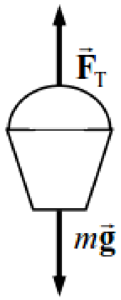
24. A bear sling, Fig. 4–30, is used in some national parks for placing backpackers' food out of the reach of bears. Explain why the force needed to pull the backpack up increases as the backpack gets higher and higher. Is it possible to pull the rope hard enough so that it doesn't sag at all?

FIGURE 4–30 Question 24.

24. No. In order to hold the backpack up, the rope must exert a vertical force equal to the backpack's weight, so that the net vertical force on the backpack is zero. The force, F, exerted by the rope on each side of the pack is always along the length of the rope. The vertical component of this force is $F\sin\theta$, where θ is the angle the rope makes with the horizontal. The higher the pack goes, the smaller θ becomes and the larger F must be to hold the pack up there. No matter how hard you pull, the rope can never be horizontal because it must exert an upward (vertical) component of force to balance the pack's weight. See also Example 4-16 and Figure 4-26.

13. (II) A 14.0-kg bucket is lowered vertically by a rope in which there is 163 N of tension at a given instant. What is the acceleration of the bucket? Is it up or down?

13. Choose up to be the positive direction. Write Newton's second law for the vertical direction, and solve for the acceleration.



$$\sum F = F_T - mg = ma$$

$$a = \frac{F_T - mg}{m} = \frac{163\,\text{N} - (14.0\,\text{kg})(9.80\,\text{m/s}^2)}{14.0\,\text{kg}} = \boxed{1.8\,\text{m/s}^2}$$

Since the acceleration is positive, the bucket has an $\boxed{\text{upward}}$ acceleration.

5. (II) Superman must stop a 120-km/h train in 150 m to keep it from hitting a stalled car on the tracks. If the train's mass is 3.6×10^5 kg, how much force must he exert? Compare to the weight of the train (give as %). How much force does the train exert on Superman?

5. Find the average acceleration from Eq. 2-12c, and then find the force needed from Newton's second law. We assume the train is moving in the positive direction.

$$v = 0 \qquad v_0 = (120\,\text{km/h})\left(\frac{1\,\text{m/s}}{3.6\,\text{km/h}}\right) = 33.33\,\text{m/s} \qquad a_{avg} = \frac{v^2 - v_0^2}{2(x - x_0)}$$

$$F_{avg} = ma_{avg} = m\frac{v^2 - v_0^2}{2(x - x_0)} = (3.6\times10^5\,\text{kg})\left[\frac{0 - (33.33\,\text{m/s})^2}{2(150\,\text{m})}\right] = -1.333\times10^6\,\text{N} \approx \boxed{-1.3\times10^6\,\text{N}}$$

The negative sign indicates the direction of the force, in the opposite direction to the initial velocity. We compare the magnitude of this force to the weight of the train.

$$\frac{F_{avg}}{mg} = \frac{1.333\times10^6\,\text{N}}{(3.6\times10^5\,\text{kg})(9.80\,\text{m/s}^2)} = 0.3886$$

Thus the force is $\boxed{\text{39\% of the weight}}$ of the train.

By Newton's third law, the train exerts the same magnitude of force on Superman that Superman exerts on the train, but in the opposite direction. So the train exerts a force of $\boxed{1.3\times10^6\,\text{N}}$ in the forward direction on Superman.

20. (II) Using focused laser light, *optical tweezers* can apply a force of about 10 pN to a 1.0-μm diameter polystyrene bead, which has a density about equal to that of water: a volume of 1.0 cm^3 has a mass of about 1.0 g. Estimate the bead's acceleration in *g*'s.

20. The ratio of accelerations is the same as the ratio of the force.

$$\frac{a_{\text{optics}}}{g}=\frac{ma_{\text{optics}}}{mg}=\frac{F_{\text{optics}}}{mg}=\frac{F_{\text{optics}}}{\rho\left(\frac{4}{3}\pi r^3\right)g}$$

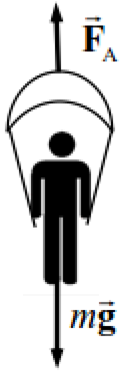
$$=\frac{10\times10^{-12}\,\text{N}}{\left(\frac{1.0\,\text{g}}{1.0\,\text{cm}^3}\frac{1\,\text{kg}}{1000\,\text{g}}\frac{10^6\,\text{cm}^3}{1\,\text{m}^3}\right)\frac{4}{3}\pi\left(.5\times10^{-6}\,\text{m}\right)^3\left(9.80\,\text{m/s}^2\right)}=1949\;\rightarrow$$

$$a\approx\boxed{2000\,g\text{'s}}$$

22. (II) (*a*) What is the acceleration of two falling sky divers (mass = 132 kg including parachute) when the upward force of air resistance is equal to one-fourth of their weight? (*b*) After popping open the parachute, the divers descend leisurely to the ground at constant speed. What now is the force of air resistance on the sky divers and their parachute? See Fig. 4–32.

FIGURE 4–32 Problem 22.

22. (*a*) There will be two forces on the skydivers – their combined weight, and the upward force of air resistance, $\vec{\mathbf{F}}_A$. Choose up to be the positive direction. Write Newton's second law for the skydivers.



$$\sum F=F_A-mg=ma\;\rightarrow\;0.25mg-mg=ma\;\rightarrow$$

$$a=-0.75g=-0.75\left(9.80\,\text{m/s}^2\right)=\boxed{-7.35\,\text{m/s}^2}$$

Due to the sign of the result, the direction of the acceleration is down.

(*b*) If they are descending at constant speed, then the net force on them must be zero, and so the force of air resistance must be equal to their weight.

$$F_A=mg=(132\text{ kg})\left(9.80\,\text{m/s}^2\right)=\boxed{1.29\times10^3\,\text{N}}$$

25. (III) The 100-m dash can be run by the best sprinters in 10.0 s. A 66-kg sprinter accelerates uniformly for the first 45 m to reach top speed, which he maintains for the remaining 55 m. (*a*) What is the average horizontal component of force exerted on his feet by the ground during acceleration? (*b*) What is the speed of the sprinter over the last 55 m of the race (i.e., his top speed)?

25. We break the race up into two portions. For the acceleration phase, we call the distance d_1 and the time t_1. For the constant speed phase, we call the distance d_2 and the time t_2. We know that $d_1 = 45\,\text{m}$, $d_2 = 55\,\text{m}$, and $t_2 = 10.0\,\text{s} - t_1$. Eq. 2-12b is used for the acceleration phase and Eq. 2-2 is used for the constant speed phase. The speed during the constant speed phase is the final speed of the acceleration phase, found from Eq. 2-12a.

$$x - x_0 = v_0 t + \tfrac{1}{2}at^2 \;\rightarrow\; d_1 = \tfrac{1}{2}at_1^2 \;;\; \Delta x = vt \;\rightarrow\; d_2 = vt_2 = v\left(10.0\,\text{s} - t_1\right) \;;\; v = v_0 + at_1$$

This set of equations can be solved for the acceleration and the velocity.

$$d_1 = \tfrac{1}{2}at_1^2 \;;\; d_2 = v\left(10.0\,\text{s} - t_1\right) \;;\; v = at_1 \;\rightarrow\; 2d_1 = at_1^2 \;;\; d_2 = at_1\left(10.0 - t_1\right) \;\rightarrow$$

$$a = \frac{2d_1}{t_1^2} \;;\; d_2 = \frac{2d_1}{t_1^2}t_1\left(10.0 - t_1\right) = \frac{2d_1}{t_1}\left(10.0 - t_1\right) \;\rightarrow\; d_2 t_1 = 2d_1\left(10.0 - t_1\right) \;\rightarrow$$

$$t_1 = \frac{20.0 d_1}{\left(d_2 + 2d_1\right)} \;\rightarrow\; a = \frac{2d_1}{t_1^2} = \frac{2d_1}{\left[\dfrac{20.0 d_1}{\left(d_2 + 2d_1\right)}\right]^2} = \frac{\left(d_2 + 2d_1\right)^2}{\left(200\,\text{s}^2\right)d_1}$$

$$v = at_1 = \frac{\left(d_2 + 2d_1\right)^2}{200 d_1}\frac{20.0 d_1}{\left(d_2 + 2d_1\right)} = \frac{\left(d_2 + 2d_1\right)}{10.0\,\text{s}}$$

(*a*) The horizontal force is the mass of the sprinter times their acceleration.

$$F = ma = m\frac{\left(d_2 + 2d_1\right)^2}{\left(200\,\text{s}^2\right)d_1} = \left(66\,\text{kg}\right)\frac{\left(145\,\text{m}\right)^2}{\left(200\,\text{s}^2\right)\left(45\,\text{m}\right)} = 154\,\text{N} \approx \boxed{150\,\text{N}}$$

(*b*) The velocity for the second portion of the race was found above.

$$v = \frac{\left(d_2 + 2d_1\right)}{10.0\,\text{s}} = \frac{145\,\text{m}}{10.0\,\text{s}} = \boxed{14.5\,\text{m/s}}$$

37. (II) The two forces $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$ shown in Fig. 4–40a an (looking down) act on a 18.5-kg object on a friction tabletop. If $F_1 = 10.2\ \text{N}$ and $F_2 = 16.0\ \text{N}$, find the force on the object and its acceleration for (a) and (b).

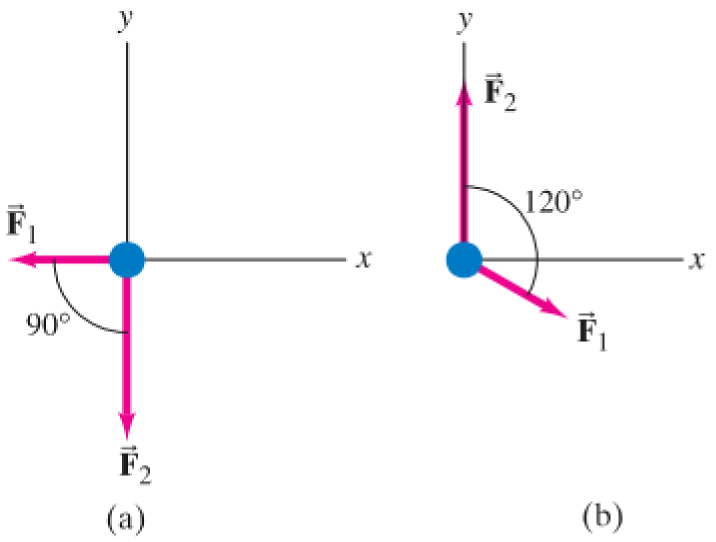


FIGURE 4–40 Problem 37.

37. The net force in each case is found by vector addition with components.

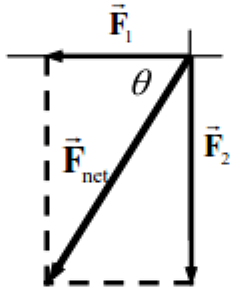
(*a*) $F_{\text{Net x}} = -F_1 = -10.2\ \text{N} \quad F_{\text{Net y}} = -F_2 = -16.0\ \text{N}$

$$F_{\text{Net}} = \sqrt{(-10.2)^2 + (-16.0)^2} = 19.0\ \text{N} \qquad \theta = \tan^{-1}\frac{-16.0}{-10.2} = 57.48^\circ$$

The actual angle from the *x*-axis is then 237.48°. Thus the net force is

$$F_{\text{Net}} = \boxed{19.0\ \text{N at } 237.5^\circ}$$

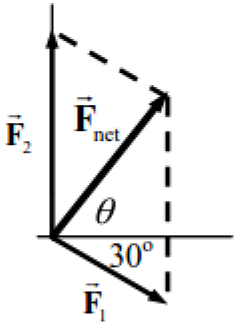
$$a = \frac{F_{\text{Net}}}{m} = \frac{19.0\ \text{N}}{18.5\ \text{kg}} = \boxed{1.03\ \text{m/s}^2 \text{ at } 237.5^\circ}$$



(*b*) $F_{\text{Net x}} = F_1 \cos 30^\circ = 8.833\ \text{N} \quad F_{\text{Net y}} = F_2 - F_1 \sin 30^\circ = 10.9\ \text{N}$

$$F_{\text{Net}} = \sqrt{(8.833\ \text{N})^2 + (10.9\ \text{N})^2} = 14.03\text{N} \approx \boxed{14.0\ \text{N}}$$

$$\theta = \tan^{-1}\frac{10.9}{8.833} = \boxed{51.0^\circ} \qquad a = \frac{F_{\text{Net}}}{m} = \frac{14.03\ \text{N}}{18.5\ \text{kg}} = \boxed{0.758\ \text{m/s}^2} \text{ at } \boxed{51.0^\circ}$$



40. (II) A 3.0-kg object has the following two forces acting on it:

$$\vec{\mathbf{F}}_1 = (16\hat{\mathbf{i}} + 12\hat{\mathbf{j}})\ \text{N}$$
$$\vec{\mathbf{F}}_2 = (-10\hat{\mathbf{i}} + 22\hat{\mathbf{j}})\ \text{N}$$

If the object is initially at rest, determine its velocity $\vec{\mathbf{v}}$ at $t = 3.0\ \text{s}$.

40. Find the net force by adding the force vectors. Divide that net force by the mass to find the acceleration, and then use Eq. 3-13a to find the velocity at the given time.

$$\sum \vec{\mathbf{F}} = (16\hat{\mathbf{i}} + 12\hat{\mathbf{j}})\text{N} + (-10\hat{\mathbf{i}} + 22\hat{\mathbf{j}})\text{N} = (6\hat{\mathbf{i}} + 34\hat{\mathbf{j}})\text{N} = m\vec{\mathbf{a}} = (3.0\ \text{kg})\vec{\mathbf{a}} \rightarrow$$

$$\vec{\mathbf{a}} = \frac{(6\hat{\mathbf{i}} + 34\hat{\mathbf{j}})\text{N}}{3.0\ \text{kg}} \qquad \vec{\mathbf{v}} = \vec{\mathbf{v}}_0 + \vec{\mathbf{a}}t = 0 + \frac{(6\hat{\mathbf{i}} + 34\hat{\mathbf{j}})\text{N}}{3.0\ \text{kg}}(3.0\ \text{s}) = \boxed{(6\hat{\mathbf{i}} + 34\hat{\mathbf{j}})\ \text{m/s}}$$

In magnitude and direction, the velocity is $35\ \text{m/s}$ at an angle of 80°.

46. (II) Three blocks on a frictionless horizontal surface are in contact with each other as shown in Fig. 4–42. A force $\vec{\mathbf{F}}$ is applied to block A (mass m_A). (*a*) Draw a free-body diagram for each block. Determine (*b*) the acceleration of the system (in terms of m_A, m_B, and m_C), (*c*) the net force on each block, and (*d*) the force of contact that each block exerts on its neighbor. (*e*) If $m_A = m_B = m_C = 10.0$ kg and $F = 96.0$ N, give numerical answers to (*b*), (*c*), and (*d*). Explain how your answers make sense intuitively.

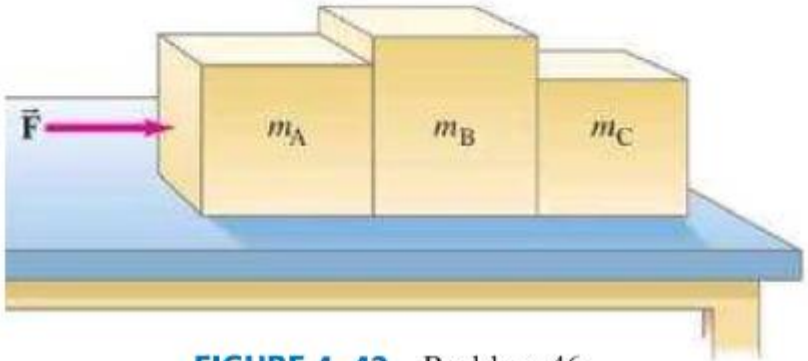
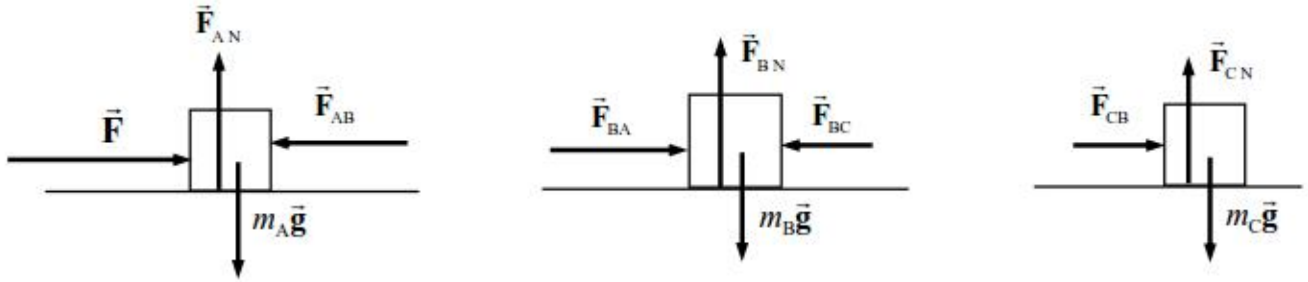


FIGURE 4–42 Problem 46.

46. (*a*) In the free-body diagrams below, $\vec{\mathbf{F}}_{AB}$ = force on block A exerted by block B, $\vec{\mathbf{F}}_{BA}$ = force on block B exerted by block A, $\vec{\mathbf{F}}_{BC}$ = force on block B exerted by block C, and $\vec{\mathbf{F}}_{CB}$ = force on block C exerted by block B. The magnitudes of $\vec{\mathbf{F}}_{BA}$ and $\vec{\mathbf{F}}_{AB}$ are equal, and the magnitudes of $\vec{\mathbf{F}}_{BC}$ and $\vec{\mathbf{F}}_{CB}$ are equal, by Newton's third law.



(*b*) All of the vertical forces on each block add up to zero, since there is no acceleration in the vertical direction. Thus for each block, $F_N = mg$. For the horizontal direction, we have the following.

$$\sum F = F - F_{AB} + F_{BA} - F_{BC} + F_{CB} = F = (m_A + m_B + m_C)a \rightarrow \boxed{a = \frac{F}{m_A + m_B + m_C}}$$

(*c*) For each block, the net force must be *ma* by Newton's second law. Each block has the same acceleration since they are in contact with each other.

$$\boxed{F_{A\,net} = F\frac{m_A}{m_A + m_B + m_C}} \quad \boxed{F_{B\,net} = F\frac{m_B}{m_A + m_B + m_C}} \quad \boxed{F_{3net} = F\frac{m_C}{m_A + m_B + m_C}}$$

(*d*) From the free-body diagram, we see that for m_C, $F_{CB} = F_{C\,net} = \boxed{F\dfrac{m_C}{m_A + m_B + m_C}}$. And by Newton's third law, $F_{BC} = F_{CB} = \boxed{F\dfrac{m_C}{m_A + m_B + m_C}}$. Of course, $\vec{\mathbf{F}}_{23}$ and $\vec{\mathbf{F}}_{32}$ are in opposite directions. Also from the free-body diagram, we use the net force on m_A.

$$F - F_{AB} = F_{A\,net} = F\frac{m_A}{m_A + m_B + m_C} \rightarrow F_{AB} = F - F\frac{m_A}{m_A + m_B + m_C} \rightarrow$$

$$\boxed{F_{AB} = F\frac{m_B + m_C}{m_A + m_B + m_C}}$$

By Newton's third law, $F_{BC} = F_{AB} = \boxed{F\dfrac{m_2 + m_3}{m_1 + m_2 + m_3}}$.

(*e*) Using the given values, $a = \dfrac{F}{m_1 + m_2 + m_3} = \dfrac{96.0\text{ N}}{30.0\text{ kg}} = \boxed{3.20\text{ m/s}^2}$. Since all three masses are the same value, the net force on each mass is $F_{net} = ma = (10.0\text{ kg})(3.20\text{ m/s}^2) = 32.0\text{ N}$.

This is also the value of F_{CB} and F_{BC}. The value of F_{AB} and F_{BA} is found as follows.

$$F_{AB} = F_{BA} = (m_2 + m_3)a = (20.0\text{ kg})(3.20\text{ m/s}^2) = 64.0\text{ N}$$

To summarize:

$$F_{A\,net} = F_{B\,net} = F_{C\,net} = \boxed{32.0\text{ N}} \qquad F_{AB} = F_{BA} = \boxed{64.0\text{ N}} \qquad F_{BC} = F_{CB} = \boxed{32.0\text{ N}}$$

The values make sense in that in order of magnitude, we should have $F > F_{BA} > F_{CB}$, since F is the net force pushing the entire set of blocks, F_{AB} is the net force pushing the right two blocks, and F_{BC} is the net force pushing the right block only.

69. The masses m_A and m_B slide on the smooth (frictionless) inclines fixed as shown in Fig. 4–55. (*a*) Determine a formula for the acceleration of the system in terms of m_A, m_B, θ_A, θ_B, and g. (*b*) If $\theta_A = 32°$, $\theta_B = 23°$, and $m_A = 5.0\,\text{kg}$, what value of m_B would keep the system at rest? What would be the tension in the cord (negligible mass) in this case? (*c*) What ratio, m_A/m_B, would allow the masses to move at constant speed along their ramps in either direction?

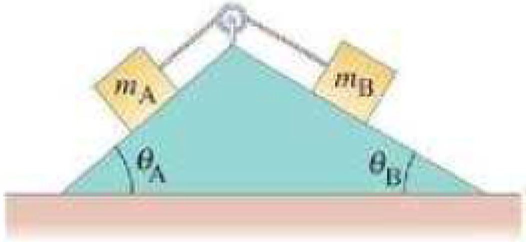
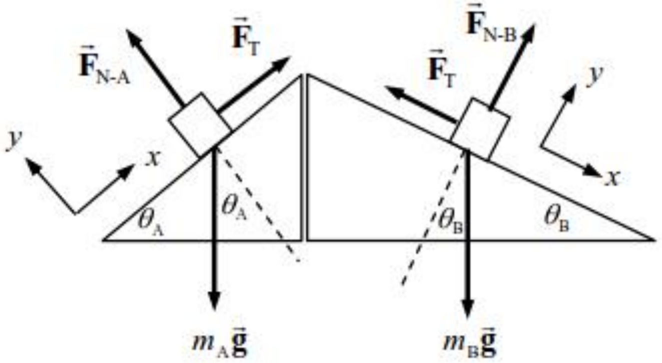


FIGURE 4–55 Problem 69.

69. (*a*) A free-body diagram is shown for each block. We define the positive *x*-direction for m_A to be up its incline, and the positive *x*-direction for m_B to be down its incline. With that definition the masses will both have the same acceleration. Write Newton's second law for each body in the *x* direction, and combine those equations to find the acceleration.



$$m_A:\ \sum F_x = F_T - m_A g\sin\theta_A = m_A a$$

$$m_B:\ \sum F_x = m_B g\sin\theta_B - F_T = m_B a \qquad \text{add these two equations}$$

$$(F_T - m_A g\sin\theta_A) + (m_B g\sin\theta_B - F_T) = m_A a + m_B a \ \rightarrow\ a = \boxed{\frac{m_B\sin\theta_B - m_A\sin\theta_A}{m_A + m_B}g}$$

(*b*) For the system to be at rest, the acceleration must be 0.

$$a = \frac{m_B\sin\theta_B - m_A\sin\theta_A}{m_A + m_B}g = 0 \ \rightarrow\ m_B\sin\theta_B - m_A\sin\theta_A \ \rightarrow$$

$$m_B = m_A\frac{\sin\theta_A}{\sin\theta_B} = (5.0\,\text{kg})\frac{\sin 32°}{\sin 23°} = \boxed{6.8\,\text{kg}}$$

The tension can be found from one of the Newton's second law expression from part (*a*).

$$m_A:\ F_T - m_A g\sin\theta_A = 0 \ \rightarrow\ F_T = m_A g\sin\theta_A = (5.0\,\text{kg})(9.80\,\text{m/s}^2)\sin 32° = \boxed{26\,\text{N}}$$

(*c*) As in part (*b*), the acceleration will be 0 for constant velocity in either direction.

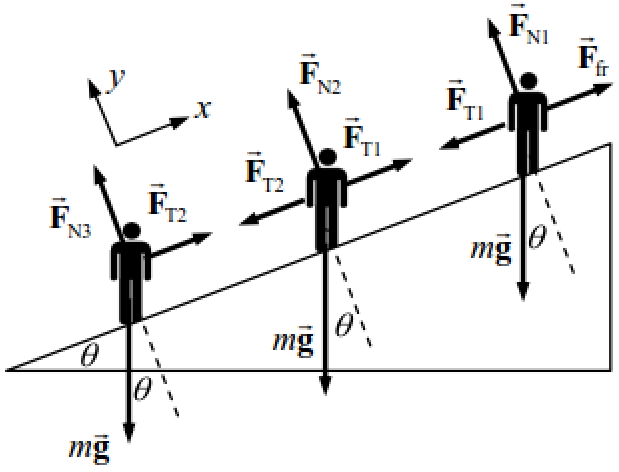
$$a = \frac{m_B\sin\theta_B - m_A\sin\theta_A}{m_A + m_B}g = 0 \ \rightarrow\ m_B\sin\theta_B - m_A\sin\theta_A \ \rightarrow$$

$$\frac{m_A}{m_B} = \frac{\sin\theta_B}{\sin\theta_A} = \frac{\sin 23°}{\sin 32°} = \boxed{0.74}$$

83. Three mountain climbers who are roped together in a line are ascending an icefield inclined at 31.0° to the horizontal (Fig. 4–61). The last climber slips, pulling the second climber off his feet. The first climber is able to hold them both. If each climber has a mass of 75 kg, calculate the tension in each of the two sections of rope between the three climbers. Ignore friction between the ice and the fallen climbers.

FIGURE 4–61 Problem 83.

83. Since the climbers are on ice, the frictional force for the lower two climbers is negligible. Consider the free-body diagram as shown. Note that all the masses are the same. Write Newton's second law in the *x* direction for the lowest climber, assuming he is at rest.



$$\sum F_x = F_{T2} - mg\sin\theta = 0$$

$$F_{T2} = mg\sin\theta = (75\,\text{kg})(9.80\,\text{m/s}^2)\sin 31.0°$$

$$= \boxed{380\,\text{N}}$$

Write Newton's second law in the *x* direction for the middle climber, assuming he is at rest.

$$\sum F_x = F_{T1} - F_{T2} - mg\sin\theta = 0 \rightarrow F_{T1} = F_{T2} + mg\sin\theta = 2F_{T2}g\sin\theta = \boxed{760\,\text{N}}$$

87. A 1.5-kg block rests on top of a 7.5-kg block (Fig. 4–63). The cord and pulley have negligible mass, and there is no significant friction anywhere. (*a*) What force F must be applied to the bottom block so the top block accelerates to the right at $2.5\ \mathrm{m/s^2}$? (*b*) What is the tension in the connecting cord?

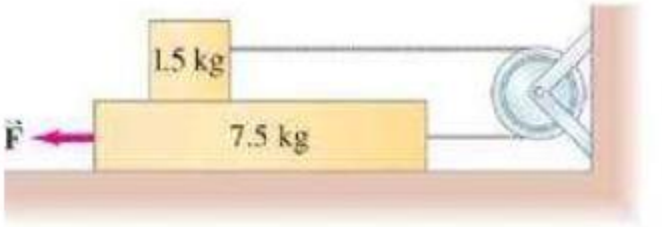


FIGURE 4–63
Problem 87.

87. (*a*) If the 2-block system is taken as a whole system, then the net force on the system is just the force $\vec{\mathbf{F}}$, accelerating the total mass. Use Newton's second law to find the force from the mass and acceleration. Take the direction of motion caused by the force (left for the bottom block, right for the top block) as the positive direction. Then both blocks have the same acceleration.

$$\sum F_x = F = \left(m_{\text{top}} + m_{\text{bottom}}\right)a = (9.0\,\text{kg})\left(2.5\,\text{m/s}^2\right) = 22.5\,\text{N} \approx \boxed{23\,\text{N}}$$

(*b*) The tension in the connecting cord is the only force acting on the top block, and so must be causing its acceleration. Again use Newton's second law.

$$\sum F_x = F_{\text{T}} = m_{\text{top}}a = (1.5\,\text{kg})\left(2.5\,\text{m/s}^2\right) = 3.75\,\text{N} \approx \boxed{3.8\,\text{N}}$$

This could be checked by using the bottom block.

$$\sum F_x = F - F_{\text{T}} = m_{\text{bottom}}a \quad \rightarrow \quad F_{\text{T}} = F - m_{\text{bottom}}a = 22.5\,\text{N} - (7.5\,\text{kg})\left(2.5\,\text{m/s}^2\right) = 3.75\,\text{N}$$