5.4. IDENTIFY: Apply Newton's 1st law to the person. Each half of the rope exerts a force on him, directed along the rope and equal to the tension *T* in the rope.

SET UP: **(a)** The force diagram for the person is given in Figure 5.4

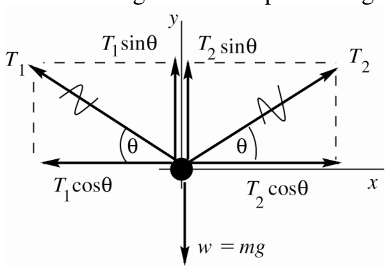

Figure 5.4

T_1 and T_2 are the tensions in each half of the rope.

EXECUTE: $\sum F_x = 0$

$T_2\cos\theta - T_1\cos\theta = 0$

This says that $T_1 = T_2 = T$ (The tension is the same on both sides of the person.)

$\sum F_y = 0$

$T_1\sin\theta + T_2\sin\theta - mg = 0$

But $T_1 = T_2 = T$, so $2T\sin\theta = mg$

$$T = \frac{mg}{2\sin\theta} = \frac{(90.0\text{ kg})(9.80\text{ m/s}^2)}{2\sin 10.0°} = 2540\text{ N}$$

(b) The relation $2T\sin\theta = mg$ still applies but now we are given that $T = 2.50\times10^4$ N (the breaking strength) and are asked to find θ.

$$\sin\theta = \frac{mg}{2T} = \frac{(90.0\text{ kg})(9.80\text{ m/s}^2)}{2(2.50\times10^4\text{ N})} = 0.01764,\ \ \theta = 1.01°.$$

EVALUATE: $T = mg/(2\sin\theta)$ says that $T = mg/2$ when $\theta = 90°$ (rope is vertical).

$T \to \infty$ when $\theta \to 0$ since the upward component of the tension becomes a smaller fraction of the tension.

5.7. IDENTIFY: Apply $\sum \vec{F} = m\vec{a}$ to the car.

SET UP: Use coordinates with $+x$ parallel to the surface of the street.

EXECUTE: $\sum F_x = 0$ gives $T = w\sin\alpha$. $F = mg\sin\theta = (1390\text{ kg})(9.80\text{ m/s}^2)\sin 17.5° = 4.10\times10^3$ N .

EVALUATE: The force required is less than the weight of the car by the factor $\sin\alpha$.

5.8. IDENTIFY: Apply Newton's 1st 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 Figure 5.8.

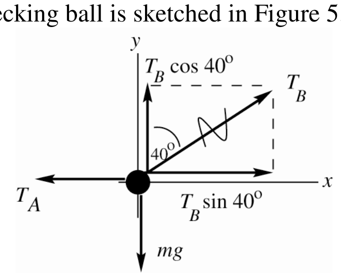

Figure 5.8

EXECUTE:

(a) $\sum F_y = ma_y$

$T_B\cos 40° - mg = 0$

$$T_B = \frac{mg}{\cos 40°} = \frac{(4090\text{ kg})(9.80\text{ m/s}^2)}{\cos 40°} = 5.23\times10^4\text{ N}$$

(b) $\sum F_x = ma_x$

$T_B \sin 40° - T_A = 0$

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

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

5.13. **IDENTIFY:** Apply Newton's first law to the ball. The force of the wall on the ball and the force of the ball on the wall are related by Newton's third law.

SET UP: The forces on the ball are its weight, the tension in the wire, and the normal force applied by the wall. To calculate the angle ϕ that the wire makes with the wall, use Figure 5.13a. $\sin\phi = \dfrac{16.0 \text{ cm}}{46.0 \text{ cm}}$ and $\phi = 20.35°$

EXECUTE: **(a)** The free-body diagram is shown in Figure 5.13b. Use the *x* and *y* coordinates shown in the figure. $\sum F_y = 0$ gives $T\cos\phi - w = 0$ and $T = \dfrac{w}{\cos\phi} = \dfrac{(45.0 \text{ kg})(9.80 \text{ m/s}^2)}{\cos 20.35°} = 470 \text{ N}$

(b) $\sum F_x = 0$ gives $T\sin\phi - n = 0$. $n = (470 \text{ N})\sin 20.35° = 163 \text{ N}$. By Newton's third law, the force the ball exerts on the wall is 163 N, directed to the right.

EVALUATE: $n = \left(\dfrac{w}{\cos\phi}\right)\sin\phi = w\tan\phi$. As the angle ϕ decreases (by increasing the length of the wire), *T* decreases and *n* decreases.

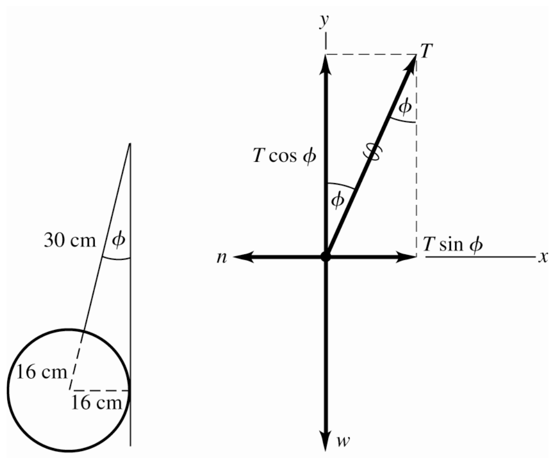

Figure 5.13a, b

5.18. **IDENTIFY:** Apply Newton's second law to the three sleds taken together as a composite object and to each individual sled. All three sleds have the same horizontal acceleration *a*.

SET UP: The free-body diagram for the three sleds taken as a composite object is given in Figure 5.18a and for each individual sled in Figure 5.18b-d. Let $+x$ be to the right, in the direction of the acceleration. $m_{\text{tot}} = 60.0 \text{ kg}$.

EXECUTE: **(a)** $\sum F_x = ma_x$ for the three sleds as a composite object gives $P = m_{\text{tot}}a$ and $a = \dfrac{P}{m_{\text{tot}}} = \dfrac{125 \text{ N}}{60.0 \text{ kg}} = 2.08 \text{ m/s}^2$.

(b) $\sum F_x = ma_x$ applied to the 10.0 kg sled gives $P - T_A = m_{10}a$ and $T_A = P - m_{10}a = 125 \text{ N} - (10.0 \text{ kg})(2.08 \text{ m/s}^2) = 104 \text{ N}$. $\sum F_x = ma_x$ applied to the 30.0 kg sled gives $T_B = m_{30}a = (30.0 \text{ kg})(2.08 \text{ m/s}^2) = 62.4 \text{ N}$.

EVALUATE: If we apply $\sum F_x = ma_x$ to the 20.0 kg sled and calculate *a* from T_A and T_B found in part (b), we get $T_A - T_B = m_{20}a$. $a = \dfrac{T_A - T_B}{m_{20}} = \dfrac{104 \text{ N} - 62.4 \text{ N}}{20.0 \text{ kg}} = 2.08 \text{ m/s}^2$, which agrees with the value we calculated in part (a).

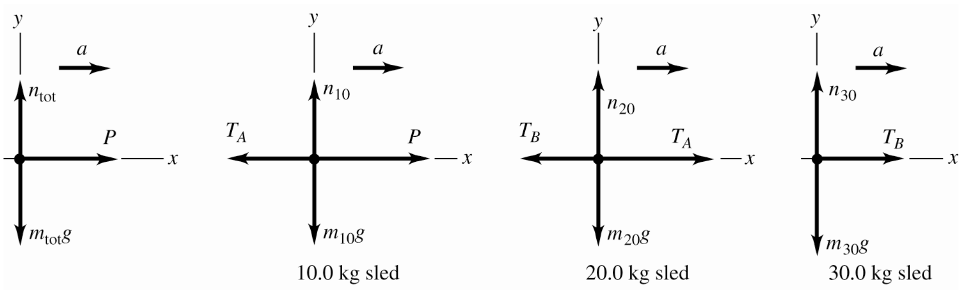

Figure 5.18a–d

5.19. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$ 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 5.19.

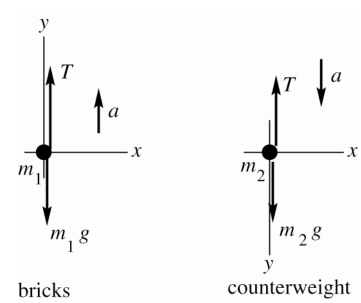

Figure 5.19

(b) EXECUTE: Apply $\sum F_y = ma_y$ 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>: $\sum F_y = ma_y$

$T - m_1 g = m_1 a$

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

$m_2 g - T = m_2 a$

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.

5.23. **IDENTIFY:** The maximum tension in the chain is at the top of the chain. Apply $\sum\vec{F} = m\vec{a}$ to the composite object of chain and boulder. Use the constant acceleration kinematic equations to relate the acceleration to the time.
SET UP: Let $+y$ be upward. The free-body diagram for the composite object is given in Figure 5.23.
$T = 2.50 w_{\text{chain}}$. $m_{\text{tot}} = m_{\text{chain}} + m_{\text{boulder}} = 1325\text{ kg}$.

EXECUTE: **(a)** $\sum F_y = ma_y$ gives $T - m_{\text{tot}}g = m_{\text{tot}}a$. $a = \dfrac{T - m_{\text{tot}}g}{m_{\text{tot}}} = \dfrac{2.50m_{\text{chain}}g - m_{\text{tot}}g}{m_{\text{tot}}} = \left(\dfrac{2.50m_{\text{chain}}}{m_{\text{tot}}} - 1\right)g$

$$a = \left(\frac{2.50[575\text{ kg}]}{1325\text{ kg}} - 1\right)(9.80\text{ m/s}^2) = 0.832\text{ m/s}^2.$$

(b) Assume the acceleration has its maximum value: $a_y = 0.832\text{ m/s}^2$, $y - y_0 = 125$ m and $v_{0y} = 0$.

$y - y_0 = v_{0y}t + \frac{1}{2}a_yt^2$ gives $t = \sqrt{\dfrac{2(y - y_0)}{a_y}} = \sqrt{\dfrac{2(125\text{ m})}{0.832\text{ m/s}^2}} = 17.3\text{ s}$

EVALUATE: The tension in the chain is $T = 1.41\times10^4$ N and the total weight is 1.30×10^4 N. The upward force exceeds the downward force and the acceleration is upward.

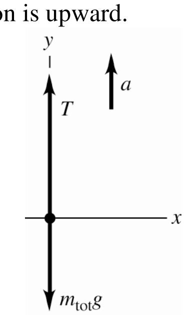

Figure 5.23

5.24. **IDENTIFY:** Apply $\sum\vec{F} = m\vec{a}$ to the composite object of elevator plus student ($m_{\text{tot}} = 850$ kg) and also to the student ($w = 550$ 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 Figure 5.24a 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 $m = w/g = 56.1$ kg.

EXECUTE: **(a)** $\sum F_y = ma_y$ 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) $\sum F_y = ma_y$ 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), $T = (850\text{ kg})(-1.78\text{ m/s}^2 + 9.80\text{ m/s}^2) = 6820$ N. In part (c), $a_y = -g$ and $T = 0$.

EVALUATE: In part (b), $T = (850\text{ kg})(2.14\text{ m/s}^2 + 9.80\text{ m/s}^2) = 10{,}150$ 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.

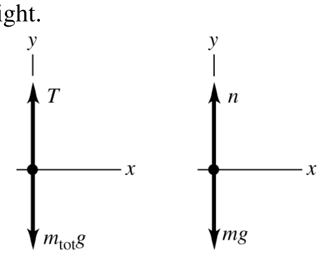

Figure 5.24a, b