Solutions to Practice Problems Chapter 5

Responses to Questions

Q5.2 (1) If a book sits at rest on a horizontal tabletop the only vertical forces on the book are the upward normal force and the downward weight, and these forces are equal in magnitude. (2) If a crate sits at rest on a ramp that is inclined at an angle α above the horizontal, the normal force is $n = w\cos\alpha$. (3) If a crate sits on a horizontal surface and you push on the book with force P that is at an angle below the horizontal, then $n = w + P\sin\alpha$.

Q5.10 There is a component $w\sin\alpha$ of the weight of the block that is directed down the incline. To start the block moving down the incline, the force P you apply must satisfy $P + w\sin\alpha > f$ and $P > f - w\sin\alpha$. $w\sin\alpha$ is in the direction of your push and adds to it. To start the block moving up the incline, P must satisfy $P > w\sin\alpha + f$. $w\sin\alpha$ is opposite to your push and subtracts from it. To push the block sideways, it must be that $P > f$. It is easiest to get it moving down the incline and hardest to get it moving up the incline.

Q5.19 The speed doesn't change because there is no component of net force in the direction of the particle's velocity. The net force and hence the acceleration are perpendicular to the velocity, and this produces a change in the direction of the velocity but not in its magnitude.

Solutions to Problem

P5.2. **IDENTIFY:** Apply $\Sigma\vec{F} = m\vec{a}$ to each weight.

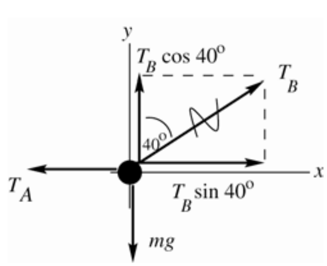
SET UP: Two forces act on each mass: w down and $T(= w)$ up.

EXECUTE: In all cases, each string is supporting a weight w against gravity, and the tension in each string is w.

EVALUATE: The tension is the same in all three cases.

P5.6. **IDENTIFY:** Apply Newton's first law to the wrecking ball. Each cable exerts a force on the ball, directed along the cable.

SET UP: The force diagram for the wrecking ball is sketched in the Figure below:



EXECUTE: **(a)** $\Sigma F_y = ma_y$

$T_B \cos 40° - mg = 0$

$$T_B = \frac{mg}{\cos 40°} = \frac{(4090\text{ kg})(9.80\text{ m/s}^2)}{\cos 40°} = 5.23\times 10^4\text{ N}$$

(b) $\Sigma F_x = ma_x$

$T_B \sin 40° - T_A = 0$

$T_A = T_B \sin 40° = 3.36\times 10^4\text{ N}$

EVALUATE: If the angle 40° is replaced by 0° (cable *B* is vertical), then $T_B = mg$ and $T_A = 0.$

P5.12. **IDENTIFY:** Apply Newton's second law to the rocket plus its contents and to the power supply. Both the rocket and the power supply have the same acceleration.

SET UP: The free-body diagrams for the rocket and for the power supply are given in Figures 5.12a and b. Since the highest altitude of the rocket is 120 m, it is near to the surface of the earth and there is a downward gravity force on each object. Let $+y$ be upward, since that is the direction of the acceleration. The power supply has mass $m_{\text{ps}} = (15.5\text{ N})/(9.80\text{ m/s}^2) = 1.58\text{ kg}.$

EXECUTE: **(a)** $\Sigma F_y = ma_y$ applied to the rocket gives $F - m_{\text{r}}g = m_{\text{r}}a.$

$$a = \frac{F - m_{\text{r}}g}{m_{\text{r}}} = \frac{1720\text{ N} - (125\text{ kg})(9.80\text{ m/s}^2)}{125\text{ kg}} = 3.96\text{ m/s}^2.$$

(b) $\Sigma F_y = ma_y$ applied to the power supply gives $n - m_{\text{ps}}g = m_{\text{ps}}a.$

$n = m_{\text{ps}}(g + a) = (1.58\text{ kg})(9.80\text{ m/s}^2 + 3.96\text{ m/s}^2) = 21.7\text{ N}.$

EVALUATE: The acceleration is constant while the thrust is constant and the normal force is constant while the acceleration is constant. The altitude of 120 m is not used in the calculation.

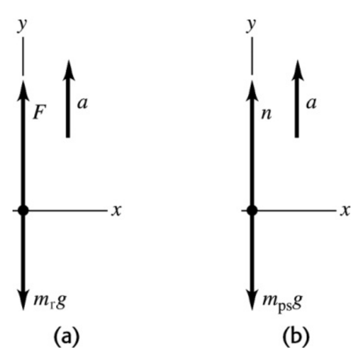


Figure 5.12

P5.15. **IDENTIFY:** Apply $\Sigma\vec{F} = m\vec{a}$ to the load of bricks and to the counterweight. The tension is the same at each end of the rope. The rope pulls up with the same force (T) on the bricks and on the counterweight. The counterweight accelerates downward and the bricks accelerate upward; these accelerations have the same magnitude.

(a) SET UP: The free-body diagrams for the bricks and counterweight are given in Figure 5.15.

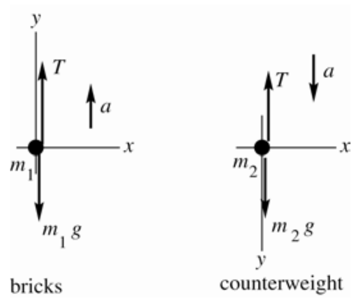


Figure 5.15

(b) EXECUTE: Apply $\Sigma F_y = ma_y$ to each object. The acceleration magnitude is the same for the two objects. For the bricks take $+y$ to be upward since $\vec{a}$ for the bricks is upward. For the counterweight take $+y$ to be downward since $\vec{a}$ is downward.

<u>bricks</u>: $\Sigma F_y = ma_y$

$T - m_1 g = m_1 a$

<u>counterweight</u>: $\Sigma F_y = ma_y$

$m_2 g - T = m_2 a$

Add these two equations to eliminate *T*:

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

$$a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g = \left(\frac{28.0\text{ kg} - 15.0\text{ kg}}{15.0\text{ kg} + 28.0\text{ kg}}\right)(9.80\text{ m/s}^2) = 2.96\text{ m/s}^2$$

(c) $T - m_1 g = m_1 a$ gives $T = m_1(a + g) = (15.0\text{ kg})(2.96\text{ m/s}^2 + 9.80\text{ m/s}^2) = 191\text{ N}$

As a check, calculate *T* using the other equation.

$m_2 g - T = m_2 a$ gives $T = m_2(g - a) = 28.0\text{ kg}(9.80\text{ m/s}^2 - 2.96\text{ m/s}^2) = 191\text{ N},$ which checks.

EVALUATE: The tension is 1.30 times the weight of the bricks; this causes the bricks to accelerate upward. The tension is 0.696 times the weight of the counterweight; this causes the counterweight to accelerate downward. If $m_1 = m_2$, $a = 0$ and $T = m_1 g = m_2 g$. In this special case the objects don't move. If $m_1 = 0$, $a = g$ and $T = 0$; in this special case the counterweight is in free fall. Our general result is correct in these two special cases.

P5.20. IDENTIFY: Apply $\Sigma \vec{F} = m\vec{a}$ to the composite object of elevator plus student $(m_{\text{tot}} = 850\text{ kg})$ and also to the student $(w = 550\text{ N})$. The elevator and the student have the same acceleration.

SET UP: Let $+y$ be upward. The free-body diagrams for the composite object and for the student are given in Figures 5.20a and b. *T* is the tension in the cable and *n* is the scale reading, the normal force the scale exerts on the student. The mass of the student is $m = w/g = 56.1\text{ kg}.$

EXECUTE: **(a)** $\Sigma F_y = ma_y$ applied to the student gives $n - mg = ma_y$. $a_y = \dfrac{n - mg}{m} = \dfrac{450\text{ N} - 550\text{ N}}{56.1\text{ kg}} = -1.78\text{ m/s}^2$. The elevator has a downward acceleration of 1.78 m/s^2.

(b) $a_y = \dfrac{670\text{ N} - 550\text{ N}}{56.1\text{ kg}} = 2.14\text{ m/s}^2$.

(c) $n = 0$ means $a_y = -g$. The student should worry; the elevator is in free fall.

(d) $\Sigma F_y = ma_y$ applied to the composite object gives $T - m_{\text{tot}}g = m_{\text{tot}}a$. $T = m_{\text{tot}}(a_y + g)$. In part (a), $T = (850\text{ kg})(-1.78\text{ m/s}^2 + 9.80\text{ m/s}^2) = 6820\text{ N}$. In part (c), $a_y = -g$ and $T = 0$.

EVALUATE: In part (b), $T = (850\text{ kg})(2.14\text{ m/s}^2 + 9.80\text{ m/s}^2) = 10{,}150\text{ N}$. The weight of the composite object is 8330 N. When the acceleration is upward the tension is greater than the weight and when the acceleration is downward the tension is less than the weight.

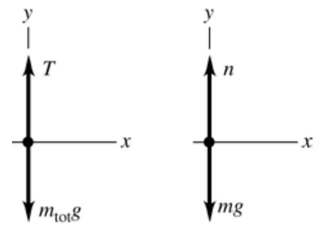


Figure 5.20a, b

P5.27. **(a) IDENTIFY:** Constant speed implies $a = 0$. Apply Newton's first law to the box. The friction force is directed opposite to the motion of the box.

SET UP: Consider the free-body diagram for the box, given in Figure 5.27a. Let $\vec{F}$ be the horizontal force applied by the worker. The friction is kinetic friction since the box is sliding along the surface.

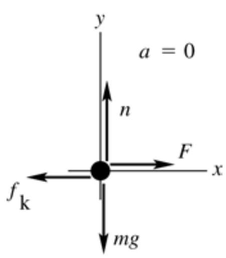


Figure 5.27a

EXECUTE:

$\Sigma F_y = ma_y$

$n - mg = 0$

$n = mg$

so $f_k = \mu_k n = \mu_k mg$

$\Sigma F_x = ma_x$

$F - f_k = 0$

$F = f_k = \mu_k mg = (0.20)(11.2\text{ kg})(9.80\text{ m/s}^2) = 22\text{ N}$

(b) IDENTIFY: Now the only horizontal force on the box is the kinetic friction force. Apply Newton's second law to the box to calculate its acceleration. Once we have the acceleration, we can find the distance using a constant acceleration equation. The friction force is $f_k = \mu_k mg,$ just as in part (a).

SET UP: The free-body diagram is sketched in Figure 5.27b.

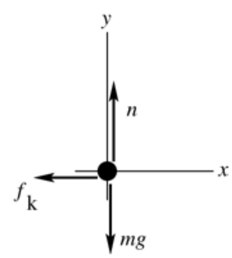


Figure 5.27b

EXECUTE:

$$\Sigma F_x = ma_x$$

$$-f_k = ma_x$$

$$-\mu_k mg = ma_x$$

$$a_x = -\mu_k g = -(0.20)(9.80 \text{ m/s}^2) = -1.96 \text{ m/s}^2$$

Use the constant acceleration equations to find the distance the box travels:

$$v_x = 0, \quad v_{0x} = 3.50 \text{ m/s}, \quad a_x = -1.96 \text{ m/s}^2, \quad x - x_0 = ?$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$x - x_0 = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0 - (3.50 \text{ m/s})^2}{2(-1.96 \text{ m/s}^2)} = 3.1 \text{ m}$$

EVALUATE: The normal force is the component of force exerted by a surface perpendicular to the surface. Its magnitude is determined by $\Sigma\vec{F} = m\vec{a}.$ In this case n and mg are the only vertical forces and $a_y = 0,$ so $n = mg.$ Also note that f_k and n are proportional in magnitude but perpendicular in direction.

P5.34. **IDENTIFY:** Constant speed means zero acceleration for each block. If the block is moving, the friction force the tabletop exerts on it is kinetic friction. Apply $\Sigma\vec{F} = m\vec{a}$ to each block.

SET UP: The free-body diagrams and choice of coordinates for each block are given by Figure 5.34. $m_A = 4.59$ kg and $m_B = 2.55$ kg.

EXECUTE: **(a)** $\Sigma F_y = ma_y$ with $a_y = 0$ applied to block B gives $m_B g - T = 0$ and $T = 25.0$ N. $\Sigma F_x = ma_x$ with $a_x = 0$ applied to block A gives $T - f_k = 0$ and $f_k = 25.0$ N. $n_A = m_A g = 45.0$ N and $\mu_k = \frac{f_k}{n_A} = \frac{25.0 \text{ N}}{45.0 \text{ N}} = 0.556.$

(b) Now let A be block A plus the cat, so $m_A = 9.18$ kg. $n_A = 90.0$ N and $f_k = \mu_k n = (0.556)(90.0 \text{ N}) = 50.0$ N. $\sum F_x = ma_x$ for A gives $T - f_k = m_A a_x.$ $\sum Fy = ma_y$ for block B gives $m_B g - T = m_B a_y.$ a_x for A equals a_y for $B,$ so adding the two equations gives

$m_B g - f_k = (m_A + m_B)a_y$ and $a_y = \dfrac{m_B g - f_k}{m_A + m_B} = \dfrac{25.0\text{ N} - 50.0\text{ N}}{9.18\text{ kg} + 2.55\text{ kg}} = -2.13\text{ m/s}^2$. The acceleration is upward and block B slows down.

EVALUATE: The equation $m_B g - f_k = (m_A + m_B)a_y$ has a simple interpretation. If both blocks are considered together then there are two external forces: $m_B g$ that acts to move the system one way and f_k that acts oppositely. The net force of $m_B g - f_k$ must accelerate a total mass of $m_A + m_B$.

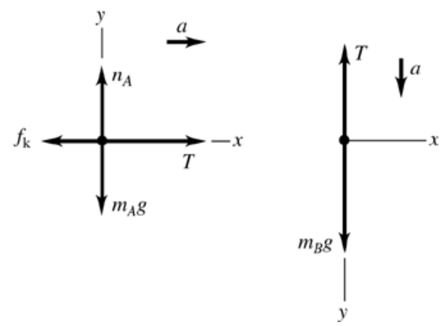


Figure 5.34

P5.46. IDENTIFY: The acceleration of the person is $a_{rad} = v^2/R$, directed horizontally to the left in the figure in the problem. The time for one revolution is the period $T = \dfrac{2\pi R}{v}$. Apply $\Sigma\vec{F} = m\vec{a}$ to the person.

SET UP: The person moves in a circle of radius $R = 3.00\text{ m} + (5.00\text{ m})\sin 30.0° = 5.50\text{ m}$. The free-body diagram is given in Figure 5.46. $\vec{F}$ is the force applied to the seat by the rod.

EXECUTE: (a) $\Sigma F_y = ma_y$ gives $F\cos 30.0° = mg$ and $F = \dfrac{mg}{\cos 30.0°}$. $\Sigma F_x = ma_x$ gives $F\sin 30.0° = m\dfrac{v^2}{R}$. Combining these two equations gives $v = \sqrt{Rg\tan\theta} = \sqrt{(5.50\text{ m})(9.80\text{ m/s}^2)\tan 30.0°} = 5.58\text{ m/s}$. Then the period is $T = \dfrac{2\pi R}{v} = \dfrac{2\pi(5.50\text{ m})}{5.58\text{ m/s}} = 6.19\text{ s}$.

(b) The net force is proportional to m so in $\Sigma\vec{F} = m\vec{a}$ the mass divides out and the angle for a given rate of rotation is independent of the mass of the passengers.

EVALUATE: The person moves in a horizontal circle so the acceleration is horizontal. The net inward force required for circular motion is produced by a component of the force exerted on the seat by the rod.

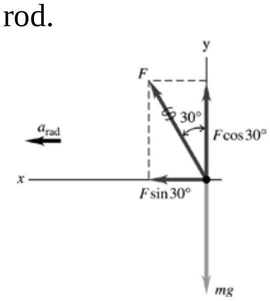


Figure 5.46

P5.51. **IDENTIFY:** Apply $\Sigma\vec{F} = m\vec{a}$ to the motion of the pilot. The pilot moves in a vertical circle. The apparent weight is the normal force exerted on him. At each point $\vec{a}_{rad}$ is directed toward the center of the circular path.

(a) SET UP: "the pilot feels weightless" means that the vertical normal force n exerted on the pilot by the chair on which the pilot sits is zero. The force diagram for the pilot at the top of the path is given in Figure 5.51a.

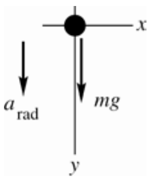


Figure 5.51a

EXECUTE:

$\Sigma F_y = ma_y$

$mg = ma_{rad}$

$g = \dfrac{v^2}{R}$

Thus $v = \sqrt{gR} = \sqrt{(9.80\ \text{m/s}^2)(150\ \text{m})} = 38.34\ \text{m/s}$

$$v = (38.34\ \text{m/s})\left(\frac{1\ \text{km}}{10^3\ \text{m}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right) = 138\ \text{km/h}$$

(b) Set Up: The force diagram for the pilot at the bottom of the path is given in Figure 5.51b. Note that the vertical normal force exerted on the pilot by the chair on which the pilot sits is now upward.

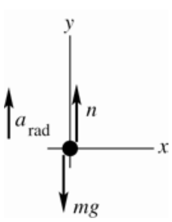


Figure 5.51b

EXECUTE:

$\Sigma F_y = ma_y$

$n - mg = m\dfrac{v^2}{R}$

$n = mg + m\dfrac{v^2}{R}$

This normal force is the pilot's apparent weight.

$w = 700\ \text{N}$, so $m = \dfrac{w}{g} = 71.43\ \text{kg}$

$$v = (280\ \text{km/h})\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)\left(\frac{10^3\ \text{m}}{1\ \text{km}}\right) = 77.78\ \text{m/s}$$

Thus $n = 700\ \text{N} + 71.43\ \text{kg}\dfrac{(77.78\ \text{m/s})^2}{150\ \text{m}} = 3580\ \text{N}.$

EVALUATE: In part (b), $n > mg$ since the acceleration is upward. The pilot feels he is much heavier than when at rest. The speed is not constant, but it is still true that $a_{rad} = v^2/R$ at each point of the motion.

P5.72. **IDENTIFY:** The system is in equilibrium. Apply Newton's first law to block *A*, to the hanging weight and to the knot where the cords meet. Target variables are the two forces.

(a) SET UP: The free-body diagram for the hanging block is given in Figure 5.72a.

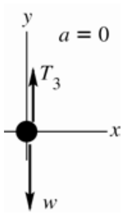


Figure 5.72a

EXECUTE:

$\Sigma F_y = ma_y$

$T_3 - w = 0$

$T_3 = 12.0 \text{ N}$

SET UP: The free-body diagram for the knot is given in Figure 5.72b.

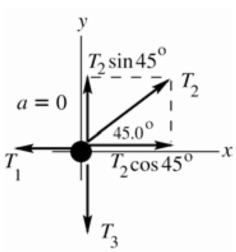


Figure 5.72b

EXECUTE:

$\Sigma F_y = ma_y$

$T_2 \sin 45.0° - T_3 = 0$

$$T_2 = \frac{T_3}{\sin 45.0°} = \frac{12.0 \text{ N}}{\sin 45.0°}$$

$T_2 = 17.0 \text{ N}$

$\Sigma F_x = ma_x$

$T_2 \cos 45.0° - T_1 = 0$

$T_1 = T_2 \cos 45.0° = 12.0 \text{ N}$

SET UP: The free-body diagram for block *A* is given in Figure 5.72c.

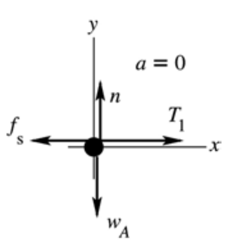


Figure 5.72c

EXECUTE:

$\Sigma F_x = ma_x$

$T_1 - f_s = 0$

$f_s = T_1 = 12.0 \text{ N}$

EVALUATE: Also can apply $\Sigma F_y = ma_y$ to this block:

$n - w_A = 0$

$n = w_A = 60.0 \text{ N}$

Then $\mu_s n = (0.25)(60.0 \text{ N}) = 15.0 \text{ N}$; this is the maximum possible value for the static friction force.

We see that $f_s < \mu_s n$; for this value of w the static friction force can hold the blocks in place.

(b) SET UP: We have all the same free-body diagrams and force equations as in part (a) but now the static friction force has its largest possible value, $f_s = \mu_s n = 15.0\ \text{N}$. Then $T_1 = f_s = 15.0\ \text{N}$.

EXECUTE: From the equations for the forces on the knot

$T_2 \cos 45.0° - T_1 = 0$ implies $T_2 = T_1/\cos 45.0° = \dfrac{15.0\ \text{N}}{\cos 45.0°} = 21.2\ \text{N}$

$T_2 \sin 45.0° - T_3 = 0$ implies $T_3 = T_2 \sin 45.0° = (21.2\ \text{N})\sin 45.0° = 15.0\ \text{N}$

And finally $T_3 - w = 0$ implies $w = T_3 = 15.0\ \text{N}$.

EVALUATE: Compared to part (a), the friction is larger in part (b) by a factor of $(15.0/12.0)$ and w is larger by this same ratio.