a) An explanation proceeding from fundamental physical principles will be best for the parents and for you. Consider forces on the bit of string touching the weight hanger as shown in the free-body diagram:

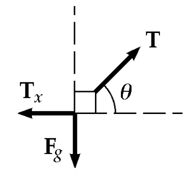


FIG. P5.20

Horizontal Forces: $\sum F_x = ma_x: -T_x + T\cos\theta = 0$

Vertical Forces: $\sum F_y = ma_y: -F_g + T\sin\theta = 0$

You need only the equation for the vertical forces to find that the tension in the string is given by $T = \boxed{\dfrac{F_g}{\sin\theta}}$. The force the child feels gets smaller, changing from T to $T\cos\theta$, while the counterweight hangs on the string. On the other hand, the kite does not notice what you are doing and the tension in the main part of the string stays constant. You do not need a level, since you learned in physics lab to sight to a horizontal line in a building. Share with the parents your estimate of the experimental uncertainty, which you make by thinking critically about the measurement, by repeating trials, practicing in advance and looking for variations and improvements in technique, including using other observers. You will then be glad to have the parents themselves repeat your measurements.

(b) $$T = \frac{F_g}{\sin\theta} = \frac{0.132\text{ kg}\left(9.80\text{ m/s}^2\right)}{\sin 46.3°} = \boxed{1.79\text{ N}}$$

P5.21 (a) Isolate either mass

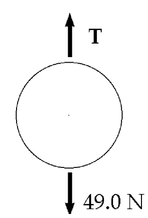


FIG. P5.21(a)

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

The scale reads the tension T,

so

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

(b) Isolate the pulley

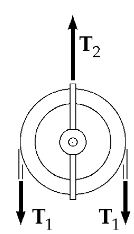


FIG. P5.21(b)

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

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

Take the component along the incline

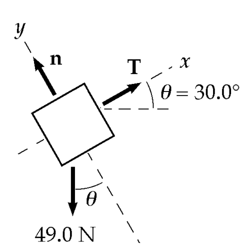


FIG. P5.21(c)

$$\mathbf{n}_x + \mathbf{T}_x + m\mathbf{g}_x = 0$$

or

$$0 + T - mg\sin 30.0° = 0$$

$$T = mg\sin 30.0° = \frac{mg}{2} = \frac{5.00(9.80)}{2}$$
$$= \boxed{24.5\text{ N}}.$$

P5.22 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

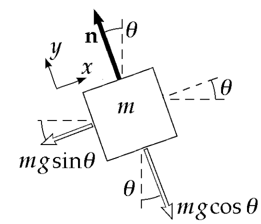


FIG. P5.22

$$\sum F_y = n - mg\cos\theta = 0:\ n = mg\cos\theta$$
$$\sum F_x = -mg\sin\theta = ma:\ a = -g\sin\theta$$

(a) When $\theta = 15.0°$

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

(b) Starting from rest

$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) = 2ax_f$$
$$\left|v_f\right| = \sqrt{2ax_f} = \sqrt{2\left(-2.54\ \text{m/s}^2\right)(-2.00\ \text{m})} = \boxed{3.18\ \text{m/s}}$$

P5.23 Choose a coordinate system with $\hat{\mathbf{i}}$ East and $\hat{\mathbf{j}}$ North.

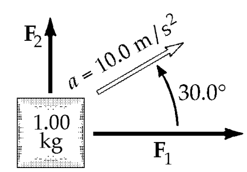


FIG. P5.23

$\sum \mathbf{F} = m\mathbf{a} = 1.00\ \text{kg}\left(10.0\ \text{m/s}^2\right)$ at 30.0°

$(5.00\ \text{N})\hat{\mathbf{j}} + \mathbf{F}_1 = (10.0\ \text{N})\angle 30.0° = (5.00\ \text{N})\hat{\mathbf{j}} + (8.66\ \text{N})\hat{\mathbf{i}}$

$\therefore F_1 = \boxed{8.66\ \text{N (East)}}$

***P5.24** First, consider the block moving along the horizontal. The only force in the direction of movement is T. Thus, $\sum F_x = ma$

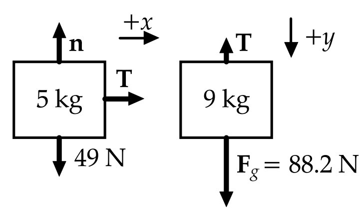


FIG. P5.24

$$T = (5\ \text{kg})a \qquad (1)$$

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

We have $\sum F_y = ma$

$$88.2\ \text{N} - T = (9\ \text{kg})a \qquad (2)$$

Note that both blocks must have the same magnitude of acceleration. Equations (1) and (2) can be added to give $88.2\ \text{N} = (14\ \text{kg})a$. Then

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

P5.25 After it leaves your hand, the block's speed changes only because of one component of its weight:

$$\sum F_x = ma_x \quad -mg\sin 20.0° = ma$$
$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right).$$

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

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

or

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

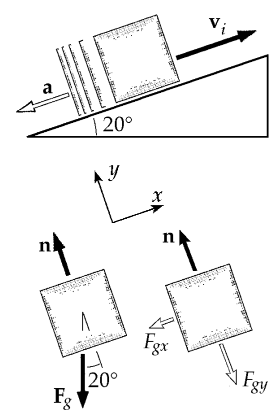


FIG. P5.25

P5.26 $m_1 = 2.00$ kg, $m_2 = 6.00$ kg, $\theta = 55.0°$

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

and

$$T - m_1 g = m_1 a$$
$$a = \frac{m_2 g\sin\theta - m_1 g}{m_1 + m_2} = \boxed{3.57 \text{ m/s}^2}$$

(b) $T = m_1(a + g) = \boxed{26.7 \text{ N}}$

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

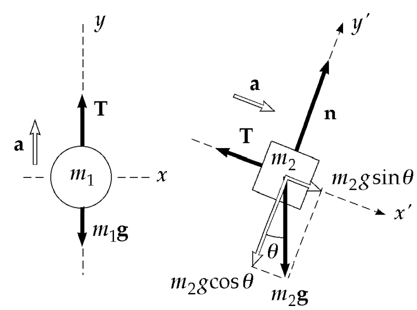


FIG. P5.26

***P5.27** 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 $-50°$.

$$\sum F_x = 0: \quad -2\,500 \text{ N}\cos 30° + B\cos 50° = 0$$
$$\boxed{B = 3.37 \times 10^3 \text{ N}}$$
$$\sum F_y = 0: \quad -2\,500 \text{ N}\sin 30° + A - 3.37 \times 10^3 \text{ N}\ \sin 50° = 0$$
$$\boxed{A = 3.83 \times 10^3 \text{ N}}$$

Positive answers confirm that

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

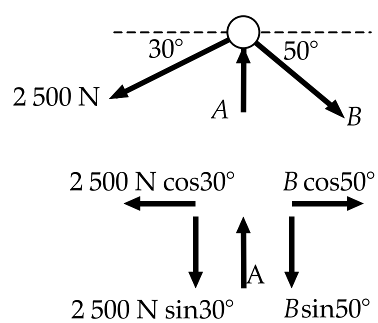


FIG. P5.27

P5.28 First, consider the 3.00 kg rising mass. The forces on it are the tension, T, and its weight, 29.4 N. With the upward direction as positive, the second law becomes

$$\sum F_y = ma_y: T - 29.4 \text{ N} = (3.00 \text{ kg})a \qquad (1)$$

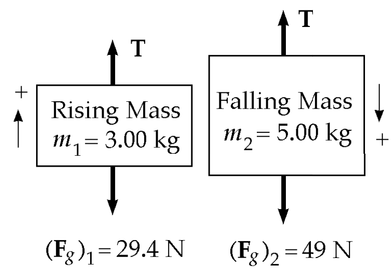


FIG. P5.28

The forces on the falling 5.00 kg mass are its weight and T, and its acceleration is the same as that of the rising mass. Calling the positive direction down for this mass, we have

$$\sum F_y = ma_y: 49 \text{ N} - T = (5.00 \text{ kg})a \qquad (2)$$

Equations (1) and (2) can be solved simultaneously by adding them:

$$T - 29.4 \text{ N} + 49.0 \text{ N} - T = (3.00 \text{ kg})a + (5.00 \text{ kg})a$$

(b) This gives the acceleration as

$$a = \frac{19.6 \text{ N}}{8.00 \text{ kg}} = \boxed{2.45 \text{ m/s}^2}.$$

(a) Then

$$T - 29.4 \text{ N} = (3.00 \text{ kg})(2.45 \text{ m/s}^2) = 7.35 \text{ N}.$$

The tension is

$$T = \boxed{36.8 \text{ N}}.$$

(c) Consider either mass. We have

$$y = v_i t + \frac{1}{2}at^2 = 0 + \frac{1}{2}(2.45 \text{ m/s}^2)(1.00 \text{ s})^2 = \boxed{1.23 \text{ m}}.$$

***P5.29** As the man rises steadily the pulley turns steadily and the tension in the rope is the same on both sides of the pulley. Choose man-pulley-and-platform as the system:

$$\sum F_y = ma_y$$
$$+T - 950 \text{ N} = 0$$
$$T = 950 \text{ N}.$$

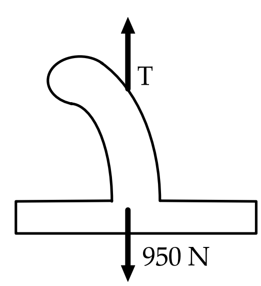


FIG. P5.29

The worker must pull on the rope with force $\boxed{950 \text{ N}}$.

***P5.30** Both blocks move with acceleration $a = \left(\frac{m_2 - m_1}{m_2 + m_1}\right)g$:

$$a = \left(\frac{7\text{ kg} - 2\text{ kg}}{7\text{ kg} + 2\text{ kg}}\right)9.8\text{ m/s}^2 = 5.44\text{ m/s}^2.$$

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

$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i): \quad 0 = (-2.4\text{ m/s})^2 + 2(5.44\text{ m/s}^2)(x_f - 0)$$

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

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

(b) $v_{xf} = v_{xi} + a_x t$: $v_{xf} = -2.40\text{ m/s} + (5.44\text{ m/s}^2)(1.80\text{ s})$

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

P5.31 Forces acting on 2.00 kg block:

$$T - m_1 g = m_1 a \qquad (1)$$

Forces acting on 8.00 kg block:

$$F_x - T = m_2 a \qquad (2)$$

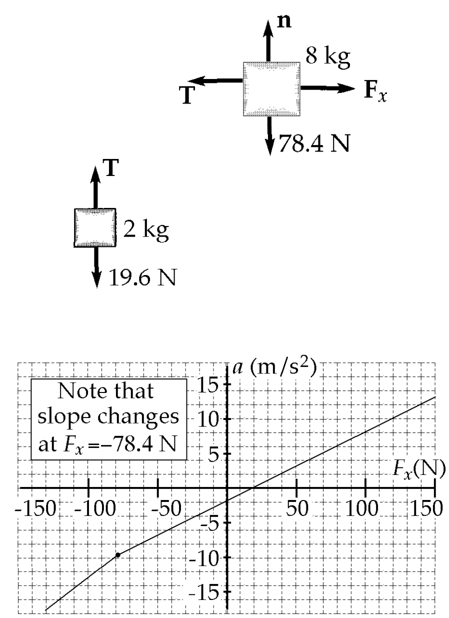


FIG. P5.31

(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:

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

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

(c)

F_x, N	–100	–78.4	–50.0	0	50.0	100
a_x, m/s²	–12.5	–9.80	–6.96	–1.96	3.04	8.04

***P5.32** (a) For force components along the incline, with the upward direction taken as positive,

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

$$a_x = -g\sin\theta = -\left(9.8\ \text{m/s}^2\right)\sin 35° = -5.62\ \text{m/s}^2\,.$$

For the upward motion,

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

$$0 = (5\ \text{m/s})^2 + 2\left(-5.62\ \text{m/s}^2\right)\left(x_f - 0\right)$$

$$x_f = \frac{25\ \text{m}^2/\text{s}^2}{2\left(5.62\ \text{m/s}^2\right)} = \boxed{2.22\ \text{m}}\,.$$

(b) The time to slide down is given by

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

$$0 = 2.22\ \text{m} + 0 + \frac{1}{2}\left(-5.62\ \text{m/s}^2\right)t^2$$

$$t = \sqrt{\frac{2(2.22\ \text{m})}{5.62\ \text{m/s}^2}} = 0.890\ \text{s}\,.$$

For the second particle,

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

$$0 = 10\ \text{m} + v_{xi}(0.890\ \text{s}) + \left(-5.62\ \text{m/s}^2\right)(0.890\ \text{s})^2$$

$$v_{xi} = \frac{-10\ \text{m} + 2.22\ \text{m}}{0.890\ \text{s}} = -8.74\ \text{m/s}$$

$$\text{speed} = \boxed{8.74\ \text{m/s}}\,.$$

P5.33 First, we will compute the needed accelerations:

(1) Before it starts to move: $a_y = 0$

(2) During the first 0.800 s: $a_y = \dfrac{v_{yf} - v_{yi}}{t} = \dfrac{1.20 \text{ m/s} - 0}{0.800 \text{ s}} = 1.50 \text{ m/s}^2$

(3) While moving at constant velocity: $a_y = 0$

(4) During the last 1.50 s: $a_y = \dfrac{v_{yf} - v_{yi}}{t} = \dfrac{0 - 1.20 \text{ m/s}}{1.50 \text{ s}} = -0.800 \text{ m/s}^2$

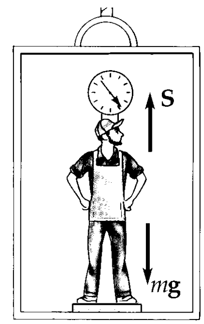


FIG. P5.33

Newton's second law is: $\sum F_y = ma_y$

$$+S - (72.0 \text{ kg})(9.80 \text{ m/s}^2) = (72.0 \text{ kg})a_y$$
$$S = 706 \text{ N} + (72.0 \text{ kg})a_y.$$

(a) When $a_y = 0$, $S = \boxed{706 \text{ N}}$.

(b) When $a_y = 1.50 \text{ m/s}^2$, $S = \boxed{814 \text{ N}}$.

(c) When $a_y = 0$, $S = \boxed{706 \text{ N}}$.

(d) When $a_y = -0.800 \text{ m/s}^2$, $S = \boxed{648 \text{ N}}$.

P5.34 (a) Pulley P_1 has acceleration a_2.
Since m_1 moves *twice* the distance P_1 moves in the same time, m_1 has twice the acceleration of P_1, i.e., $\boxed{a_1 = 2a_2}$.

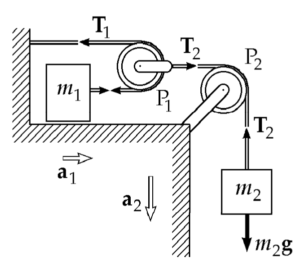


FIG. P5.34

(b) From the figure, and using

$$\sum F = ma: \quad m_2 g - T_2 = m_2 a_2 \quad (1)$$
$$T_1 = m_1 a_1 = 2m_1 a_2 \quad (2)$$
$$T_2 - 2T_1 = 0 \quad (3)$$

Equation (1) becomes $m_2 g - 2T_1 = m_2 a_2$. This equation combined with Equation (2) yields

$$\frac{T_1}{m_1}\left(2m_1 + \frac{m_2}{2}\right) = m_2 g$$

$$\boxed{T_1 = \frac{m_1 m_2}{2m_1 + \frac{1}{2}m_2} g} \text{ and } \boxed{T_2 = \frac{m_1 m_2}{m_1 + \frac{1}{4}m_2} g}.$$

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

$$a_1 = \frac{T_1}{m_1} = \boxed{\frac{m_2 g}{2m_1 + \frac{1}{2}m_2}} \text{ and } a_2 = \frac{1}{2}a_1 = \boxed{\frac{m_2 g}{4m_1 + m_2}}.$$

Section 5.8 Forces of Friction

***P5.35**

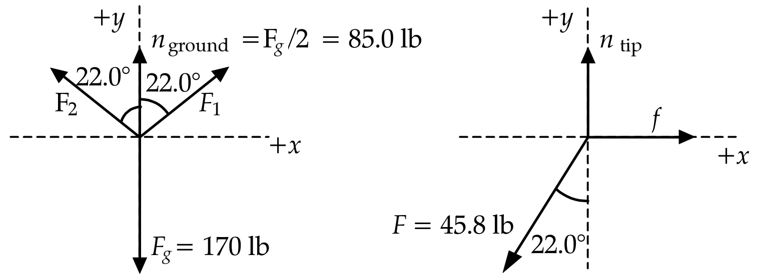


FIG. P5.35

From the free-body diagram of 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 $F = 45.8 \text{ lb}$.

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

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

or

$$f = 17.2 \text{ lb}.$$

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

which gives

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

For minimum coefficient of friction, the crutch tip will be on the verge of slipping, so $f = (f_s)_{max} = \mu_s n_{tip}$ and $\mu_s = \frac{f}{n_{tip}} = \frac{17.2 \text{ lb}}{42.5 \text{ lb}} = \boxed{0.404}$.

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

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

P5.36 For equilibrium: $f = F$ and $n = F_g$. Also, $f = \mu n$ i.e.,

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

$$\mu_s = \frac{75.0\text{ N}}{25.0(9.80)\text{ N}} = \boxed{0.306}$$

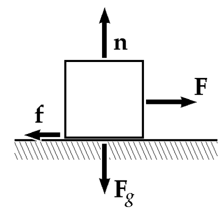


FIG. P5.36

and

$$\mu_k = \frac{60.0\text{ N}}{25.0(9.80)\text{ N}} = \boxed{0.245}.$$

P5.37 $\sum F_y = ma_y$: $\quad +n - mg = 0$

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

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

$$\sum F_x = ma_x: \quad -f_s = ma$$

The maximum acceleration is

$$a = -\mu_s g.$$

The initial and final conditions are: $x_i = 0$, $v_i = 50.0\text{ mi/h} = 22.4\text{ m/s}$, $v_f = 0$

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

(a) $$x_f = \frac{v_i^2}{2\mu g}$$

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

(b) $$x_f = \frac{v_i^2}{2\mu g}$$

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

P5.38 If all the weight is on the rear wheels,

(a) $F = ma$: $\mu_s mg = ma$

But

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

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

$$\mu_s = \frac{2(0.250 \text{ mi})(1\,609 \text{ m/mi})}{(9.80 \text{ m/s}^2)(4.96 \text{ s})^2} = \boxed{3.34}.$$

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

***P5.39** (a) The person pushes backward on the floor. The floor pushes forward on the person with a force of friction. This is the only horizontal force on the person. If the person's shoe is on the point of slipping the static friction force has its maximum value.

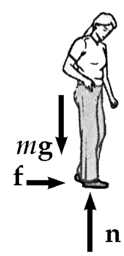


FIG. P5.39

$$\sum F_x = ma_x: \quad f = \mu_s n = ma_x$$

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

$$ma_x = \mu_s mg \quad a_x = \mu_s g = 0.5(9.8 \text{ m/s}^2) = 4.9 \text{ m/s}^2$$

$$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2 \quad 3 \text{ m} = 0 + 0 + \frac{1}{2}(4.9 \text{ m/s}^2)t^2$$

$$t = \boxed{1.11 \text{ s}}$$

(b) $x_f = \dfrac{1}{2}\mu_s g t^2$, $t = \sqrt{\dfrac{2x_f}{\mu_s g}} = \sqrt{\dfrac{2(3 \text{ m})}{(0.8)(9.8 \text{ m/s}^2)}} = \boxed{0.875 \text{ s}}$

P5.40 $m_{\text{suitcase}} = 20.0 \text{ kg}$, $F = 35.0 \text{ N}$

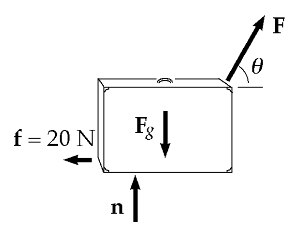


FIG. P5.40

$$\sum F_x = ma_x: \quad -20.0 \text{ N} + F\cos\theta = 0$$

$$\sum F_y = ma_y: \quad +n + F\sin\theta - F_g = 0$$

(a) $F\cos\theta = 20.0 \text{ N}$

$$\cos\theta = \frac{20.0 \text{ N}}{35.0 \text{ N}} = 0.571$$

$$\boxed{\theta = 55.2°}$$

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

$$\boxed{n = 167 \text{ N}}$$

P5.41 $m = 3.00\text{ kg}$, $\theta = 30.0°$, $x = 2.00\text{ m}$, $t = 1.50\text{ s}$

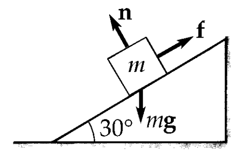


FIG. P5.41

(a) $x = \frac{1}{2}at^2$:

$$2.00\text{ m} = \frac{1}{2}a(1.50\text{ s})^2$$
$$a = \frac{4.00}{(1.50)^2} = \boxed{1.78\text{ m/s}^2}$$

$\sum \mathbf{F} = \mathbf{n} + \mathbf{f} + m\mathbf{g} = m\mathbf{a}$:

$$\text{Along } x: \quad 0 - f + mg\sin 30.0° = ma$$
$$f = m(g\sin 30.0° - a)$$
$$\text{Along } y: \quad n + 0 - mg\cos 30.0° = 0$$
$$n = mg\cos 30.0°$$

(b) $\mu_k = \frac{f}{n} = \frac{m(g\sin 30.0° - a)}{mg\cos 30.0°}$, $\mu_k = \tan 30.0° - \frac{a}{g\cos 30.0°} = \boxed{0.368}$

(c) $f = m(g\sin 30.0° - a)$, $f = 3.00(9.80\sin 30.0° - 1.78) = \boxed{9.37\text{ N}}$

(d) $v_f^2 = v_i^2 + 2a(x_f - x_i)$

where

$$x_f - x_i = 2.00\text{ m}$$

$$v_f^2 = 0 + 2(1.78)(2.00) = 7.11\text{ m}^2/\text{s}^2$$
$$v_f = \sqrt{7.11\text{ m}^2/\text{s}^2} = \boxed{2.67\text{ m/s}}$$

***P5.42** First we find the coefficient of friction:

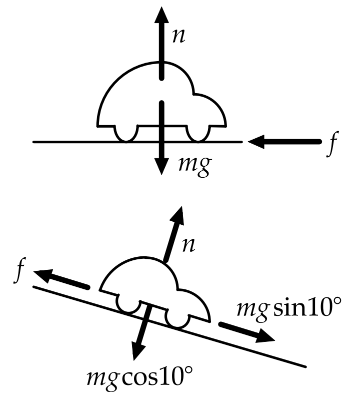


FIG. P5.42

$$\sum F_y = 0: \qquad +n - mg = 0$$

$$f = \mu_s n = \mu_s mg$$

$$\sum F_x = ma_x: \qquad v_f^2 = v_i^2 + 2a_x \Delta x = 0$$

$$-\mu_s mg = -\frac{mv_i^2}{2\Delta x}$$

$$\mu_s = \frac{v_i^2}{2g\Delta x} = \frac{(88\ \text{ft/s})^2}{2(32.1\ \text{ft/s}^2)(123\ \text{ft})} = 0.981$$

Now on the slope

$$\sum F_y = 0: \qquad +n - mg\cos 10° = 0$$

$$f_s = \mu_s n = \mu_s mg\cos 10°$$

$$\sum F_x = ma_x: \quad -\mu_s mg\cos 10° + mg\sin 10° = -\frac{mv_i^2}{2\Delta x}$$

$$\Delta x = \frac{v_i^2}{2g(\mu_s \cos 10° - \sin 10°)}$$

$$= \frac{(88\ \text{ft/s})^2}{2(32.1\ \text{ft/s}^2)(0.981\cos 10° - \sin 10°)} = \boxed{152\ \text{ft}}.$$

P5.43 $T - f_k = 5.00a$ (for 5.00 kg mass)

$9.00g - T = 9.00a$ (for 9.00 kg mass)

Adding these two equations gives:

$$9.00(9.80) - 0.200(5.00)(9.80) = 14.0a$$

$$a = 5.60\ \text{m/s}^2$$

$$\therefore T = 5.00(5.60) + 0.200(5.00)(9.80)$$

$$= \boxed{37.8\ \text{N}}$$

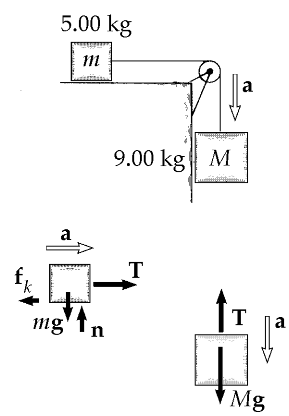


FIG. P5.43

P5.44 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 rope and T_{23} the tension in the cord on the right.

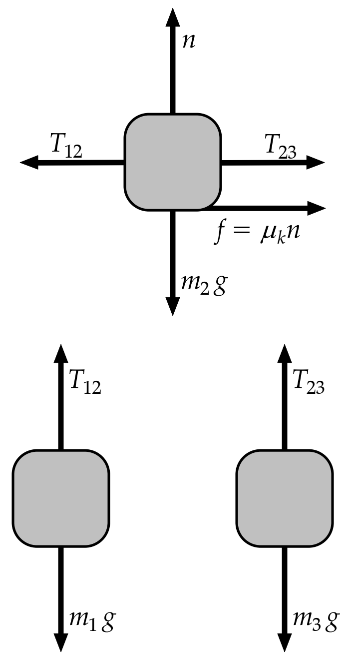


FIG. P5.44

For m_1, $\quad \sum F_y = ma_y \quad +T_{12} - m_1 g = -m_1 a$

For m_2, $\quad \sum F_x = ma_x \quad -T_{12} + \mu_k n + T_{23} = -m_2 a$

and $\quad \sum F_y = ma_y \quad n - m_2 g = 0$

for m_3, $\quad \sum F_y = ma_y \quad T_{23} - m_3 g = +m_3 a$

we have three simultaneous equations

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

(a) Add them up:

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

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

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

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

P5.45 (a) See Figure to the right

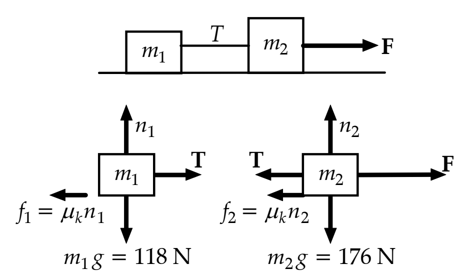


FIG. P5.45

(b) $68.0 - T - \mu m_2 g = m_2 a$ (Block #2)

$T - \mu m_1 g = m_1 a$ (Block #1)

Adding,

$$68.0 - \mu(m_1 + m_2)g = (m_1 + m_2)a$$
$$a = \frac{68.0}{(m_1 + m_2)} - \mu g = \boxed{1.29\text{ m/s}^2}$$
$$T = m_1 a + \mu m_1 g = \boxed{27.2\text{ N}}$$

P5.46 (Case 1, impending upward motion)
Setting

$$\sum F_x = 0: \quad P\cos 50.0° - n = 0$$
$$f_{s,\,\max} = \mu_s n: \quad f_{s,\,\max} = \mu_s P\cos 50.0° = 0.250(0.643)P = 0.161P$$

Setting

$$\sum F_y = 0: \quad P\sin 50.0° - 0.161P - 3.00(9.80) = 0$$
$$P_{\max} = \boxed{48.6 \text{ N}}$$

(Case 2, impending downward motion)
As in Case 1,

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

Setting

$$\sum F_y = 0: \quad P\sin 50.0° + 0.161P - 3.00(9.80) = 0$$
$$P_{\min} = \boxed{31.7 \text{ N}}$$

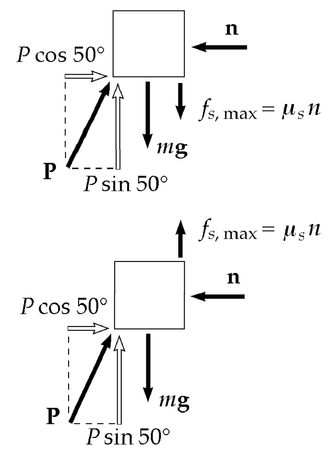


FIG. P5.46

***P5.47** When the sled is sliding uphill

$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$
$$f = \mu_k n = \mu_k mg\cos\theta$$
$$\sum F_x = ma_x: \quad +mg\sin\theta + \mu_k mg\cos\theta = ma_{\text{up}}$$
$$v_f = 0 = v_i + a_{\text{up}} t_{\text{up}}$$
$$v_i = -a_{\text{up}} t_{\text{up}}$$
$$\Delta x = \frac{1}{2}\left(v_i + v_f\right)t_{\text{up}}$$
$$\Delta x = \frac{1}{2}\left(a_{\text{up}} t_{\text{up}} + 0\right)t_{\text{up}} = \frac{1}{2} a_{\text{up}} t_{\text{up}}^2$$

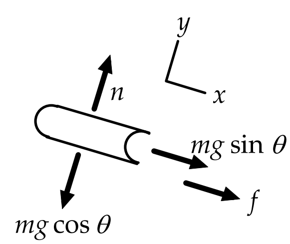


FIG. P5.47

When the sled is sliding down, the direction of the friction force is reversed:

$$mg\sin\theta - \mu_k mg\cos\theta = ma_{\text{down}}$$
$$\Delta x = \frac{1}{2} a_{\text{down}} t_{\text{down}}^2 .$$

Now

$$t_{\text{down}} = 2t_{\text{up}}$$
$$\frac{1}{2} a_{\text{up}} t_{\text{up}}^2 = \frac{1}{2} a_{\text{down}} \left(2t_{\text{up}}\right)^2$$
$$a_{\text{up}} = 4a_{\text{down}}$$
$$g\sin\theta + \mu_k g\cos\theta = 4\left(g\sin\theta - \mu_k g\cos\theta\right)$$
$$5\mu_k \cos\theta = 3\sin\theta$$
$$\boxed{\mu_k = \left(\frac{3}{5}\right)\tan\theta}$$

***P5.48** 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

$$f = (f_s)_{\max} = \mu_s n.$$

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

$$n = \frac{f}{\mu_s} = \frac{F_g}{2\mu_s} = \frac{95.5 \text{ N}}{2(0.663)} = \boxed{72.0 \text{ N}}.$$

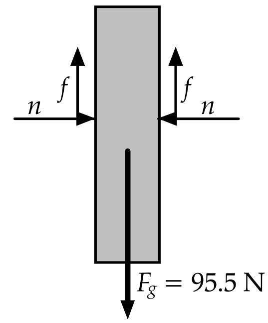


FIG. P5.48

***P5.49** (a) $n + F\sin 15° - (75 \text{ N})\cos 25° = 0$

$\therefore n = 67.97 - 0.259F$

$f_{s,\max} = \mu_s n = 24.67 - 0.094F$

For equilibrium: $F\cos 15° + 24.67 - 0.094F - 75\sin 25° = 0$.

This gives $\boxed{F = 8.05 \text{ N}}$.

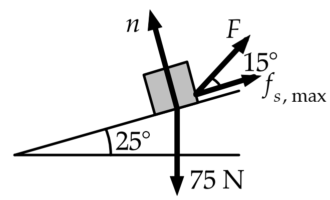


FIG. P5.49(a)

(b) $F\cos 15° - (24.67 - 0.094F) - 75\sin 25° = 0$.

This gives $\boxed{F = 53.2 \text{ N}}$.

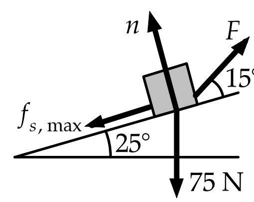


FIG. P5.49(b)

(c) $f_k = \mu_k n = 10.6 - 0.040F$. Since the velocity is constant, the net force is zero:

$$F\cos 15° - (10.6 - 0.040F) - 75\sin 25° = 0.$$

This gives $\boxed{F = 42.0 \text{ N}}$.

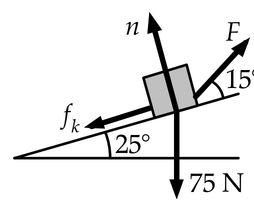


FIG. P5.49(c)

***P5.50** We must consider separately the disk 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:

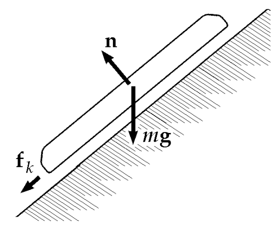


FIG. P5.50

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

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

$$\sum F_x = ma_x: \quad -f_k - mg\sin\theta = ma_x$$
$$a_x = -\mu_k g\cos\theta - g\sin\theta = (-0.4\cos 37° - \sin 37°)9.8\ \text{m/s}^2 = -9.03\ \text{m/s}^2$$

The Frisbee goes ballistic with speed given by

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

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

$$v_{yf}^2 = v_{yi}^2 + 2a_y(y_f - y_i)$$
$$0 = (6.67\ \text{m/s}\ \sin 37°)^2 + 2(-9.8\ \text{m/s}^2)(y_f - 10\ \text{m}\ \sin 37°)$$
$$y_f = 6.02\ \text{m} + \frac{(4.01\ \text{m/s})^2}{19.6\ \text{m/s}^2} = \boxed{6.84\ \text{m}}$$

Additional Problems

P5.51 (a) see figure to the right

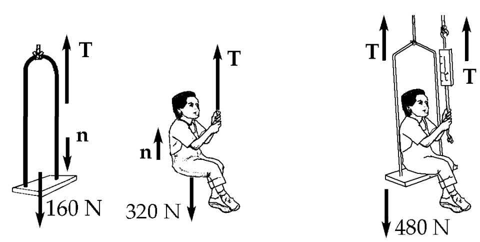


FIG. P5.51

(b) First consider Pat and the chair as the system. Note that *two* ropes support the system, and $T = 250$ N in each rope. Applying $\sum F = ma$

$$2T - 480 = ma, \text{ where } m = \frac{480}{9.80} = 49.0\ \text{kg}.$$

Solving for a gives

$$a = \frac{500 - 480}{49.0} = \boxed{0.408\ \text{m/s}^2}.$$

(c) $\sum F = ma$ on Pat:

$$\sum F = n + T - 320 = ma, \text{ where } m = \frac{320}{9.80} = 32.7\ \text{kg}$$

$$n = ma + 320 - T = 32.7(0.408) + 320 - 250 = \boxed{83.3\ \text{N}}.$$

P5.52 $\sum \mathbf{F} = m\mathbf{a}$ gives the object's acceleration

$$\mathbf{a} = \frac{\sum F}{m} = \frac{\left(8.00\hat{\mathbf{i}} - 4.00t\hat{\mathbf{j}}\right)\text{ N}}{2.00\text{ kg}}$$

$$\mathbf{a} = \left(4.00\ \text{m/s}^2\right)\hat{\mathbf{i}} - \left(2.00\ \text{m/s}^3\right)t\hat{\mathbf{j}} = \frac{d\mathbf{v}}{dt}.$$

Its velocity is

$$\int_{v_i}^{v} d\mathbf{v} = \mathbf{v} - \mathbf{v}_i = \mathbf{v} - 0 = \int_0^t \mathbf{a}dt$$

$$\mathbf{v} = \int_0^t \left[\left(4.00\ \text{m/s}^2\right)\hat{\mathbf{i}} - \left(2.00\ \text{m/s}^3\right)t\hat{\mathbf{j}}\right]dt$$

$$\mathbf{v} = \left(4.00t\ \text{m/s}^2\right)\hat{\mathbf{i}} - \left(1.00t^2\ \text{m/s}^3\right)\hat{\mathbf{j}}.$$

(a) We require $|\mathbf{v}| = 15.0\ \text{m/s}$, $|\mathbf{v}|^2 = 225\ \text{m}^2/\text{s}^2$

$$16.0t^2\ \text{m}^2/\text{s}^4 + 1.00t^4\ \text{m}^2/\text{s}^6 = 225\ \text{m}^2/\text{s}^2$$

$$1.00t^4 + 16.0\ \text{s}^2t^2 - 225\ \text{s}^4 = 0$$

$$t^2 = \frac{-16.0 \pm \sqrt{(16.0)^2 - 4(-225)}}{2.00} = 9.00\ \text{s}^2$$

$$t = \boxed{3.00\ \text{s}}.$$

Take $\mathbf{r}_i = 0$ at $t = 0$. The position is

$$\mathbf{r} = \int_0^t \mathbf{v}dt = \int_0^t \left[\left(4.00t\ \text{m/s}^2\right)\hat{\mathbf{i}} - \left(1.00t^2\ \text{m/s}^3\right)\hat{\mathbf{j}}\right]dt$$

$$\mathbf{r} = \left(4.00\ \text{m/s}^2\right)\frac{t^2}{2}\hat{\mathbf{i}} - \left(1.00\ \text{m/s}^3\right)\frac{t^3}{3}\hat{\mathbf{j}}$$

at $t = 3$ s we evaluate.

(c) $\mathbf{r} = \boxed{\left(18.0\hat{\mathbf{i}} - 9.00\hat{\mathbf{j}}\right)\text{ m}}$

(b) So $|\mathbf{r}| = \sqrt{(18.0)^2 + (9.00)^2}\ \text{m} = \boxed{20.1\ \text{m}}$

***P5.53** (a) Situation A

$$\sum F_x = ma_x: \quad F_A + \mu_s n - mg\sin\theta = 0$$
$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$

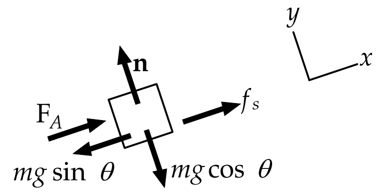


FIG. P5.53(a)

Eliminate $n = mg\cos\theta$ to solve for

$$\boxed{F_A = mg(\sin\theta - \mu_s\cos\theta)}.$$

(b) Situation B

$$\sum F_x = ma_x: \quad F_B\cos\theta + \mu_s n - mg\sin\theta = 0$$
$$\sum F_y = ma_y: \quad -F_B\sin\theta + n - mg\cos\theta = 0$$

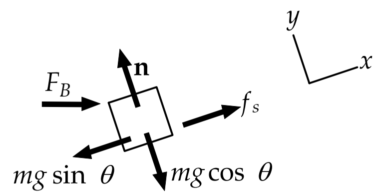


FIG. P5.53(b)

Substitute $n = mg\cos\theta + F_B\sin\theta$ to find

$$F_B\cos\theta + \mu_s mg\cos\theta + \mu_s F_B\sin\theta - mg\sin\theta = 0$$
$$\boxed{F_B = \frac{mg(\sin\theta - \mu_s\cos\theta)}{\cos\theta + \mu_s\sin\theta}}$$

(c) $F_A = 2\text{ kg } 9.8\text{ m/s}^2(\sin 25° – 0.16\cos 25°) = 5.44\text{ N}$

$$F_B = \frac{19.6\text{ N}(0.278)}{\cos 25° + 0.16\sin 25°} = 5.59\text{ N}$$

Student $\boxed{A}$ need exert less force.

(d) $$F_B = \frac{F_A}{\cos 25° + 0.38\sin 25°} = \frac{F_A}{1.07}$$

Student $\boxed{B}$ need exert less force.

P5.54

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

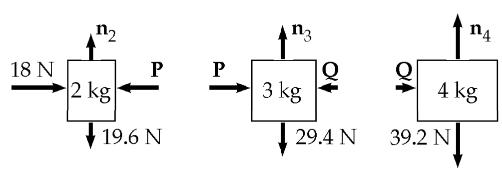


FIG. P5.54

Adding gives $18\text{ N} = (9\text{ kg})a$ so

$$a = \boxed{2.00\text{ m/s}^2}.$$

(b) $Q = 4\text{ kg}\left(2\text{ m/s}^2\right) = \boxed{8.00\text{ N net force on the 4 kg}}$

$P - 8\text{ N} = 3\text{ kg}\left(2\text{ m/s}^2\right) = \boxed{6.00\text{ N net force on the 3 kg}}$ and $P = 14\text{ N}$

$18\text{ N} - 14\text{ N} = 2\text{ kg}\left(2\text{ m/s}^2\right) = \boxed{4.00\text{ N net force on the 2 kg}}$

continued on next page

(c) From above, $Q = \boxed{8.00\text{ N}}$ and $P = \boxed{14.0\text{ N}}$.

(d) 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. The acceleration is real and nonzero, but lasts for so short a time that it never is associated with a large velocity. The frame of the building and your legs exert forces, small relative to the hammer blow, to bring the partition, block, and you to rest again over a time large relative to the hammer blow. This problem lends itself to interesting lecture demonstrations. One person can hold a lead brick in one hand while another hits the brick with a hammer.

P5.55 (a) First, we note that $F = T_1$. Next, we focus on the mass M and write $T_5 = Mg$. Next, we focus on the bottom pulley and write $T_5 = T_2 + T_3$. Finally, we focus on the top pulley and write $T_4 = T_1 + T_2 + T_3$.

Since the pulleys are not starting to rotate and are frictionless, $T_1 = T_3$, and $T_2 = T_3$. From this information, we have $T_5 = 2T_2$, so $T_2 = \frac{Mg}{2}$.

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

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

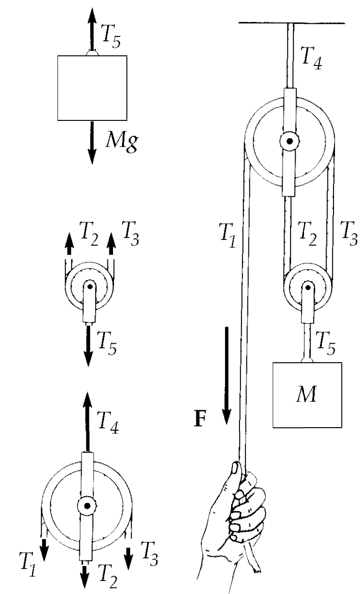


FIG. P5.55

P5.56 We find the diver's impact speed by analyzing his free-fall motion:

$$v_f^2 = v_i^2 + 2ax = 0 + 2(-9.80\text{ m/s}^2)(-10.0\text{ m}) \text{ so } v_f = -14.0\text{ m/s}.$$

Now for the 2.00 s of stopping, we have $v_f = v_i + at$:

$$0 = -14.0\text{ m/s} + a(2.00\text{ s})$$
$$a = +7.00\text{ m/s}^2.$$

Call the force exerted by the water on the diver R. Using $\sum F_y = ma$,

$$+R - 70.0\text{ kg}(9.80\text{ m/s}^2) = 70.0\text{ kg}(7.00\text{ m/s}^2)$$
$$R = \boxed{1.18\text{ kN}}.$$

P5.57 (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.

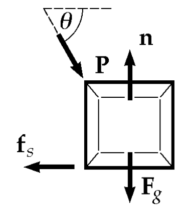


FIG. P5.57

Resolving vertically:

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

Horizontally:

$$P\cos\theta = f_s$$

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

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

(b) $P = \dfrac{0.400(100\text{ N})\sec\theta}{1 - 0.400\tan\theta}$

θ(deg)	0.00	15.0	30.0	45.0	60.0
$P(N)$	40.0	46.4	60.1	94.3	260

If the angle were 68.2° or more, the expression for P would go to infinity and motion would become impossible.

P5.58 (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 $\sin 30.0° = \dfrac{0.500\ \text{m}}{x}$

$x = 1.00\ \text{m}$: $v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) = 0 + 2\left(4.90\ \text{m/s}^2\right)(1.00\ \text{m})$

$v_f = \boxed{3.13\ \text{m/s}}$ after time $t_s = \dfrac{2x_f}{v_f} = \dfrac{2(1.00\ \text{m})}{3.13\ \text{m/s}} = 0.639\ \text{s}$.

(c) Now in free fall $y_f - y_i = v_{yi}t + \dfrac{1}{2}a_y t^2$:

$$-2.00 = (-3.13\ \text{m/s})\sin 30.0°\, t - \frac{1}{2}\left(9.80\ \text{m/s}^2\right)t^2$$

$$\left(4.90\ \text{m/s}^2\right)t^2 + (1.56\ \text{m/s})t - 2.00\ \text{m} = 0$$

$$t = \frac{-1.56\ \text{m/s} \pm \sqrt{(1.56\ \text{m/s})^2 - 4\left(4.90\ \text{m/s}^2\right)(-2.00\ \text{m})}}{9.80\ \text{m/s}^2}$$

Only one root is physical

$$t = 0.499\ \text{s}$$

$$x_f = v_x t = \left[(3.13\ \text{m/s})\cos 30.0°\right](0.499\ \text{s}) = \boxed{1.35\ \text{m}}$$

(d) 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.

P5.59 With motion impending,

$$n + T\sin\theta - mg = 0$$
$$f = \mu_s(mg - T\sin\theta)$$

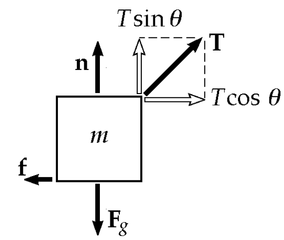


FIG. P5.59

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 $\cos\theta + \mu_s\sin\theta$

$$\frac{d}{d\theta}(\cos\theta + \mu_s\sin\theta) = 0 = -\sin\theta + \mu_s\cos\theta.$$

(a) $\theta = \tan^{-1}\mu_s = \tan^{-1}0.350 = \boxed{19.3°}$

(b) $T = \frac{0.350(1.30\text{ kg})(9.80\text{ m/s}^2)}{\cos 19.3° + 0.350\sin 19.3°} = \boxed{4.21\text{ N}}$

***P5.60** (a) See Figure (a) to the right.

(b) See Figure (b) to the right.

$m\mathbf{g} = (36.4\text{ kg})(9.8\text{ m/s}^2) = 357\text{ N}$

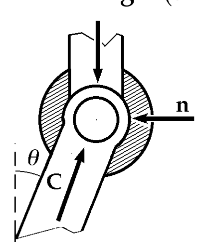


FIG. P5.60(a)

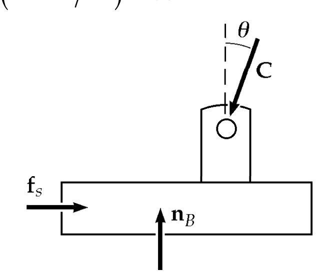


FIG. P5.60(b)

(c) For the pin,

$$\sum F_y = ma_y: \quad C\cos\theta - 357\text{ N} = 0$$
$$C = \frac{357\text{ N}}{\cos\theta}.$$

For the foot,

$$\sum F_y = ma_y: \quad +n_B - C\cos\theta = 0$$
$$n_B = \boxed{357\text{ N}}.$$

(d) For the foot with motion impending,

$$\sum F_x = ma_x: \quad +f_s - C\sin\theta_s = 0$$
$$\mu_s n_B = C\sin\theta_s$$
$$\mu_s = \frac{C\sin\theta_s}{n_B} = \frac{(357\text{ N}/\cos\theta_s)\sin\theta_s}{357\text{ N}} = \tan\theta_s.$$

(e) The maximum coefficient is

$$\mu_s = \tan\theta_s = \tan 50.2° = \boxed{1.20}.$$

P5.61 $\sum F = ma$

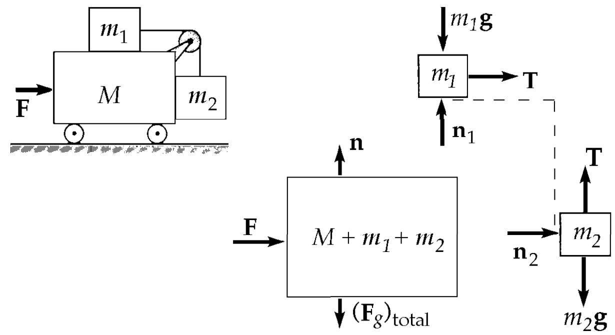


FIG. P5.61

For m_1: $T = m_1 a$

For m_2: $T - m_2 g = 0$

Eliminating T,

$$a = \frac{m_2 g}{m_1}$$

For all 3 blocks:

$$F = (M + m_1 + m_2)a = \boxed{(M + m_1 + m_2)\left(\frac{m_2 g}{m_1}\right)}$$

P5.62

t(s)	$t^2\left(\text{s}^2\right)$	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

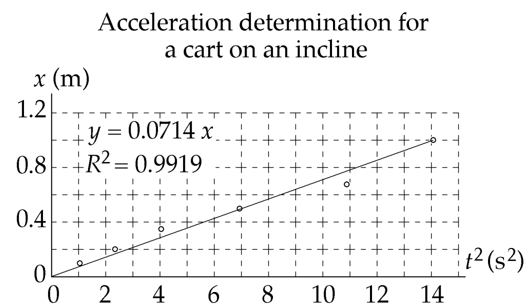


FIG. P5.62

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

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

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

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

P5.63 (1) $m_1(a-A)=T \Rightarrow a=\dfrac{T}{m_1}+A$

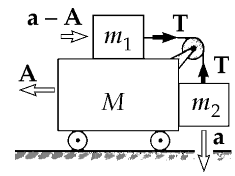


FIG. P5.63

(2) $MA=R_x=T \Rightarrow A=\dfrac{T}{M}$

(3) $m_2a=m_2g-T \Rightarrow T=m_2(g-a)$

(a) Substitute the value for a from (1) into (3) and solve for T:

$$T=m_2\left[g-\left(\frac{T}{m_1}+A\right)\right].$$

Substitute for A from (2):

$$T=m_2\left[g-\left(\frac{T}{m_1}+\frac{T}{M}\right)\right]=\boxed{m_2g\left[\frac{m_1M}{m_1M+m_2(m_1+M)}\right]}.$$

(b) Solve (3) for a and substitute value of T:

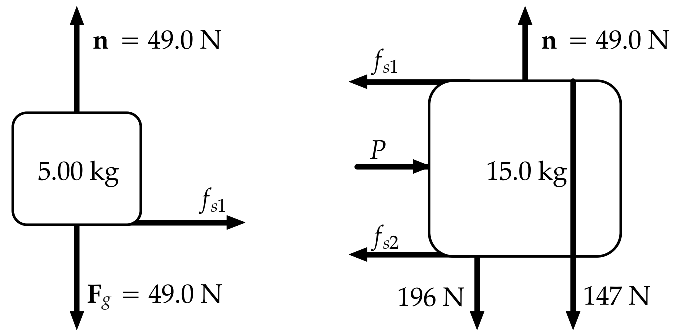
$$\boxed{a=\frac{m_2g(m_1+M)}{m_1M+m_2(M+m_1)}}.$$

(c) From (2), $A=\dfrac{T}{M}$, Substitute the value of T:

$$\boxed{A=\frac{m_1m_2g}{m_1M+m_2(m_1+M)}}.$$

(d) $$\boxed{a-A=\frac{Mm_2g}{m_1M+m_2(m_1+M)}}$$

P5.64 (a), (b) Motion impending



$f_{s1} = \mu n = 14.7 \text{ N}$ $\qquad$ $f_{s2} = 0.500(196 \text{ N}) = 98.0 \text{ N}$

FIG. P5.64

$$P = f_{s1} + f_{s2} = 14.7 \text{ N} + 98.0 \text{ N} = \boxed{113 \text{ N}}$$

(c) Once motion starts, kinetic friction acts.

$$112.7 \text{ N} - 0.100(49.0 \text{ N}) - 0.400(196 \text{ N}) = (15.0 \text{ kg})a_2$$
$$a_2 = \boxed{1.96 \text{ m/s}^2}$$
$$0.100(49.0 \text{ N}) = (5.00 \text{ kg})a_1$$
$$a_1 = \boxed{0.980 \text{ m/s}^2}$$

***P5.65** (a) Let x represent the position of the glider along the air track. Then $z^2 = x^2 + h_0^2$, $x = \left(z^2 - h_0^2\right)^{1/2}$, $v_x = \frac{dx}{dt} = \frac{1}{2}\left(z^2 - h_0^2\right)^{-1/2}(2z)\frac{dz}{dt}$. Now $\frac{dz}{dt}$ is the rate at which string passes over the pulley, so it is equal to v_y of the counterweight.

$$v_x = z\left(z^2 - h_0^2\right)^{-1/2} v_y = u v_y$$

(b) $a_x = \frac{dv_x}{dt} = \frac{d}{dt} u v_y = u\frac{dv_y}{dt} + v_y\frac{du}{dt}$ at release from rest, $v_y = 0$ and $a_x = u a_y$.

(c) $\sin 30.0° = \frac{80.0 \text{ cm}}{z}$, $z = 1.60 \text{ m}$, $u = \left(z^2 - h_0^2\right)^{-1/2} z = \left(1.6^2 - 0.8^2\right)^{-1/2}(1.6) = 1.15$.
For the counterweight

$$\sum F_y = ma_y: \quad T - 0.5 \text{ kg } 9.8 \text{ m/s}^2 = -0.5 \text{ kg} a_y$$
$$a_y = -2T + 9.8$$

For the glider

$$\sum F_x = ma_x: \quad T\cos 30° = 1.00 \text{ kg } a_x = 1.15 a_y = 1.15(-2T + 9.8) = -2.31T + 11.3 \text{ N}$$
$$3.18T = 11.3 \text{ N}$$
$$T = \boxed{3.56 \text{ N}}$$

***P5.66** The upward acceleration of the rod is described by

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

$$1\times 10^{-3}\ \text{m} = 0 + 0 + \frac{1}{2}a_y\left(8\times 10^{-3}\ \text{s}\right)^2$$

$$a_y = 31.2\ \text{m/s}^2$$

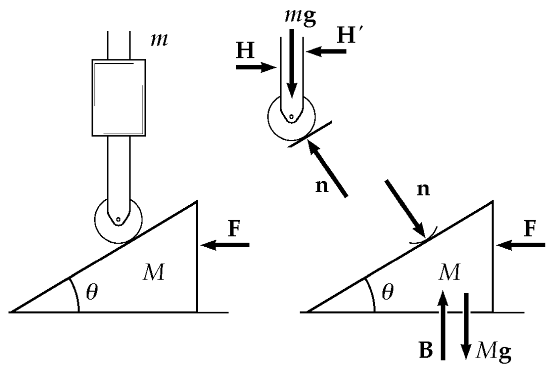


FIG. P5.66

The distance y moved by the rod and the distance x moved by the wedge in the same time are related by $\tan 15° = \frac{y}{x} \Rightarrow x = \frac{y}{\tan 15°}$. Then their speeds and accelerations are related by

$$\frac{dx}{dt} = \frac{1}{\tan 15°}\frac{dy}{dt}$$

and

$$\frac{d^2x}{dt^2} = \frac{1}{\tan 15°}\frac{d^2y}{dt^2} = \left(\frac{1}{\tan 15°}\right)31.2\ \text{m/s}^2 = 117\ \text{m/s}^2.$$

The free body diagram for the rod is shown. Here H and H' are forces exerted by the guide.

$$\sum F_y = ma_y: \qquad n\cos 15° - mg = ma_y$$

$$n\cos 15° - 0.250\ \text{kg}\left(9.8\ \text{m/s}^2\right) = 0.250\ \text{kg}\left(31.2\ \text{m/s}^2\right)$$

$$n = \frac{10.3\ \text{N}}{\cos 15°} = 10.6\ \text{N}$$

For the wedge,

$$\sum F_x = Ma_x: \quad -n\sin 15° + F = 0.5\ \text{kg}\left(117\ \text{m/s}^2\right)$$

$$F = (10.6\ \text{N})\sin 15° + 58.3\ \text{N} = \boxed{61.1\ \text{N}}$$

***P5.67** (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:

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

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

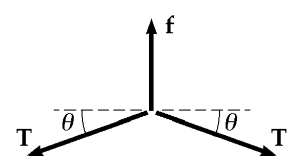


FIG. P5.67

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

P5.68 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.

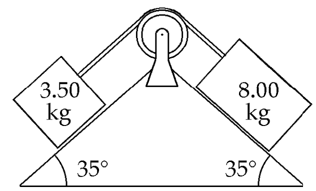


FIG. P5.68

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

and

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

Adding, we obtain

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

(b) Thus the acceleration is

$$\boxed{a = 2.20\text{ m/s}^2}.$$

By substitution,

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

(a) The tension is

$$\boxed{T = 27.4\text{ N}}.$$

P5.69 Choose the x-axis pointing down the slope.

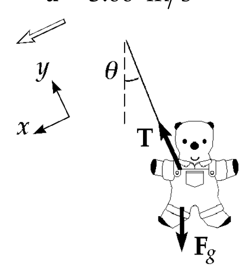


FIG. P5.69

$$v_f = v_i + at: \quad 30.0\text{ m/s} = 0 + a(6.00\text{ s})$$
$$a = 5.00\text{ m/s}^2.$$

Consider forces on the toy.

$$\sum F_x = ma_x: \quad mg\sin\theta = m(5.00\text{ m/s}^2)$$
$$\theta = \boxed{30.7°}$$
$$\sum F_y = ma_y: \quad -mg\cos\theta + T = 0$$
$$T = mg\cos\theta = (0.100)(9.80)\cos 30.7°$$
$$T = \boxed{0.843\text{ N}}$$

***P5.70** 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 $\mathbf{R} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$ represent the force of table on incline. We have

$$\sum F_x = ma_x: \quad +R_x - n\sin\theta = 0$$
$$R_x = mg\cos\theta\sin\theta$$
$$\sum F_y = ma_y: \quad -Mg - n\cos\theta + R_y = 0$$
$$R_y = Mg + mg\cos^2\theta.$$

$$\boxed{\mathbf{R} = mg\cos\theta\sin\theta \text{ to the right} + \left(M + m\cos^2\theta\right)g \text{ upward}}$$

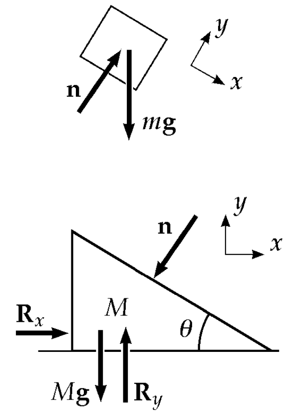


FIG. P5.70

***P5.71** 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 $0.5 \text{ m/s}^2 - 3 \text{ m/s}^2 = -2.5 \text{ m/s}^2$. The mug reaches the edge of the tablecloth after time given by

$$\Delta x = v_{xi}t + \frac{1}{2}a_x t^2$$
$$-0.3 \text{ m} = 0 + \frac{1}{2}\left(-2.5 \text{ m/s}^2\right)t^2$$
$$t = 0.490 \text{ s}.$$

The motion of the mug relative to tabletop is over distance

$$\frac{1}{2}a_x t^2 = \frac{1}{2}\left(0.5 \text{ m/s}^2\right)(0.490 \text{ s})^2 = \boxed{0.060\,0 \text{ m}}.$$

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

P5.72 $\sum F_y = ma_y:\ n - mg\cos\theta = 0$

or

$$n = 8.40(9.80)\cos\theta$$
$$n = (82.3\ \text{N})\cos\theta$$

$\sum F_x = ma_x:\ mg\sin\theta = ma$

or

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

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

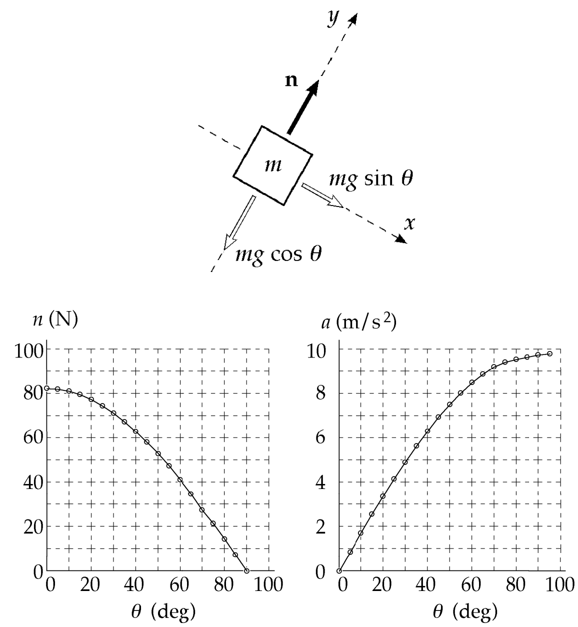


FIG. P5.72

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.

P5.73 (a) Apply Newton's second law to two points where butterflies are attached on either half of mobile (other half the same, by symmetry)

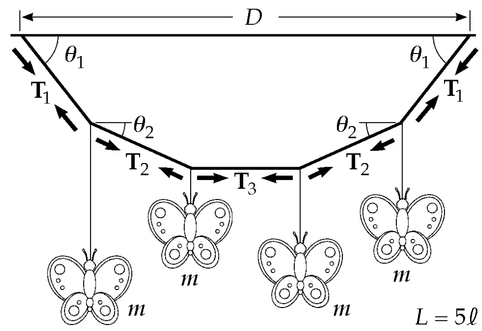


FIG. P5.69

(1) $T_2 \cos\theta_2 - T_1 \cos\theta_1 = 0$
(2) $T_1 \sin\theta_1 - T_2 \sin\theta_2 - mg = 0$
(3) $T_2 \cos\theta_2 - T_3 = 0$
(4) $T_2 \sin\theta_2 - mg = 0$

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:

$$\tan\theta_2 = \frac{mg\tan\theta_1}{2mg},\ \boxed{\theta_2 = \tan^{-1}\left(\frac{\tan\theta_1}{2}\right)}.$$

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.

$$D = 2\ell\cos\theta_1 + 2\ell\cos\theta_2 + \ell \text{ and } L = 5\ell$$

$$D = \frac{L}{5}\left\{2\cos\theta_1 + 2\cos\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right] + 1\right\}$$

ANSWERS TO EVEN PROBLEMS

P5.2 1.66×10^{6} N forward

P5.4 (a) $\dfrac{vt}{2}$; (b) $\left(\dfrac{F_g v}{gt}\right)\hat{\mathbf{i}}+F_g\hat{\mathbf{j}}$

P5.6 (a) $4.47\times10^{15}\ \mathrm{m/s^2}$ away from the wall; (b) 2.09×10^{-10} N toward the wall

P5.8 (a) 534 N down; (b) 54.5 kg

P5.10 2.55 N for an 88.7 kg person

P5.12 $\left(16.3\hat{\mathbf{i}}+14.6\hat{\mathbf{j}}\right)$ N

P5.14 (a) 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

P5.16 112 N

P5.18 $T_1=296$ N; $T_2=163$ N; $T_3=325$ N

P5.20 (a) see the solution; (b) 1.79 N

P5.22 (a) $2.54\ \mathrm{m/s^2}$ down the incline; (b) 3.18 m/s

P5.24 see the solution; $6.30\ \mathrm{m/s^2}$; 31.5 N

P5.26 (a) $3.57\ \mathrm{m/s^2}$; (b) 26.7 N; (c) 7.14 m/s

P5.28 (a) 36.8 N; (b) $2.45\ \mathrm{m/s^2}$; (c) 1.23 m

P5.30 (a) 0.529 m; (b) 7.40 m/s upward

P5.32 (a) 2.22 m; (b) 8.74 m/s

P5.34 (a) $a_1=2a_2$; (b) $T_1=\dfrac{m_1m_2g}{2m_1+\frac{m_2}{2}}$; $T_2=\dfrac{m_1m_2g}{m_1+\frac{m_2}{4}}$; (c) $a_1=\dfrac{m_2g}{2m_1+\frac{m_2}{2}}$; $a_2=\dfrac{m_2g}{4m_1+m_2}$

P5.36 $\mu_s=0.306$; $\mu_k=0.245$

P5.38 (a) 3.34; (b) Time would increase

P5.40 (a) 55.2°; (b) 167 N

P5.42 152 ft

P5.44 (a) $2.31\ \mathrm{m/s^2}$ down for m_1, left for m_2 and up for m_3; (b) 30.0 N and 24.2 N

P5.46 Any value between 31.7 N and 48.6 N

P5.48 72.0 N

P5.50 6.84 m

P5.52 (a) 3.00 s; (b) 20.1 m; (c) $\left(18.0\hat{\mathbf{i}}-9.00\hat{\mathbf{j}}\right)$ m

P5.54 (a) $2.00\ \mathrm{m/s^2}$ to the right;
(b) 8.00 N right on 4 kg;
6.00 N right on 3 kg; 4 N right on 2 kg;
(c) 8.00 N between 4 kg and 3 kg;
14.0 N between 2 kg and 3 kg;
(d) see the solution

P5.56 1.18 kN

P5.58 (a) $4.90\ \mathrm{m/s^2}$; (b) 3.13 m/s at 30.0° below the horizontal; (c) 1.35 m; (d) 1.14 s; (e) No

P5.60 (a) and (b) see the solution; (c) 357 N; (d) see the solution; (e) 1.20

P5.62 see the solution; $0.143\ \mathrm{m/s^2}$ agrees with $0.137\ \mathrm{m/s^2}$

P5.64 (a) see the solution;
(b) on block one:
$49.0\text{ N }\hat{\mathbf{j}}-49.0\text{ N }\hat{\mathbf{j}}+14.7\text{ N }\hat{\mathbf{i}}$;
on block two: $-49.0\text{ N }\hat{\mathbf{j}}-14.7\text{ N }\hat{\mathbf{i}}-147\text{ N }\hat{\mathbf{j}}$
$+196\text{ N }\hat{\mathbf{j}}-98.0\text{ N }\hat{\mathbf{i}}+113\text{ N }\hat{\mathbf{i}}$;
(c) for block one: $0.980\hat{\mathbf{i}}\ \mathrm{m/s^2}$;
for block two: $1.96\ \mathrm{m/s^2}\,\hat{\mathbf{i}}$

P5.66 61.1 N

P5.68 (a) $2.20\ \mathrm{m/s^2}$; (b) 27.4 N

P5.70 $mg\cos\theta\sin\theta$ to the right $+\left(M+m\cos^2\theta\right)g$ upward

P5.72 see the solution