Pearson Physics Level 20
Unit II Dynamics: Chapter 3
Solutions

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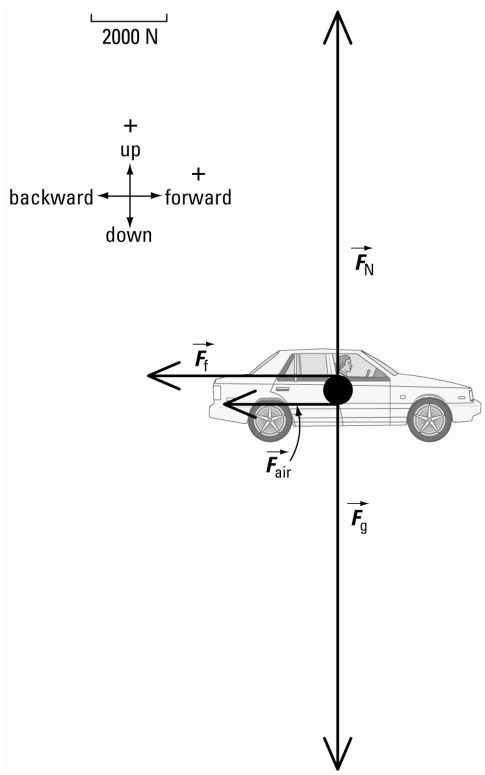
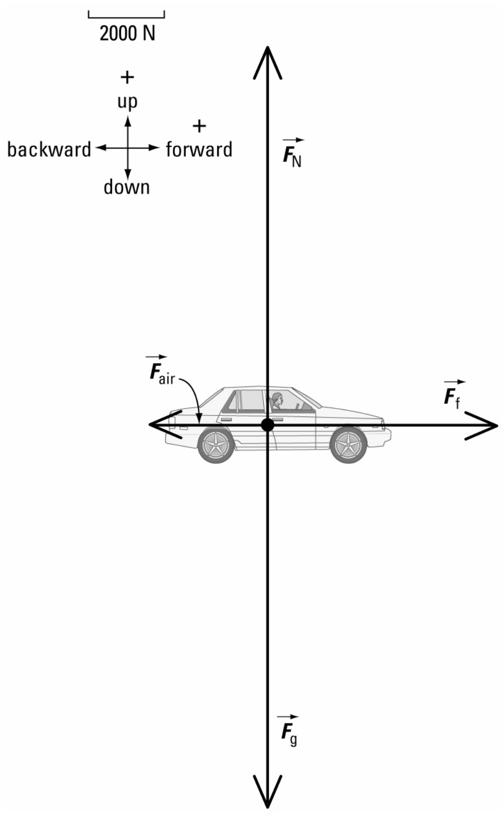
Example 3.1 Practice Problems

1. ***Analysis and Solution***
There is no forward force acting on the car.
The free-body diagram below shows four forces.



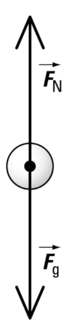
2. ***Analysis and Solution***

The free-body diagram below shows four forces.



Concept Check

The net force on an object could be zero if it is not accelerating. An example is an object that is either stationary or moving at constant velocity on a horizontal frictionless surface. In both situations, the object is neither accelerating nor experiencing any horizontal forces. So in the horizontal direction, $F_{net_h} = 0$ N. In the vertical direction, the object experiences a normal force and the force of gravity. Since $\vec{F}_N$ is equal in magnitude but opposite in direction to $\vec{F}_g$, in the vertical direction, $F_{net_v} = 0$ N.



Example 3.2 Practice Problems

1. ***Given***

$\vec{F}_A$ = 200 N [forward] $\vec{F}_B$ = 150 N [forward]

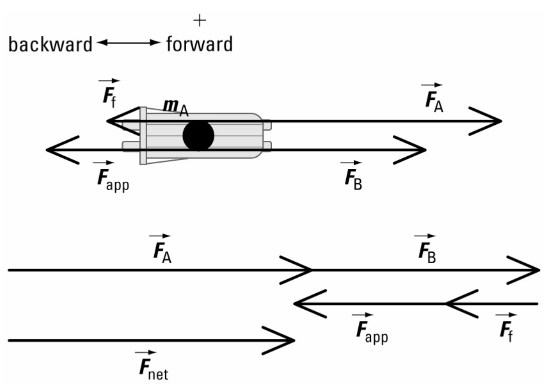
$\vec{F}_{app}$ = 100 N [backward] $\vec{F}_f$ = 60 N [backward]

Required

net force on sled ($\vec{F}_{net}$)

Analysis and Solution

Draw a free-body diagram for the sled.



Add the force vectors shown in the vector addition diagram.

$$\vec{F}_{net} = \vec{F}_A + \vec{F}_B + \vec{F}_{app} + \vec{F}_f$$

$$\begin{aligned} F_{net} &= F_A + F_B + F_{app} + F_f \\ &= 200 \text{ N} + 150 \text{ N} + (-100 \text{ N}) + (-60 \text{ N}) \\ &= 200 \text{ N} + 150 \text{ N} - 100 \text{ N} - 60 \text{ N} \\ &= 1.9 \times 10^2 \text{ N} \end{aligned}$$

$$\vec{F}_{net} = 1.9 \times 10^2 \text{ N [forward]}$$

Paraphrase

The net force on the sled is 1.9×10^2 N [forward].

2. ***Given***

$\vec{F}_A$ = 5000 N [E] $\vec{F}_B$ = 4000 N [E]

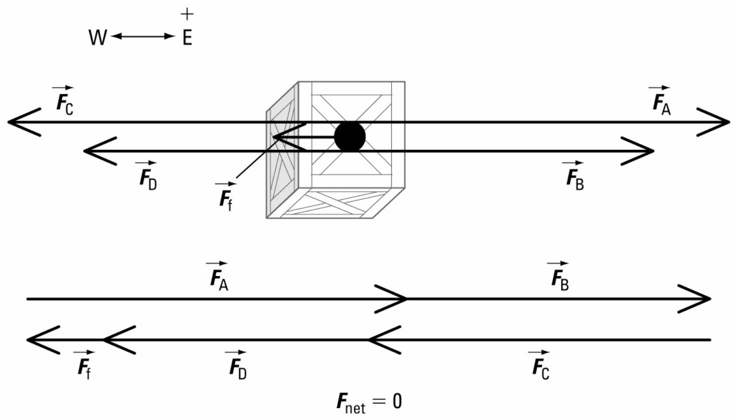
$\vec{F}_C$ = 4500 N [W] $\vec{F}_D$ = 3500 N [W]

magnitude of $\vec{F}_f$ = 1000 N

Required

net force on load ($\vec{F}_{net}$)

Analysis and Solution
Draw a free-body diagram for the load.



To determine the direction of $\vec{F}_f$, first determine $\vec{F}_{net}$ if there were no friction.

$$\vec{F}_{net_{no\ fric}} = \vec{F}_A + \vec{F}_B + \vec{F}_C + \vec{F}_D$$

$$\begin{aligned}
F_{net_{no\ fric}} &= F_A + F_B + F_C + F_D \\
&= 5000\text{ N} + 4000\text{ N} + (-4500\text{ N}) + (-3500\text{ N}) \\
&= 5000\text{ N} + 4000\text{ N} - 4500\text{ N} - 3500\text{ N} \\
&= 1000\text{ N}
\end{aligned}$$

$$\vec{F}_{net_{no\ fric}} = 1000\text{ N [E]}$$

If there were no friction, $\vec{F}_{net}$ would be directed east. So $\vec{F}_f$ must be directed west.
Calculate $\vec{F}_{net}$ for the situation in this problem.

$$\vec{F}_{net} = \vec{F}_{net_{no\ fric}} + \vec{F}_f$$

$$\begin{aligned}
F_{net} &= F_{net_{no\ fric}} + F_f \\
&= 1000\text{ N} + (-1000\text{ N}) \\
&= 1000\text{ N} - 1000\text{ N} \\
&= 0\text{ N}
\end{aligned}$$

$$\vec{F}_{net} = 0\text{ N}$$

Paraphrase
(a) The net force on the load is 0 N.
(b) If the load is initially at rest, it will not move.

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Example 3.3 Practice Problems

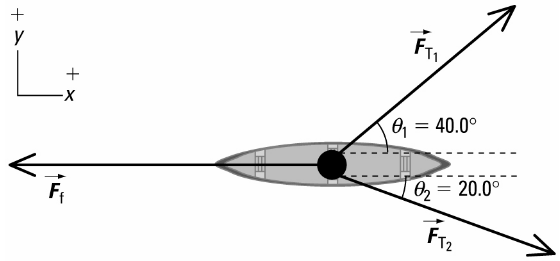
1. ***Given***

$\vec{F}_{T_1} = 60.0$ N [along rope] $\vec{F}_{T_2} = 60.0$ N [along rope]

$\theta_1 = 40.0°$ $\theta_2 = 20.0°$

Required
net force on canoe ($\vec{F}_{net}$)

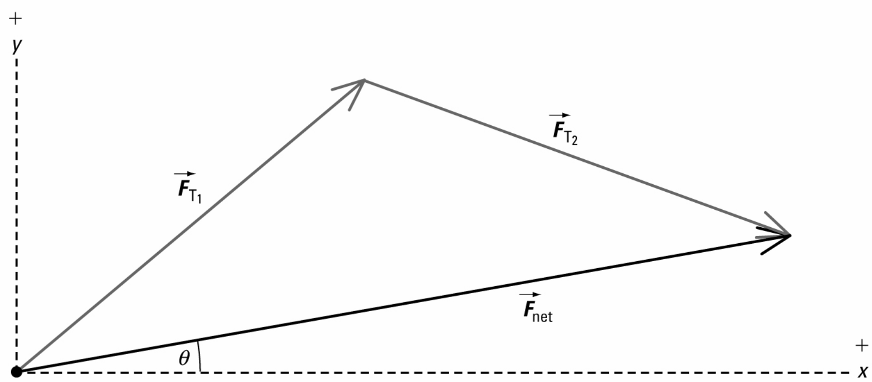
Analysis and Solution
Draw a free-body diagram for the canoe.



Resolve all forces into x and y components.

Vector	***x* component**	***y* component**
$\vec{F}_{T_1}$	(60.0 N)(cos 40.0°)	(60.0 N)(sin 40.0°)
$\vec{F}_{T_2}$	(60.0 N)(cos 20.0°)	–(60.0 N)(sin 20.0°)

Add the x and y components of all force vectors in the vector addition diagram.



x direction

$$\vec{F}_{net_x} = \vec{F}_{T_{1x}} + \vec{F}_{T_{2x}}$$

$$\begin{aligned} F_{net_x} &= F_{T_{1x}} + F_{T_{2x}} \\ &= (60.0\text{ N})(\cos 40.0°) + (60.0\text{ N})(\cos 20.0°) \\ &= 102.3\text{ N} \end{aligned}$$

y direction

$$\vec{F}_{net_y} = \vec{F}_{T_{1y}} + \vec{F}_{T_{2y}}$$

$$\begin{aligned} F_{net_y} &= F_{T_{1y}} + F_{T_{2y}} \\ &= (60.0\text{ N})(\sin 40.0°) \\ &\quad + \{-(60.0\text{ N})(\sin 20.0°)\} \\ &= 18.05\text{ N} \end{aligned}$$

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{net}$.

$$\begin{aligned} F_{net} &= \sqrt{\left(F_{net_x}\right)^2 + \left(F_{net_y}\right)^2} \\ &= \sqrt{(102.3\text{ N})^2 + (18.05\text{ N})^2} \\ &= 1.04 \times 10^2\text{ N} \end{aligned}$$

Use the tangent function to find the direction of $\vec{F}_{\text{net}}$.

$$\begin{aligned}\tan\theta &= \frac{\text{opposite}}{\text{adjacent}}\\ &= \frac{18.05\ \cancel{\text{N}}}{102.3\ \cancel{\text{N}}}\\ &= 0.1763\\ \theta &= \tan^{-1}(0.1763)\\ &= 10.0°\end{aligned}$$

From the vector addition diagram, this angle is between $\vec{F}_{\text{net}}$ and the positive |x-axis.

$$\vec{F}_{\text{net}} = 1.04 \times 10^2\ \text{N}\ [10.0°]$$

Paraphrase

The net force on the canoe is 1.04×10^2 N [10.0°].

2. *Given*

$\vec{F}_{T_1} = 65.0$ N [along rope] $\quad$ $\vec{F}_{T_2} = 70.0$ N [along rope]

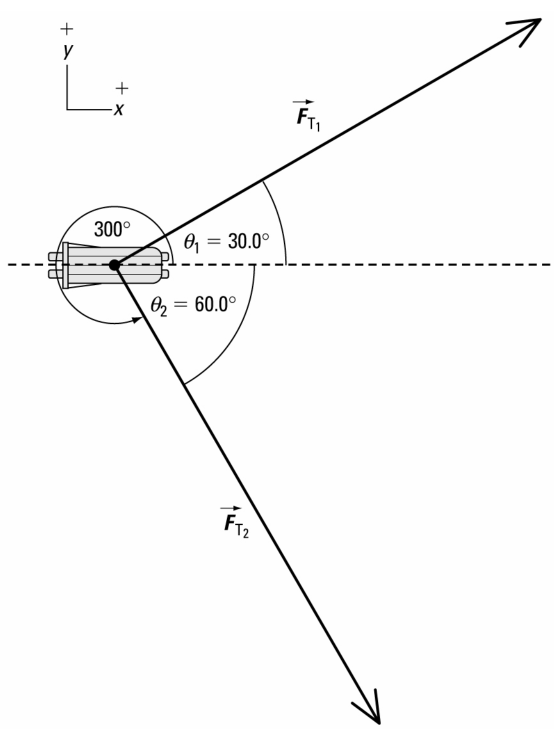
$\theta_1 = 30.0°$ $\quad$ $\theta_2 = 60.0°$

Required

net force on sled ($\vec{F}_{\text{net}}$)

Analysis and Solution

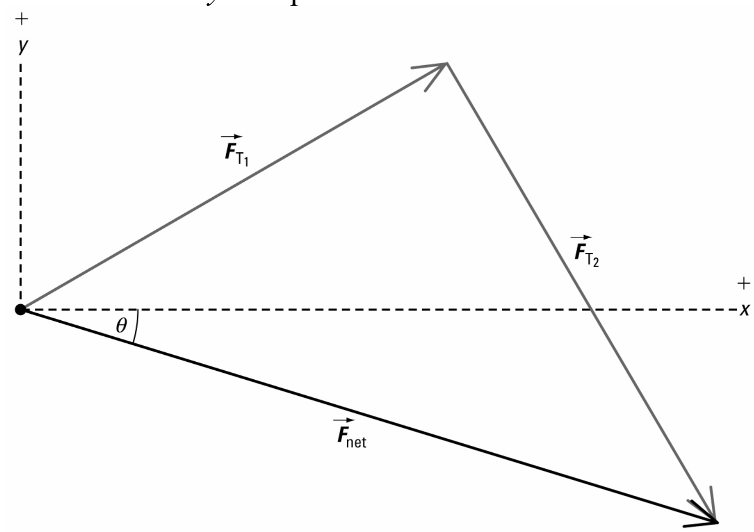
Draw a free-body diagram for the sled.



Resolve all forces into x and y components.

Vector	**x component**	**y component**
$\vec{F}_{T_1}$	(65.0 N)(cos 30.0°)	(65.0 N)(sin 30.0°)
$\vec{F}_{T_2}$	(70.0 N)(cos 60.0°)	–(70.0 N)(sin 60.0°)

Add the x and y components of all force vectors in the vector addition diagram.



x direction

$$\vec{F}_{net_x} = \vec{F}_{T_{1x}} + \vec{F}_{T_{2x}}$$

$$\begin{aligned} F_{net_x} &= F_{T_{1x}} + F_{T_{2x}} \\ &= (65.0\ \text{N})(\cos 30.0°) + (70.0\ \text{N})(\cos 60.0°) \\ &= 91.29\ \text{N} \end{aligned}$$

y direction

$$\vec{F}_{net_y} = \vec{F}_{T_{1y}} + \vec{F}_{T_{2y}}$$

$$\begin{aligned} F_{net_y} &= F_{T_{1y}} + F_{T_{2y}} \\ &= (65.0\ \text{N})(\sin 30.0°) \\ &\quad + \{-(70.0\ \text{N})(\sin 60.0°)\} \\ &= -28.12\ \text{N} \end{aligned}$$

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{net}$.

$$\begin{aligned} F_{net} &= \sqrt{\left(F_{net_x}\right)^2 + \left(F_{net_y}\right)^2} \\ &= \sqrt{(91.29\ \text{N})^2 + (-28.12\ \text{N})^2} \\ &= 95.5\ \text{N} \end{aligned}$$

Use the tangent function to find the direction of $\vec{F}_{net}$.

$$\begin{aligned} \tan\theta &= \frac{\text{opposite}}{\text{adjacent}} \\ &= \frac{28.12\ \cancel{\text{N}}}{91.29\ \cancel{\text{N}}} \\ &= 0.3080 \end{aligned}$$

$$\theta = \tan^{-1}(0.3080) = 17.1°$$

From the vector addition diagram, this angle is between $\vec{F}_{net}$ and the positive x-axis. So the direction of $\vec{F}_{net}$ measured *counterclockwise* from the positive x-axis is 360° – 17.1° = 343°.

$$\vec{F}_{net} = 95.5 \text{ N } [343°]$$

Paraphrase
The net force on the sled is 95.5 N [343°].

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Example 3.4 Practice Problems

1. ***Analysis and Solution***

From Example 3.4, $F_{T_1} \propto m$ and $F_{T_2} \propto F_{T_1}$.

If m is halved, then the magnitude of $\vec{F}_{T_1}$ would be half, which in turn would make the magnitude of $\vec{F}_{T_2}$ half. The directions of $\vec{F}_{T_1}$ and $\vec{F}_{T_2}$ would not change.

2. ***Given***

m = 25 kg $\quad$ $\vec{g}$ = 9.81 m/s^2 [down]

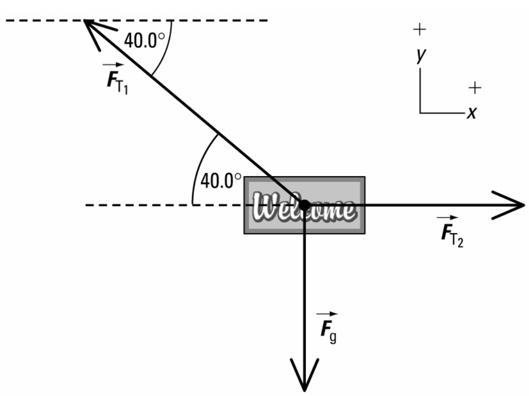
θ_1 = 40.0° $\quad$ θ_2 = 90.0°

Required

forces in ropes ($\vec{F}_{T_1}$ and $\vec{F}_{T_2}$)

Analysis and Solution

Draw a free-body diagram for the sign.



Resolve all forces into x and y components.

Vector	x component	y component
$\vec{F}_{T_1}$	$-F_{T_1}\cos 40.0°$	$F_{T_1}\sin 40.0°$
$\vec{F}_{T_2}$	F_{T_2}	0
$\vec{F}_g$	0	$-mg$

Since the sign is not accelerating, the net force in both the x and y directions is zero.

$F_{\text{net}_x} = F_{\text{net}_y} = 0\ \text{N}$

Add the x and y components of all force vectors separately.

x direction

$$\vec{F}_{\text{net}_x} = \vec{F}_{\text{T}_{1x}} + \vec{F}_{\text{T}_{2x}}$$
$$F_{\text{net}_x} = F_{\text{T}_{1x}} + F_{\text{T}_{2x}}$$
$$0 = -F_{\text{T}_1}\cos 40.0^\circ + F_{\text{T}_2}$$
$$F_{\text{T}_2} = F_{\text{T}_1}\cos 40.0^\circ$$

y direction

$$\vec{F}_{\text{net}_y} = \vec{F}_{\text{T}_{1y}} + \vec{F}_{\text{g}}$$
$$F_{\text{net}_y} = F_{\text{T}_{1y}} + F_{\text{g}}$$
$$0 = F_{\text{T}_1}\sin 40.0^\circ + (-mg)$$
$$0 = F_{\text{T}_1} - \frac{mg}{\sin 40.0^\circ}$$
$$\begin{aligned} F_{\text{T}_1} &= \frac{mg}{\sin 40.0^\circ} \\ &= \frac{(25\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}{\sin 40.0^\circ} \\ &= 382\ \frac{\text{kg}\bullet\text{m}}{\text{s}^2} \\ &= 3.8 \times 10^2\ \text{N} \end{aligned}$$

Substitute F_{T_1} into the equation for F_{T_2}.

$$\begin{aligned} F_{\text{T}_2} &= F_{\text{T}_1}\cos 40.0^\circ \\ &= (382\ \text{N})(\cos 40.0^\circ) \\ &= 2.9 \times 10^2\ \text{N} \end{aligned}$$
$$\vec{F}_{\text{T}_2} = 2.9 \times 10^2\ \text{N}\ [0^\circ]$$

From the free-body diagram, the direction of $\vec{F}_{\text{T}_1}$ measured *counterclockwise* from the positive x-axis is $180^\circ - 40.0^\circ = 140^\circ$.

$$\vec{F}_{\text{T}_1} = 3.8 \times 10^2\ \text{N}\ [140^\circ]$$

Paraphrase

The forces in the ropes are 3.8×10^2 N [140°] and 2.9×10^2 N [0°] respectively.

3. (a) ***Analysis and Solution***

Use Example 3.4 to write the equation for F_{T_1} in terms of θ_1.

$$F_{\text{T}_1} = \frac{mg}{\sin\theta_1}$$

If θ_1 decreases, $\sin\theta_1$ would approach zero and the magnitude of $\vec{F}_{\text{T}_1}$ would increase.

Since $F_{\text{T}_2} \propto F_{\text{T}_1}$, the magnitude of $\vec{F}_{\text{T}_2}$ would also increase.

(b) ***Analysis and Solution***

From the free-body diagrams in Example 3.4 and in Practice Problem 2, $F_{T_{1y}} = F_g$; otherwise, the sign would accelerate in the vertical direction.

So θ_1 can never equal zero.

This conclusion agrees with what you observe from the equation $F_{T_1} = \dfrac{mg}{\sin\ \theta_1}$,

where $\sin\ \theta_1 \neq 0$. As $\sin\ \theta_1$ approaches zero, the magnitude of $\vec{F}_{T_1}$ would increase, until eventually the rope breaks.

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3.1 Check and Reflect

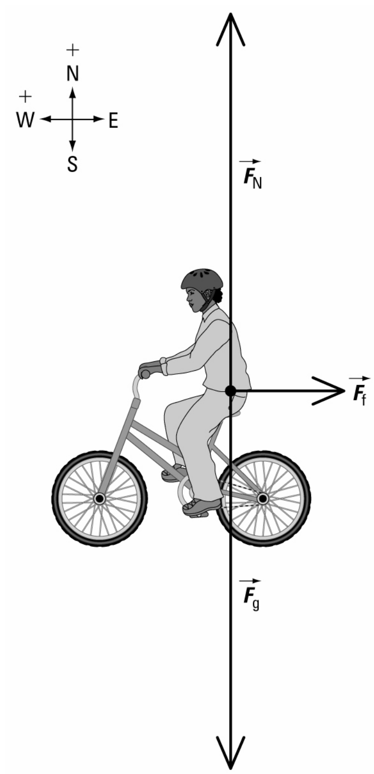
Knowledge

1. (a) Force is a push or a pull on an object. The unit of force is the newton.

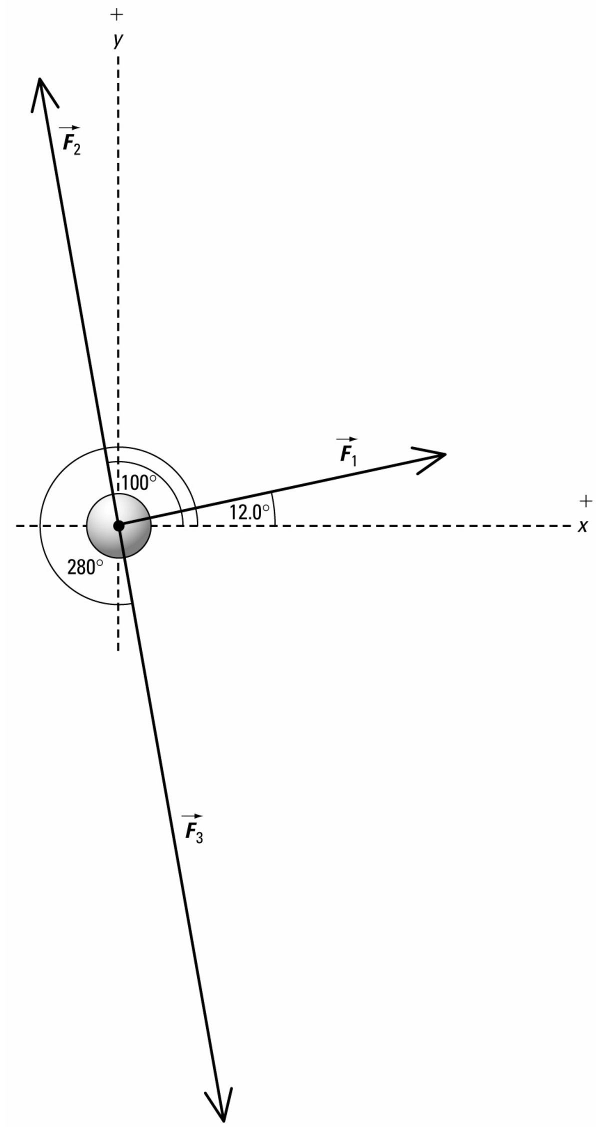
(b) Force is a dynamics quantity and not a kinematics quantity, because force explains the causes of motion while kinematics only describes motion.

Applications

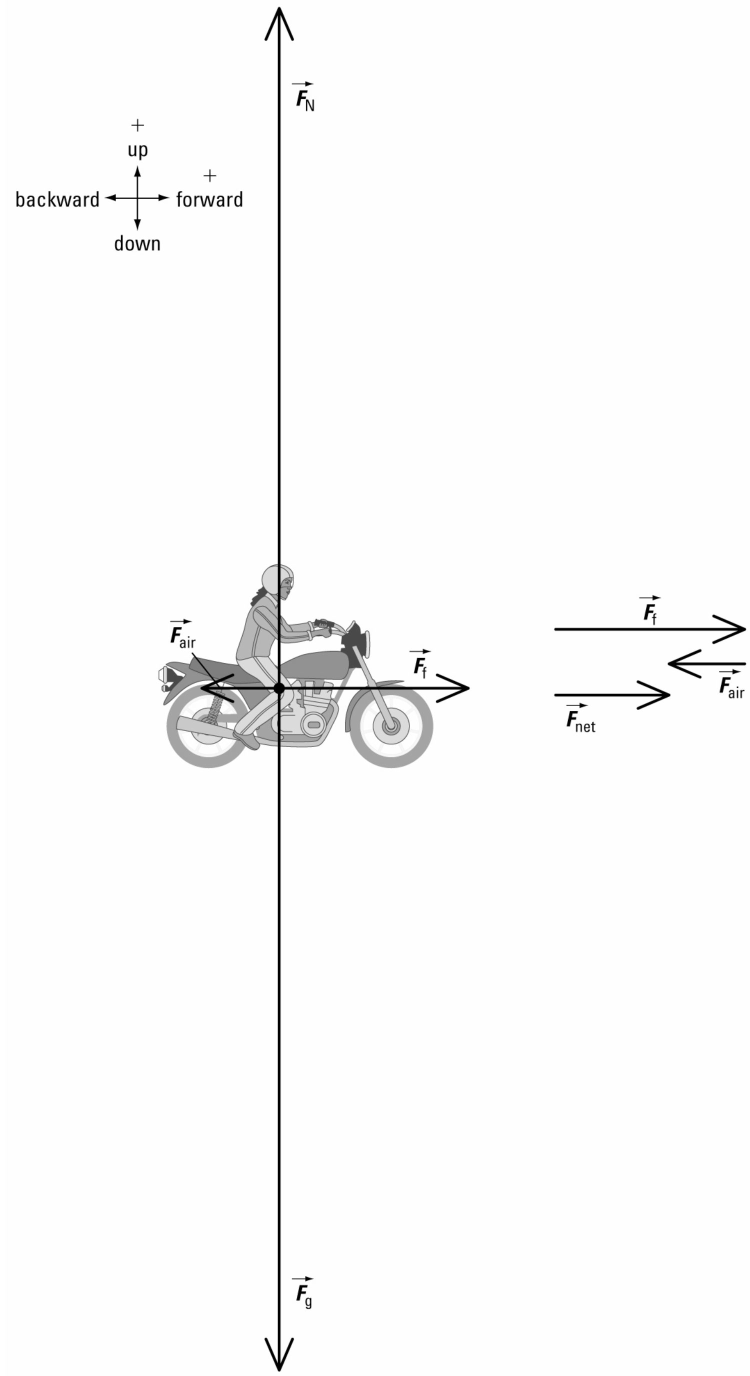
2. (a)



(b)



3. (a)



(b) ***Given***

$\vec{F}_f = 500$ N [forward] $\qquad \vec{F}_g = 1800$ N [down]

$\vec{F}_{air} = 200$ N [backward] $\qquad \vec{F}_N = 1800$ N [up]

Required

net force on biker-bike combination ($\vec{F}_{net}$)

Analysis and Solution
Since the biker-bike combination is not accelerating up or down, the net force in the vertical direction is zero.
Add the horizontal force vectors shown in the vector addition diagram in part (a).

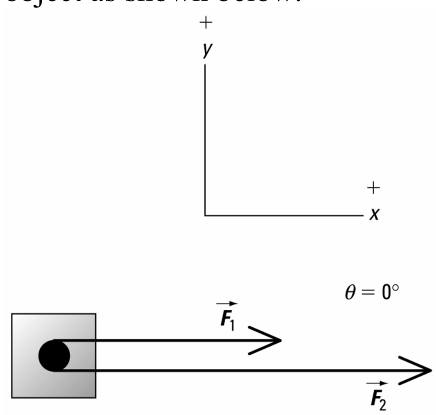
$$\vec{F}_{\text{net}} = \vec{F}_{\text{f}} + \vec{F}_{\text{air}}$$

$$\begin{aligned} F_{\text{net}} &= F_{\text{f}} + F_{\text{air}} \\ &= 500 \text{ N} + (-200 \text{ N}) \\ &= 300 \text{ N} \end{aligned}$$

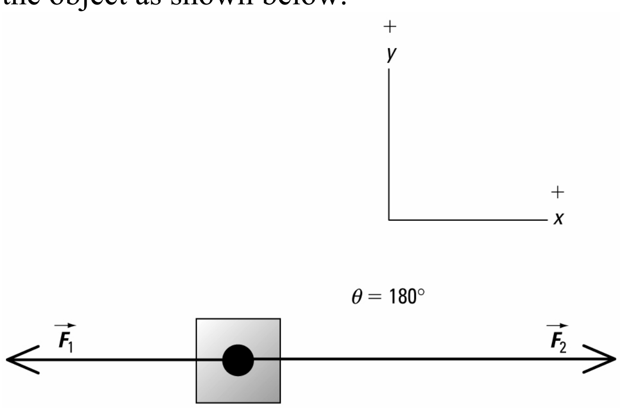
$$\vec{F}_{\text{net}} = 300 \text{ N [forward]}$$

Paraphrase
The net force on the biker-bike combination is 300 N [forward].

4. (a) An angle of 0° between forces $\vec{F}_1$ and $\vec{F}_2$ will maximize the net force acting on the object as shown below.



(b) An angle of 180° between forces $\vec{F}_1$ and $\vec{F}_2$ will minimize the net force acting on the object as shown below.



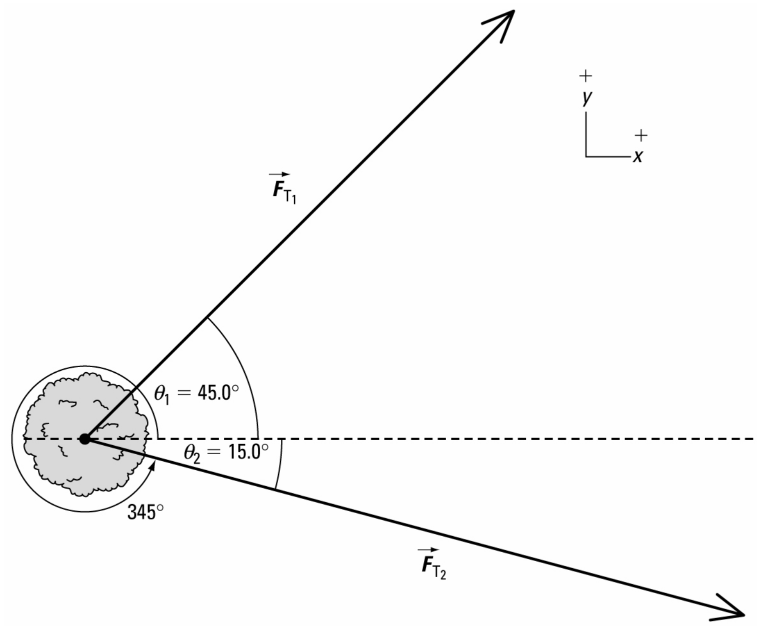
5. *Given*

$\vec{F}_{\text{T}_1} = 80.0$ N [along rope] $\qquad \vec{F}_{\text{T}_2} = 90.0$ N [along rope]

$\theta_1 = 45.0°$ $\qquad \theta_2 = 15.0°$

Required
net force on tree ($\vec{F}_{\text{net}}$)

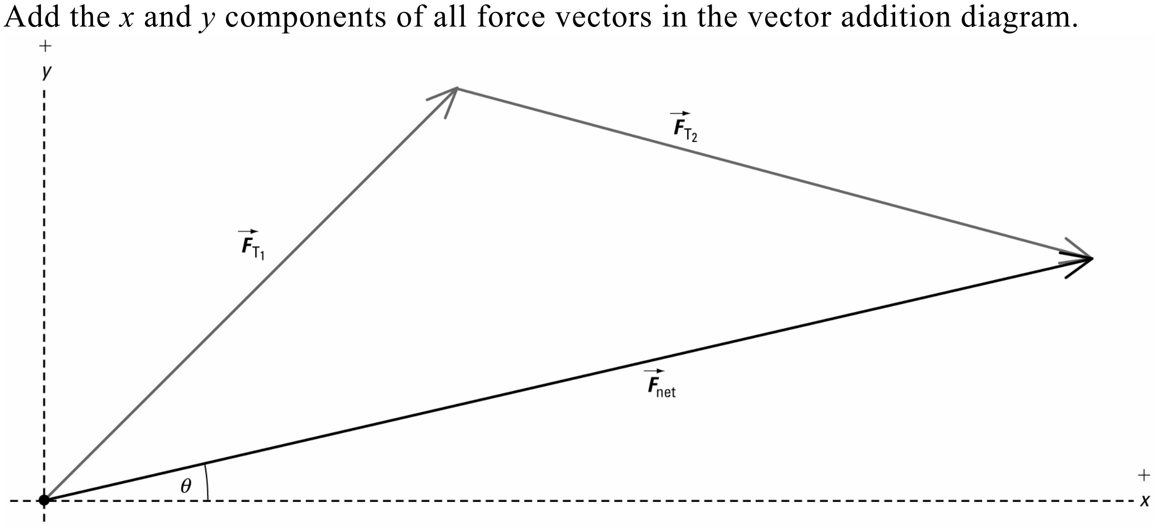
Analysis and Solution
Draw a free-body diagram for the tree.



Resolve all forces into x and y components.

Vector	x **component**	y **component**
$\vec{F}_{T_1}$	(80.0 N)(cos 45.0°)	(80.0 N)(sin 45.0°)
$\vec{F}_{T_2}$	(90.0 N)(cos 15.0°)	–(90.0 N)(sin 15.0°)

Add the x and y components of all force vectors in the vector addition diagram.



x direction

$\vec{F}_{\text{net}_x} = \vec{F}_{\text{T}_{1x}} + \vec{F}_{\text{T}_{2x}}$

$F_{\text{net}_x} = F_{\text{T}_{1x}} + F_{\text{T}_{2x}}$

$= (80.0 \text{ N})(\cos 45.0°) + (90.0 \text{ N})(\cos 15.0°)$

$= 143.5 \text{ N}$

y direction

$\vec{F}_{\text{net}_y} = \vec{F}_{\text{T}_{1y}} + \vec{F}_{\text{T}_{2y}}$

$F_{\text{net}_y} = F_{\text{T}_{1y}} + F_{\text{T}_{2y}}$

$= (80.0 \text{ N})(\sin 45.0°) + \{-(90.0 \text{ N})(\sin 15.0°)\}$

$= 33.27 \text{ N}$

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{\text{net}}$.

$$
\begin{aligned}
F_{\text{net}} &= \sqrt{\left(F_{\text{net}_x}\right)^2 + \left(F_{\text{net}_y}\right)^2} \\
&= \sqrt{(143.5 \text{ N})^2 + (33.27 \text{ N})^2} \\
&= 1.47 \times 10^2 \text{ N}
\end{aligned}
$$

Use the tangent function to find the direction of $\vec{F}_{\text{net}}$.

$$
\begin{aligned}
\tan\theta &= \frac{\text{opposite}}{\text{adjacent}} \\
&= \frac{33.27 \cancel{\text{N}}}{143.5 \cancel{\text{N}}} \\
&= 0.2319 \\
\theta &= \tan^{-1}(0.2319) \\
&= 13.1°
\end{aligned}
$$

From the vector addition diagram, this angle is between $\vec{F}_{\text{net}}$ and the positive x-axis.

$$\vec{F}_{\text{net}} = 1.47 \times 10^2 \text{ N } [13.1°]$$

Paraphrase

The net force on the tree is 1.47×10^2 N [13.1°].

6. *Given*

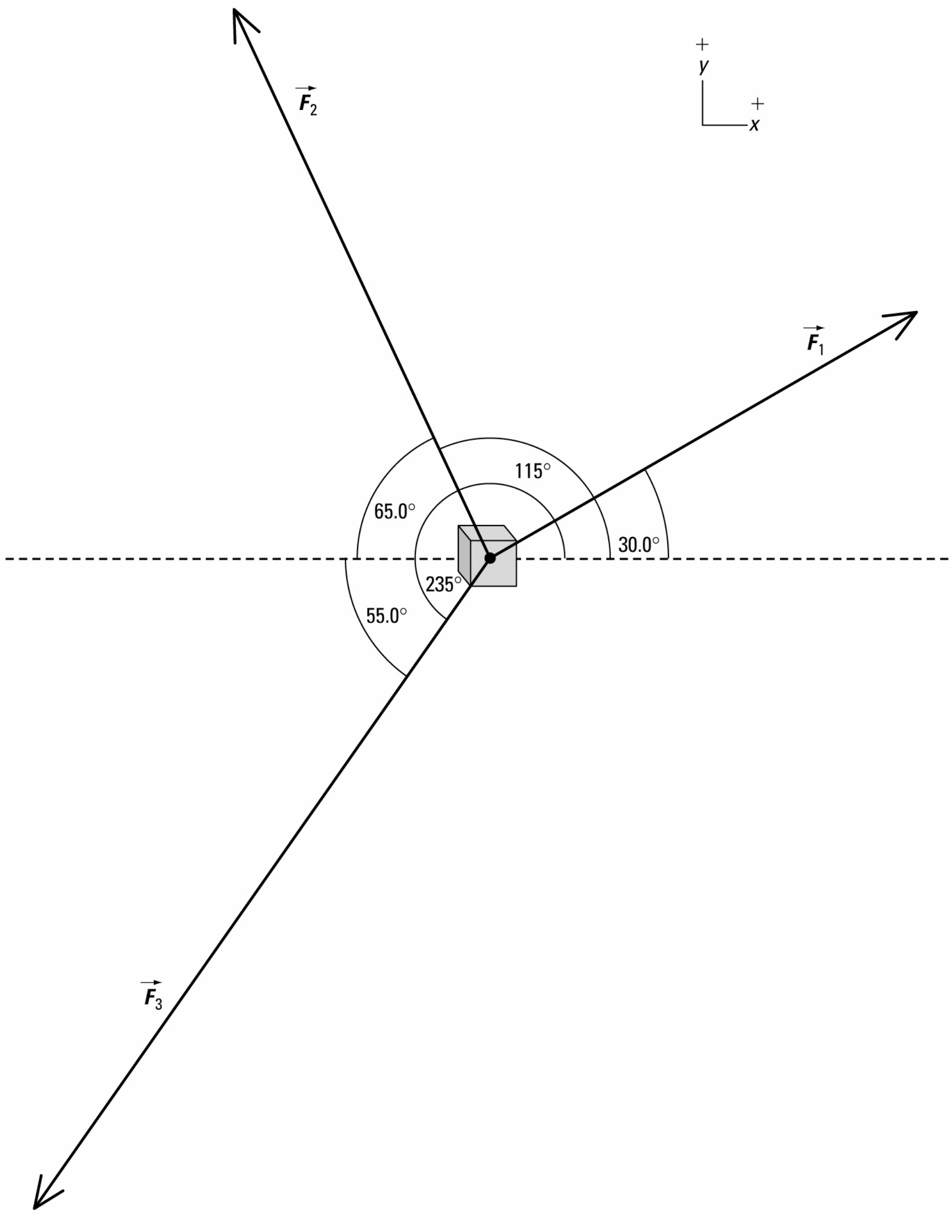
$\vec{F}_1 = 65 \text{ N } [30.0°]$ $\quad$ $\vec{F}_2 = 80 \text{ N } [115°]$ $\quad$ $\vec{F}_3 = 105 \text{ N } [235°]$

Required

net force on object ($\vec{F}_{\text{net}}$)

Analysis and Solution

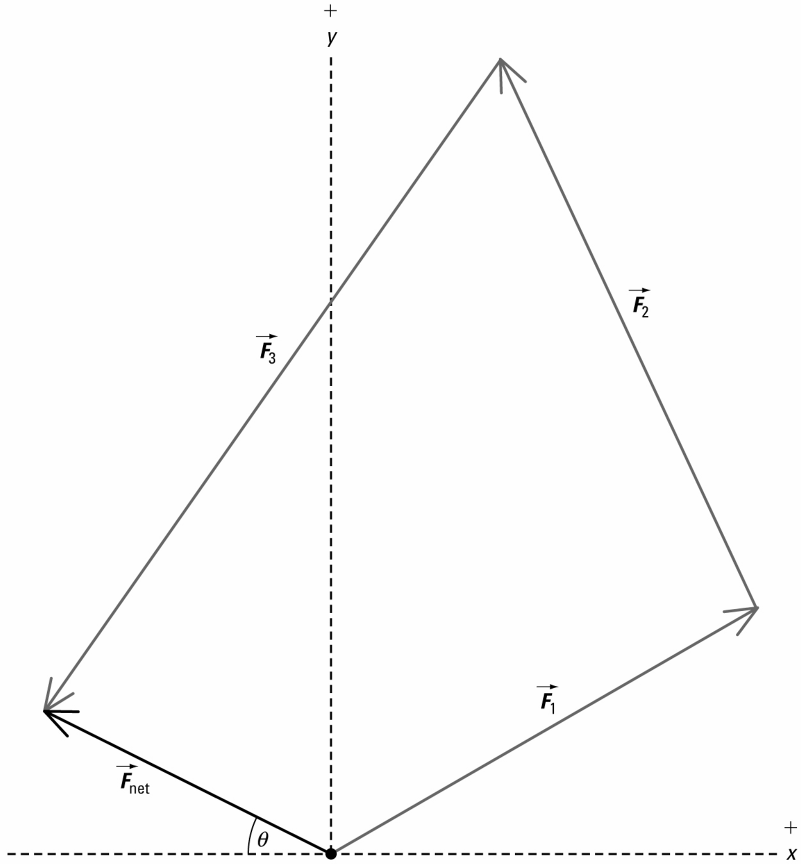
Draw a free-body diagram for the object.



Resolve all forces into *x* and *y* components.

Vector	***x* component**	***y* component**
$\vec{F}_1$	(65 N)(cos 30.0°)	(65 N)(sin 30.0°)
$\vec{F}_2$	–(80 N)(cos 65.0°)	(80 N)(sin 65.0°)
$\vec{F}_3$	–(105 N)(cos 55.0°)	–(105 N)(sin 55.0°)

Add the x and y components of all force vectors in the vector addition diagram.



x direction

$$\vec{F}_{\text{net}_x} = \vec{F}_{1_x} + \vec{F}_{2_x} + \vec{F}_{3_x}$$

$$\begin{aligned} F_{\text{net}_x} &= F_{1_x} + F_{2_x} + F_{3_x} \\ &= (65\text{ N})(\cos 30.0°) + \{-(80\text{ N})(\cos 65.0°)\} + \{-(105\text{ N})(\cos 55.0°)\} \\ &= -37.7\text{ N} \end{aligned}$$

y direction

$$\vec{F}_{\text{net}_y} = \vec{F}_{1_y} + \vec{F}_{2_y} + \vec{F}_{3_y}$$

$$\begin{aligned} F_{\text{net}_y} &= F_{1_y} + F_{2_y} + F_{3_y} \\ &= (65\text{ N})(\sin 30.0°) + (80\text{ N})(\sin 65.0°) + \{-(105\text{ N})(\sin 55.0°)\} \\ &= 19.0\text{ N} \end{aligned}$$

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{\text{net}}$.

$$\begin{aligned} F_{\text{net}} &= \sqrt{\left(F_{\text{net}_x}\right)^2 + \left(F_{\text{net}_y}\right)^2} \\ &= \sqrt{(-37.7\text{ N})^2 + (19.0\text{ N})^2} \\ &= 42\text{ N} \end{aligned}$$

Use the tangent function to find the direction of $\vec{F}_{net}$.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$
$$= \frac{19.0\ \cancel{\text{N}}}{37.7\ \cancel{\text{N}}}$$
$$= 0.5032$$
$$\theta = \tan^{-1}(0.5032)$$
$$= 26.7°$$

From the vector addition diagram, this angle is between $\vec{F}_{net}$ and the negative x-axis. So the direction of $\vec{F}_{net}$ measured *counterclockwise* from the positive x-axis is 180° – 26.7° = 153°.

$$\vec{F}_{net} = 42\ \text{N}\ [153°]$$

Paraphrase

The net force on the object is 42 N [153°].

Extensions

7. ***Given***

m = 25 kg $\qquad\qquad$ $\vec{g}$ = 9.81 m/s^2 [down]

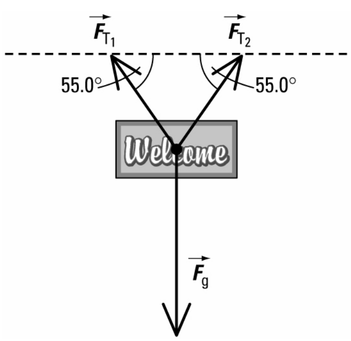
$\theta_1 = \theta_2 = 55.0°$

Required

forces in ropes ($\vec{F}_{T_1}$ and $\vec{F}_{T_2}$)

Analysis and Solution

Draw a free-body diagram for the sign.



Resolve all forces into x and y components.

Vector	x component	y component
$\vec{F}_{T_1}$	$-F_{T_1}\cos 55.0°$	$F_{T_1}\sin 55.0°$
$\vec{F}_{T_2}$	$F_{T_2}\cos 55.0°$	$F_{T_2}\sin 55.0°$
$\vec{F}_g$	0	$-mg$

Since the sign is not accelerating, $F_{\text{net}_x} = 0$.

So $$\begin{aligned}\vec{F}_{\text{net}_x} &= \vec{F}_{\text{T}_{1x}} + \vec{F}_{\text{T}_{2x}} \\ &= F_{\text{T}_{1x}} + F_{\text{T}_{2x}} \\ F_{\text{T}_{1x}} &= -F_{\text{T}_{2x}}\end{aligned}$$

Add the *y* components of all force vectors in the vector addition diagram.

y direction

$$\begin{aligned}\vec{F}_{\text{net}_y} &= \vec{F}_{\text{T}_{1y}} + \vec{F}_{\text{T}_{2y}} + \vec{F}_{\text{g}} \\ F_{\text{net}_y} &= F_{\text{T}_{1y}} + F_{\text{T}_{2y}} + F_{\text{g}} \\ 0 &= F_{\text{T}_1} \sin 55.0° + F_{\text{T}_2} \sin 55.0° + (-mg) \\ 0 &= F_{\text{T}_1} + F_{\text{T}_2} - \frac{mg}{\sin 55.0°} \\ F_{\text{T}_1} + F_{\text{T}_2} &= \frac{mg}{\sin 55.0°} \\ &= \frac{(25 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)}{\sin 55.0°} \\ &= 299 \frac{\text{kg•m}}{\text{s}^2} \\ &= 299 \text{ N}\end{aligned}$$

Since both ropes form the same angle with the ceiling, $F_{\text{T}_1} = F_{\text{T}_2}$.

$$\begin{aligned}F_{\text{T}_2} &= \frac{1}{2}(299 \text{ N}) \\ &= 1.5 \times 10^2 \text{ N} \\ \vec{F}_{\text{T}_2} &= 1.5 \times 10^2 \text{ N [55.0°]}\end{aligned}$$

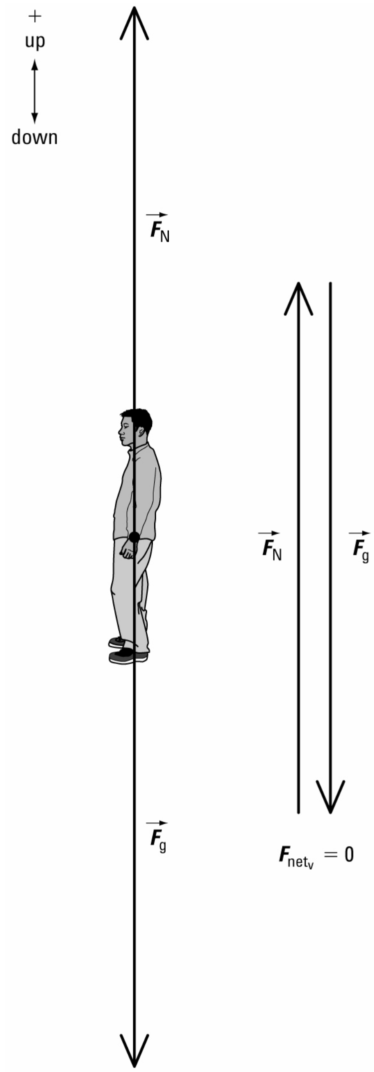
From the free-body diagram, the direction of $\vec{F}_{\text{T}_1}$ measured *counterclockwise* from the positive *x*-axis is 180° – 55.0° = 125°.

$$\vec{F}_{\text{T}_1} = 1.5 \times 10^2 \text{ N [125°]}$$

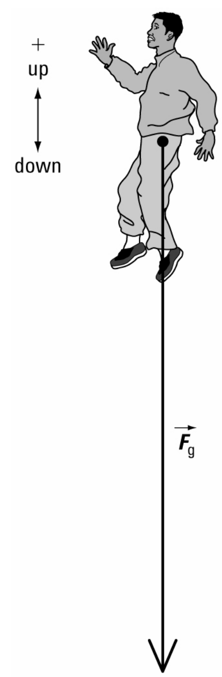
Paraphrase

The forces in the ropes are 1.5×10^2 N [125°] and 1.5×10^2 N [55.0°] respectively.

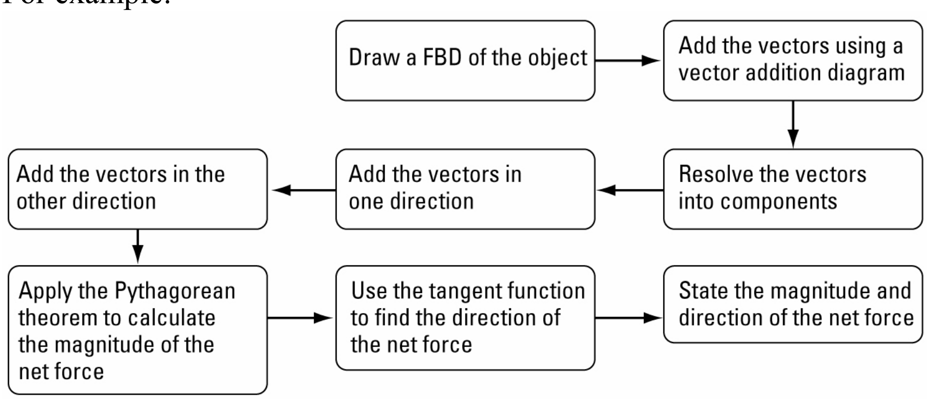
8. (a)



(b)



9. For example:



Student Book page 138

Concept Check

Inertia is the property of an object that resists acceleration and inertia is directly proportional to mass. Since the mass of the astronaut is the same everywhere in the universe, the inertia of the astronaut on Earth's surface, in orbit around Earth, and in outer space will be the same.
In order for an object to have an inertia of zero, its mass must be zero.

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Concept Check

Interstellar space is located far from any celestial body, so the gravitational force acting on Voyager 1 is negligible. As a result, the probe will continue moving at a speed of 17 km/s in a straight line as predicted by Newton's first law.

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Concept Check

(a) A steel barrier usually separates the cab of a truck from the load to protect the driver in the cab. According to Newton's first law, if the truck stops suddenly, the load will tend to continue moving at its original velocity. The steel barrier will prevent this motion and cause the load to maintain the same velocity as the truck.

(b) Trucks carrying tall loads navigate corners slowly to prevent the top of the load from shifting or the truck from rolling over. Turning a corner slowly ensures that the force of friction between the load and the bed of the truck, and between the tie-down straps and the load will be large enough to prevent the load from shifting since without a large net force, the load will continue moving in its original direction.

(c) Customers who order take-out drinks are provided with lids to prevent spillage when they walk. Without lids, the liquid in the cup will tend to keep moving at constant velocity and some may spill out of the cup.

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3.2 Check and Reflect

Knowledge

1. Newton's first law states that the motion of an object does not change unless it experiences an external non-zero net force.

2. An example that illustrates the property of inertia for a stationary object is trying to push a car out of a snow drift vs. pushing a sled out of the same drift. It is easier to push the sled because its mass is much less. So the sled has less inertia than the car, which makes the sled easier to move.
An example that illustrates the property of inertia for a moving object is being pressed into a car seat as the car accelerates forward. Your body will tend to continue moving

at the original velocity of the car. So your inertia resists the sudden change in motion of the car.

3. (a) A car that attempts to go around an icy curve too quickly slides off the curve because the car has a tendency to keep moving in a straight line at constant speed. The direction of motion is along the tangent of the curve at the instant the car starts to slide.

(b) Before the ball leaves the lacrosse stick, it has the same velocity as the stick. After leaving the stick, the ball maintains this velocity unless acted upon by an external non-zero net force. Air resistance acts on the ball causing it to slow down gradually as it moves through the air. The force of gravity acts downward on the ball, and causes the ball to accelerate downward. It is the downward force of gravity that causes the ball to have a parabolic trajectory through the air.

4. (a) According to Newton's first law, every object will continue being either in a state of rest or in motion at constant speed along a straight line unless acted upon by an external non-zero net force. Initially, both the beaker and the newspaper are at rest. If the newspaper is pulled slowly, the force of friction between the two contact surfaces will cause the beaker to move with the paper. The force of friction provides the net force to give the beaker the small acceleration needed to keep it moving with the paper. However, if the newspaper is pulled quickly, the force of friction is not large enough to give the beaker the large acceleration needed to move it along with the paper. The result is that the paper is removed quickly without the beaker moving.

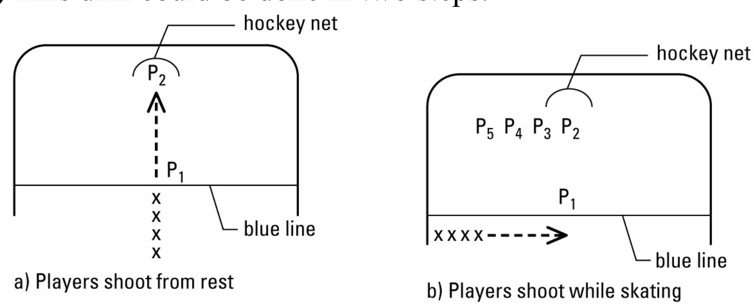
(b) When released, the velocity of the ball has two components, x and y. In the x direction, the ball continues to move at the same speed as the snowmobile (ignoring air resistance). In the y direction, the rider provides an initial upward velocity to the ball. The ball slows down as it moves upward until it comes to rest at the top of its parabolic arc, then the ball speeds up on the way down. When the ball falls back down to the same height as the launch, its y velocity will be the same magnitude but opposite in direction to its y velocity at the launch. The ball returns to the hand of the rider because the x velocity of the ball is the same as that of the snowmobile, and both objects travel for the same length of time.
If the snowmobile stops, the ball continues moving forward after it leaves the rider's hand. So the ball travels some horizontal distance before returning to the height of the launch. The snowmobile only travels the stopping distance. The result is that the ball lands ahead of the snowmobile.

Applications

5. The spark air table has the advantage that the force of friction is negligible compared to the applied force. Most air tables have a pulley to attach to the side and standard masses that fit on top of the air pucks. Place newsprint and carbon paper under a flat object such as a glass sheet to prevent ripples, which oppose motion. Remind students that the accelerating mass is part of the system and must be included when calculating the total mass being accelerated. Also, caution students against holding onto conducting parts of the table when activating the spark timer.

6. (a) Ten-year-old athletes would understand the concept of hitting a moving target as compared to a stationary target. When they skate across the ice, the empty net is moving backward relative to them, and so they will have to aim their shots differently than they would if the net was not moving relative to them.

(b) This drill could be done in two steps.



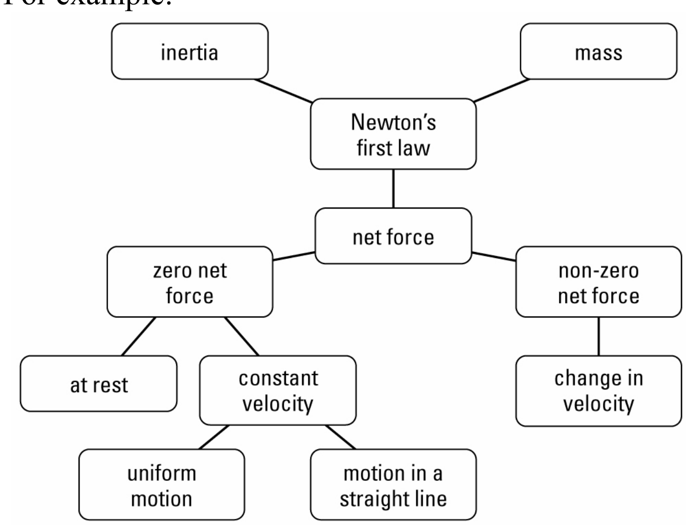
First, players line up at pylon P_1 and while at rest, aim at pylon P_2 in the centre of the net and try to score. Then, players skate along the blue line with the puck and shoot the puck when they reach pylon P_1. This time they try to aim at P_2, on another trial they aim at P_3, and so on. Players can even try skating slowly on one trial, and faster on another to determine where they must aim to compensate for their speed.

Extensions

7. Students will find Web site links at www.pearsoned.ca/school/physicssource that describe both high-back and backless booster seats. These sites also provide additional information, links, flyers, and artwork. Another link provides a good source of information on the seat belt test. In California, booster seat law mandates that a child who is less than the age of six, regardless of weight, or who is less than 132 kg, regardless of age, be properly secured in a child restraint. The new law is meant to close the safety gap for children who have outgrown infant car seats, but are not big enough to be protected by adult seat belts. Booster seats are required by law to comply with the same standards and guidelines as child safety seats.

8. Students will find a Web site link at www.pearsoned.ca/school/physicssource that provides a summary of how seat belts and the retractor mechanism work together to improve the safety of a motorist in a moving vehicle. Clear diagrams and a summary of the retractor mechanism and pretentioner are provided.

9. For example:



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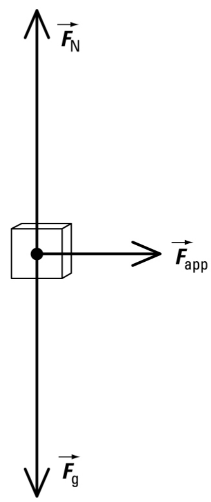
Concept Check

An applied force is a force that is provided by a person or machine. A net force is the vector sum of all the forces acting simultaneously on an object. Suppose an object, say A, is in contact with a surface and experiences an applied force. If the surface is frictionless, the free-body diagram for A will have three forces (see below). Since $\vec{F}_N$ is equal in magnitude but opposite in direction to $\vec{F}_g$, in the vertical direction, F_{net_v} = 0 N. In the horizontal direction, $\vec{F}_{net_h} = \vec{F}_{app}$.



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Concept Check

(a) If the mass and net force both decrease by a factor of 4, the acceleration will not change.

$$a = \frac{F_{net}}{m}$$

$$= \frac{\left(\frac{1}{4}\right)F_{net}}{\left(\frac{1}{4}\right)m}$$

$$= \frac{F_{net}}{m}$$

(b) If the mass and net force both increase by a factor of 4, the acceleration will not change.

$$\begin{aligned} a &= \frac{F_{\text{net}}}{m} \\ &= \frac{4F_{\text{net}}}{4m} \\ &= \frac{F_{\text{net}}}{m} \end{aligned}$$

(c) If the mass increases by a factor of 4, but the net force decreases by the same factor, the acceleration will change by a factor of $\frac{1}{16}$.

$$\begin{aligned} a &= \frac{F_{\text{net}}}{m} \\ &= \frac{\left(\frac{1}{4}\right)F_{\text{net}}}{4m} \\ &= \left(\frac{1}{16}\right)\left(\frac{F_{\text{net}}}{m}\right) \end{aligned}$$

(d) If the mass decreases by a factor of 4, and the net force is zero, the acceleration will be zero.

$$\begin{aligned} a &= \frac{F_{\text{net}}}{m} \\ &= \frac{0}{\left(\frac{1}{4}\right)m} \\ &= 0 \end{aligned}$$

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Example 3.5 Practice Problems

1. ***Given***

$\vec{F}_{\text{net}} = 12$ N [left] $\quad m = 6.0$ kg

Required

acceleration of cart ($\vec{a}$)

Analysis and Solution

The cart is not accelerating up or down.

So in the vertical direction, $F_{\text{net}_v} = 0$ N.

In the horizontal direction, the acceleration of the cart is in the direction of the net force. So use the scalar form of Newton's second law.

$$F_{\text{net}_h} = ma$$

$$a = \frac{F_{\text{net}_h}}{m}$$

$$= \frac{12\ \text{N}}{6.0\ \text{kg}}$$

$$= \frac{12\ \cancel{\text{kg}} \bullet \frac{\text{m}}{\text{s}^2}}{6.0\ \cancel{\text{kg}}}$$

$$= 2.0\ \text{m/s}^2$$

$$\vec{a} = 2.0\ \text{m/s}^2\ [\text{left}]$$

Paraphrase

The acceleration of the cart is 2.0 m/s^2 [left].

2. ***Given***

$\vec{F}_{\text{net}} = 34$ N [forward] $\vec{a} = 1.8$ m/s^2 [forward]

Required

mass of curling stone (m)

Analysis and Solution

The curling stone is not accelerating up or down.

So in the vertical direction, $F_{\text{net}_v} = 0$ N.

In the horizontal direction, the acceleration of the curling stone is in the direction of the net force. So use the scalar form of Newton's second law.

$$F_{\text{net}_h} = ma$$

$$m = \frac{F_{\text{net}_h}}{a}$$

$$= \frac{34\ \text{N}}{1.8\ \text{m/s}^2}$$

$$= \frac{34\ \text{kg} \bullet \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{1.8\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}$$

$$= 19\ \text{kg}$$

Paraphrase

The mass of the curling stone is 19 kg.

Example 3.6 Practice Problem

1. ***Given***

$m_s = 255$ kg $\quad m_p = 98$ kg $\quad m_b = 97$ kg

$\vec{F}_A = 1220$ N [forward] $\quad \vec{F}_B = 1200$ N [forward]

$\vec{F}_f = 430$ N [backward]

Required

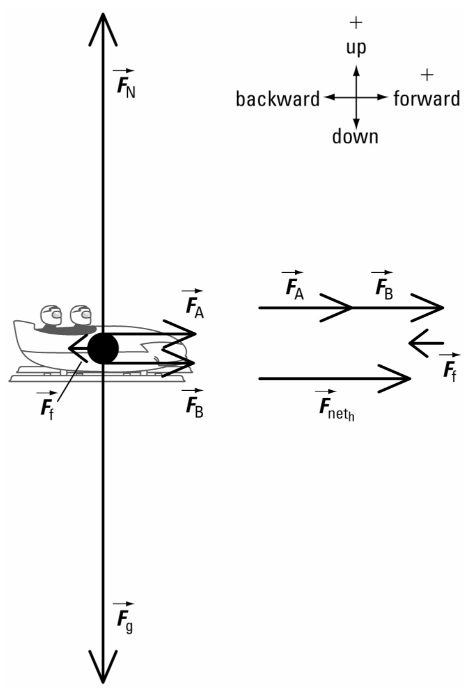
average acceleration of bobsled-pilot-brakeman combination ($\vec{a}$)

Analysis and Solution

The bobsled, pilot, and brakeman are a system because they move together as a unit. Find the total mass of the system.

$$\begin{aligned} m_T &= m_s + m_p + m_b \\ &= 255 \text{ kg} + 98 \text{ kg} + 97 \text{ kg} \\ &= 450 \text{ kg} \end{aligned}$$

Draw a free-body diagram for the system.



The system is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_A + \vec{F}_B + \vec{F}_f$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$

$F_{\text{net}_h} = F_A + F_B + F_f$

$= 1220 \text{ N} + 1200 \text{ N} + (-430 \text{ N})$

$= 1220 \text{ N} + 1200 \text{ N} - 430 \text{ N}$

$= 1990 \text{ N}$

$F_{\text{net}_v} = 0$

Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$$F_{\text{net}_h} = m_T a$$

$$a = \frac{F_{\text{net}_h}}{m_T}$$

$$= \frac{1990 \text{ N}}{450 \text{ kg}}$$

$$= \frac{1990 \ \frac{\cancel{\text{kg}} \bullet \text{m}}{\text{s}^2}}{450 \ \cancel{\text{kg}}}$$

$$= 4.4 \text{ m/s}^2$$

$$\vec{a} = 4.4 \text{ m/s}^2 \text{ [forward]}$$

Paraphrase

The bobsled-pilot-brakeman combination will have an average acceleration of 4.4 m/s^2 [forward].

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Example 3.7 Practice Problems

1. ***Given***

$m_T = 6.00 \times 10^2$ kg

$\vec{F}_T = 5.20 \times 10^3$ N [up]

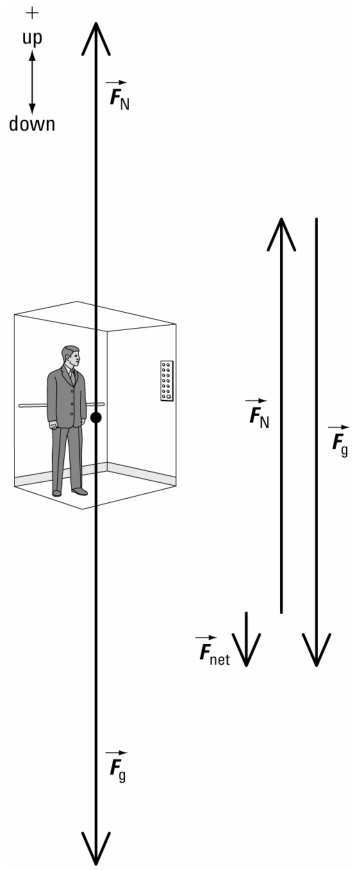
$\vec{g} = 9.81$ m/s^2 [down]

Required

acceleration of person ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the person-elevator system.



The system is not accelerating left or right.
So in the horizontal direction, $F_{net_h} = 0$ N.

Since the person is standing on the elevator floor, both the person and the elevator will have the same vertical acceleration.
For the vertical direction, write an equation to find the net force on the system.

$$\vec{F}_{net_v} = \vec{F}_T + \vec{F}_g$$

Apply Newton's second law.

$$
\begin{aligned}
m\vec{a} &= \vec{F}_T + \vec{F}_g \\
ma &= F_T + F_g \\
ma &= F_T + mg \\
a &= \frac{F_T}{m} + g \\
&= \frac{5.20 \times 10^3 \text{ N}}{6.00 \times 10^2 \text{ kg}} + (-9.81 \text{ m/s}^2) \\
&= \frac{5.20 \times 10^3 \ \frac{\cancel{\text{kg}} \bullet \text{m}}{\text{s}^2}}{6.00 \times 10^2 \ \cancel{\text{kg}}} - 9.81 \text{ m/s}^2 \\
&= -1.14 \text{ m/s}^2 \\
\vec{a} &= 1.14 \text{ m/s}^2 \text{ [down]}
\end{aligned}
$$

Paraphrase

The acceleration of the person is 1.14 m/s^2 [down].

2. ***Given***

$\vec{a}$ = 1.50 m/s^2 [up] $\quad\quad$ $\vec{F}_T$ = 2.85 × 10^3 N [up]

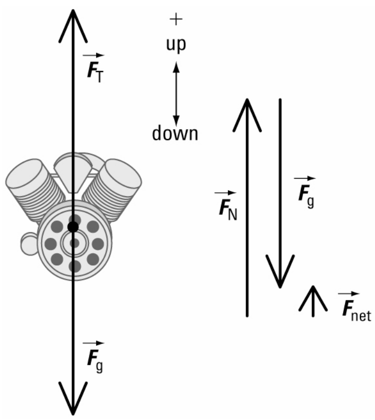
$\vec{g}$ = 9.81 m/s^2 [down]

Required

mass of engine (m)

Analysis and Solution

Draw a free-body diagram for the engine.



The engine is not accelerating left or right.

So in the horizontal direction, F_{net_h} = 0 N.

For the vertical direction, write an equation to find the net force on the engine.

$$\vec{F}_{net_v} = \vec{F}_T + \vec{F}_g$$

Apply Newton's second law.

$$\begin{aligned}
m\vec{a} &= \vec{F}_T + \vec{F}_g \\
ma &= F_T + F_g \\
ma &= F_T + mg \\
m(a - g) &= F_T \\
m &= \frac{F_T}{a - g} \\
&= \frac{2.85 \times 10^3 \text{ N}}{1.50 \text{ m/s}^2 - (-9.81 \text{ m/s}^{2)}} \\
&= \frac{2.85 \times 10^3 \text{ kg} \bullet \cancel{\frac{\text{m}}{\text{s}^2}}}{11.31 \cancel{\frac{\text{m}}{\text{s}^2}}} \\
&= 252 \text{ kg}
\end{aligned}$$

Paraphrase

The mass of the engine is 252 kg.

Example 3.8 Practice Problems

1. *Given*

m = 55 kg $\quad\quad \vec{F}_e$ = 825 N [up]

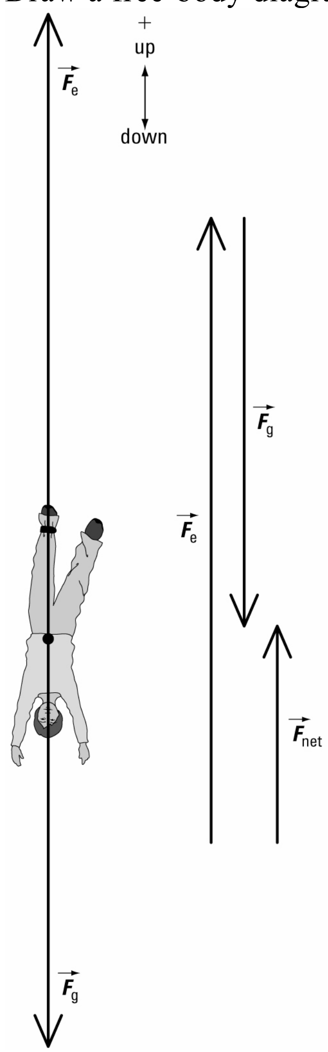
$\vec{g}$ = 9.81 m/s^2 [down]

Required

acceleration of bungee jumper ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the bungee jumper.



The bungee jumper is not accelerating left or right.
So in the horizontal direction, $F_{net_h} = 0$ N.

For the vertical direction, write an equation to find the net force on the bungee jumper.

$$\vec{F}_{net_v} = \vec{F}_e + \vec{F}_g$$

Apply Newton's second law.

$$\begin{aligned}
m\vec{a} &= \vec{F}_e + \vec{F}_g \\
ma &= F_e + F_g \\
ma &= F_e + mg \\
a &= \frac{F_e}{m} + g \\
&= \frac{825\ \text{N}}{55\ \text{kg}} + (-9.81\ \text{m/s}^2) \\
&= \frac{825\ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{55\ \cancel{\text{kg}}} - 9.81\ \text{m/s}^2 \\
&= 5.2\ \text{m/s}^2 \\
\vec{a} &= 5.2\ \text{m/s}^2\ [\text{up}]
\end{aligned}$$

Paraphrase

The acceleration of the bungee jumper is 5.2 m/s^2 [up].

2. (a), (b) ***Analysis and Solution***

During the entire jump, the force of gravity is acting on the bungee jumper. Ignoring air resistance, her acceleration is initially 9.81 m/s^2 [down] and decreases to zero when she reaches the bottom of the jump. Then she begins to accelerate up. So at the lowest part of the jump, she is accelerating up even though she is momentarily at rest.

Example 3.9 Practice Problems

1. ***Given***

m_A = 5.0 kg $\qquad$ m_B = 5.0 kg

$\vec{F}_T$ = 60 N [along rope] $\qquad$ $\vec{g}$ = 9.81 m/s^2 [down]

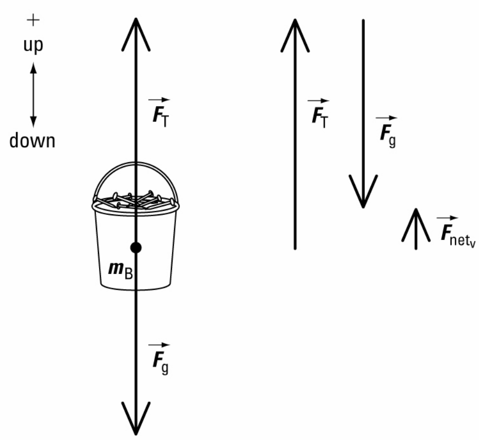
Required

acceleration of both buckets ($\vec{a}$)

Analysis and Solution

The two buckets move together as a unit with the same acceleration. So calculate the acceleration of m_B.

Draw a free-body diagram for m_B.



The bucket is not accelerating left or right.

So in the horizontal direction, $F_{net_h} = 0$ N.

For the vertical direction, write an equation to find the net force on m_B.

$$\vec{F}_{net_v} = \vec{F}_T + \vec{F}_g$$

Apply Newton's second law.

$$\begin{aligned}
m_B\vec{a} &= \vec{F}_T + \vec{F}_g \\
m_B a &= F_T + F_g \\
m_B a &= F_T + m_B g \\
a &= \frac{F_T}{m_B} + g \\
&= \frac{60\text{ N}}{5.0\text{ kg}} + (-9.81\text{ m/s}^2) \\
&= \frac{60\,\frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{5.0\,\cancel{\text{kg}}} - 9.81\text{ m/s}^2 \\
&= 2.2\text{ m/s}^2 \\
\vec{a} &= 2.2\text{ m/s}^2\text{ [up]}
\end{aligned}$$

Paraphrase

Both buckets will have an acceleration of 2.2 m/s^2 [up].

2. (a) ***Given***

$m_B = 10$ kg

$\vec{a} = 0.363$ m/s^2 [right] from Example 3.9

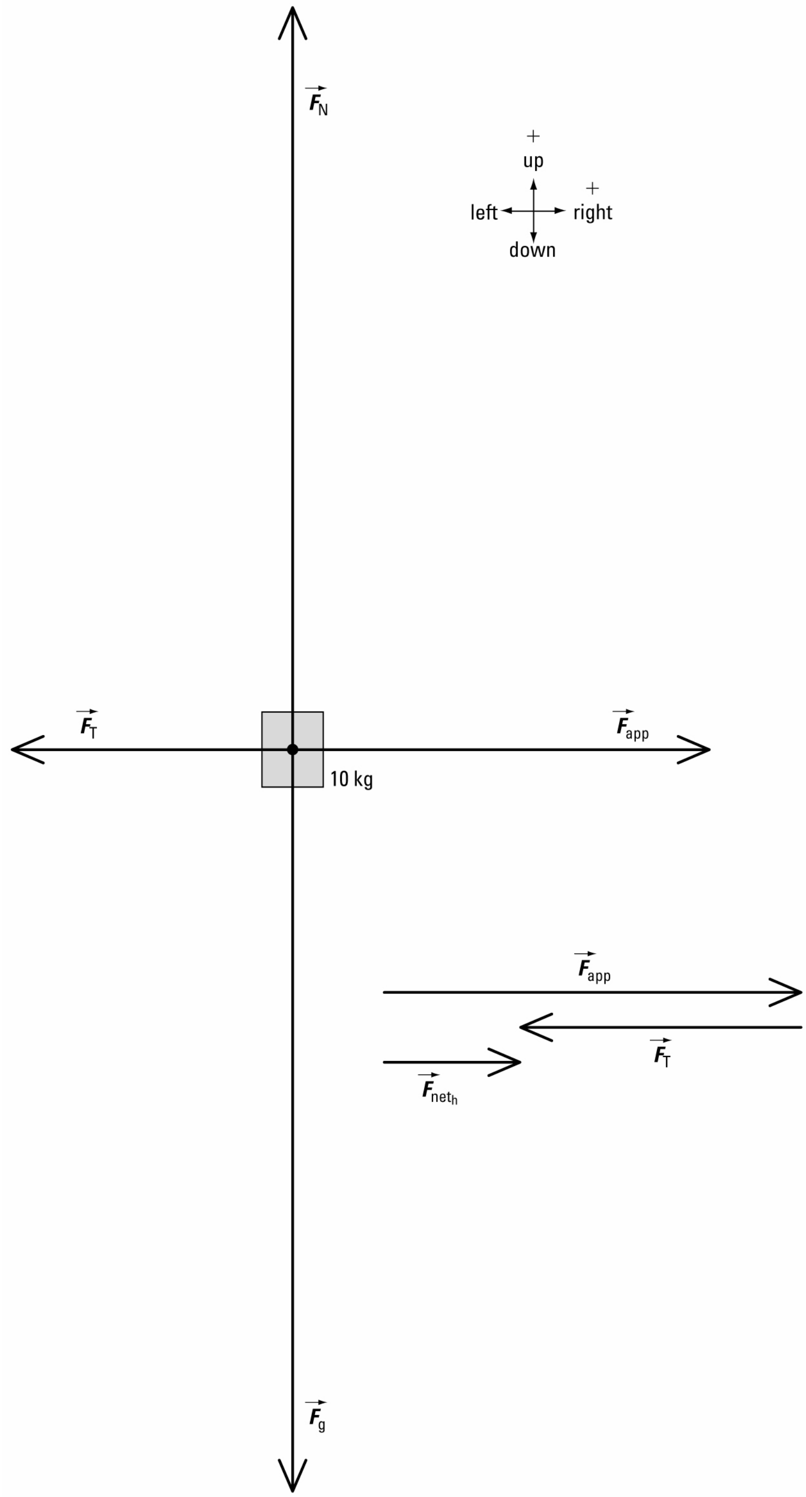
$\vec{F}_{app} = 55$ N [right]

magnitude of $\vec{F}_f = 14.7$ N

Required

tension in rope connecting the blocks

Analysis and Solution
Draw a free-body diagram for the 10-kg block.



The block is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the block in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\mathrm{net}_\mathrm{h}} = \vec{F}_{\mathrm{app}} + \vec{F}_{\mathrm{T}} + \vec{F}_{\mathrm{f}}$$

Apply Newton's second law.

$$m_{\mathrm{B}}\vec{a} = \vec{F}_{\mathrm{app}} + \vec{F}_{\mathrm{T}} + \vec{F}_{\mathrm{f}}$$

$$\begin{aligned} m_{\mathrm{B}}a &= F_{\mathrm{app}} + F_{\mathrm{T}} + F_{\mathrm{f}} \\ F_{\mathrm{T}} &= m_{\mathrm{B}}a - F_{\mathrm{app}} - F_{\mathrm{f}} \\ &= (10\text{ kg})(0.363\text{ m/s}^2) - 55\text{ N} - (-14.7\text{ N}) \\ &= 37\text{ N} \end{aligned}$$

vertical direction

$$\vec{F}_{\mathrm{net}_\mathrm{v}} = \vec{F}_{\mathrm{N}} + \vec{F}_{\mathrm{g}}$$

$$F_{\mathrm{net}_\mathrm{v}} = 0$$

Calculations in the vertical direction are not required in this problem.

Paraphrase

The tension in the rope connecting the two blocks is 37 N.

(b) ***Analysis and Solution***

For the rope between the hand and the block, the only force that creates a tension is the applied force. So the tension in this rope is 55 N.

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Example 3.10 Practice Problems

1. ***Analysis and Solution***

From Example 3.10, $\vec{F}_{\mathrm{net}} = (m_{\mathrm{B}} - m_{\mathrm{A}})g$ and $a = \dfrac{F_{\mathrm{net}}}{m_{\mathrm{T}}}$. But $m_{\mathrm{T}} = m_{\mathrm{A}} + m_{\mathrm{B}}$, so substitute m_{T} and $\vec{F}_{\mathrm{net}}$ into the equation for a.

$$a = \left(\frac{m_{\mathrm{B}} - m_{\mathrm{A}}}{m_{\mathrm{A}} + m_{\mathrm{B}}}\right)g$$

Substitute the appropriate values for m_{A} and m_{B} to determine the acceleration in each situation.

(a) $m_{\mathrm{A}} = \left(\dfrac{1}{3}\right)m_{\mathrm{B}}$

$$\begin{aligned} a &= \left(\frac{m_{\mathrm{B}} - \frac{1}{3}m_{\mathrm{B}}}{\frac{1}{3}m_{\mathrm{B}} + m_{\mathrm{B}}}\right)g \\ &= \left(\frac{\cancel{m_{\mathrm{B}}}}{\cancel{m_{\mathrm{B}}}}\right)\left(\frac{1 - \frac{1}{3}}{\frac{1}{3} + 1}\right)g \\ &= \frac{\left(\frac{2}{3}\right)}{\left(\frac{4}{3}\right)}g \\ &= \left(\frac{2}{4}\right)g \end{aligned}$$

$$= \left(\frac{1}{2}\right) g$$

The system will have an acceleration of magnitude $\left(\frac{1}{2}\right) g$.

Since $m_A < m_B$, m_A will accelerate up and m_B will accelerate down.

(b) $m_A = 2m_B$

$$a = \left(\frac{m_B - 2m_B}{2m_B + m_B}\right) g$$

$$= \left(\frac{\cancel{m_B}}{\cancel{m_B}}\right)\left(\frac{1-2}{2+1}\right) g$$

$$= -\left(\frac{1}{3}\right) g$$

The system will have an acceleration of magnitude $\left(\frac{1}{3}\right) g$.

Since $m_A > m_B$, m_A will accelerate down and m_B will accelerate up.

(c) Since $m_A = m_B$, the acceleration of the system will be zero.

2. ***Given***

$m_A = 25$ kg

$\vec{a} = 1.64 \text{ m/s}^2$ [up] from Example 3.10

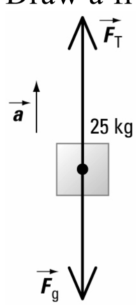
$\vec{g} = 9.81 \text{ m/s}^2$ [down]

Required

tension in rope

Analysis and Solution

Draw a free-body diagram for the 25-kg block.



The block is not accelerating left or right.

So in the horizontal direction, $F_{net_h} = 0$ N.

Write equations to find the net force on the block in the vertical direction.

vertical direction

$$\vec{F}_{net_v} = \vec{F}_T + \vec{F}_g$$

Apply Newton's second law.

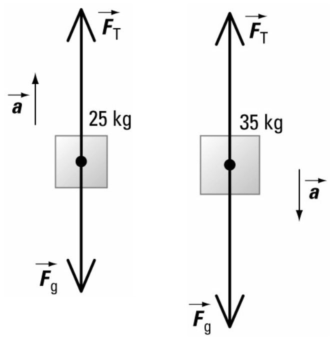
$$m_A \vec{a} = \vec{F}_T + \vec{F}_g$$

$$\begin{aligned}
m_A a &= F_T + F_g \\
F_T &= m_A a - F_g \\
&= m_A a - m_A g \\
&= (25 \text{ kg})(1.64 \text{ m/s}^2) - \{-(25 \text{ kg})(9.81 \text{ m/s}^2)\} \\
&= 2.9 \times 10^2 \text{ N}
\end{aligned}$$

Paraphrase

The tension in the rope is 2.9×10^2 N.

3.



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Example 3.11 Practice Problems

1. ***Analysis and Solution***

From Example 3.11, $\vec{F}_{net} = (m_B - m_C)g$ and $a = \dfrac{F_{net}}{m_T}$. But $m_T = m_A + m_B + m_C$, so substitute m_T and $\vec{F}_{net}$ into the equation for a.

$$a = \left(\frac{m_B - m_C}{m_A + m_B + m_C}\right) g$$

Substitute the appropriate values for m_A, m_B, and m_C to determine the acceleration.

$$\begin{aligned} a &= \left(\frac{12\text{ kg} - 6.0\text{ kg}}{20\text{ kg} + 12\text{ kg} + 6.0\text{ kg}}\right)(9.81\text{ m/s}^2) \\ &= \left(\frac{6.0\ \cancel{\text{kg}}}{38.0\ \cancel{\text{kg}}}\right)(9.81\text{ m/s}^2) \\ &= 1.5\text{ m/s}^2 \\ \vec{a} &= 1.5\text{ m/s}^2\text{ [left]} \end{aligned}$$

The tire will have an acceleration of 1.5 m/s^2 [left].

2. ***Analysis and Solution***

From Example 3.11 Practice Problem 1, $a = \left(\dfrac{m_B - m_C}{m_A + m_B + m_C}\right) g$.

Substitute the appropriate values for m_A, m_B, and m_C to determine the acceleration.

$$\begin{aligned} a &= \left(\frac{8.0\text{ kg} - 6.0\text{ kg}}{15\text{ kg} + 8.0\text{ kg} + 6.0\text{ kg}}\right)(9.81\text{ m/s}^2) \\ &= \left(\frac{2.0\ \cancel{\text{kg}}}{29.0\ \cancel{\text{kg}}}\right)(9.81\text{ m/s}^2) \\ &= 0.68\text{ m/s}^2 \\ \vec{a}_A &= 0.68\text{ m/s}^2\text{ [left]} \\ \vec{a}_B &= 0.68\text{ m/s}^2\text{ [down]} \\ \vec{a}_C &= 0.68\text{ m/s}^2\text{ [up]} \end{aligned}$$

The tire will have an acceleration of 0.68 m/s^2 [left], pail B an acceleration of 0.68 m/s^2 [down], and pail C an acceleration of 0.68 m/s^2 [up].

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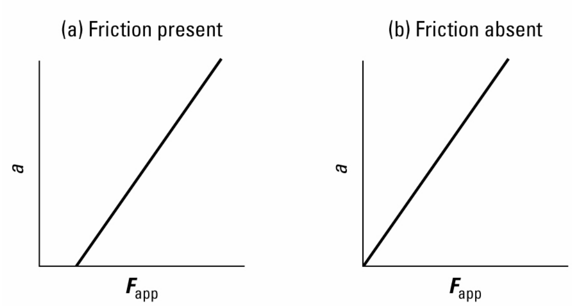
3.3 Check and Reflect

Knowledge

1. Newton's second law states that when a non-zero net force acts on an object, the object will accelerate in the direction of the net force. The magnitude of the acceleration will be directly proportional to the net force and inversely proportional to the mass of the object.

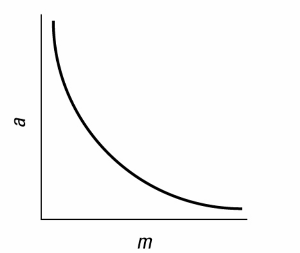
2. (a) and **(b)**

Magnitude of Acceleration vs. Magnitude of Applied Force



3.

Magnitude of Acceleration vs. Mass



4. A vehicle with a more powerful engine can exert a greater force on the axles, which in turn results in the tires exerting a greater force of friction on the ground. So the greater force of friction causes the vehicle to have a greater acceleration than another vehicle with a less powerful engine.

Applications

5. (a) ***Given***

$\vec{F}_{\text{water}}$ = 320 N [up]

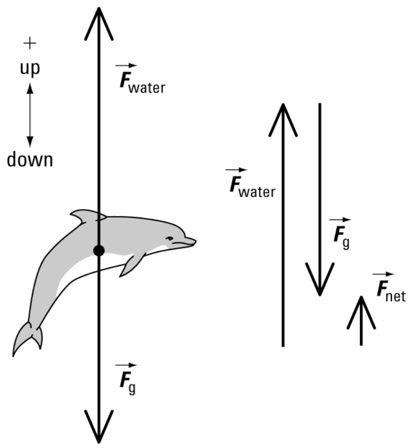
$\vec{a}$ = 2.6 m/s^2 [up]

Required

mass of dolphin (m)

Analysis and Solution

Draw a free-body diagram for the dolphin.



The dolphin is not accelerating left or right.

So in the horizontal direction, $F_{\text{net}_\text{h}} = 0$ N.

Write equations to find the net force on the dolphin in the vertical direction.

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_{\text{water}} + \vec{F}_{\text{g}}$$

Apply Newton's second law.

$$\begin{aligned}
m\vec{a} &= \vec{F}_{\text{water}} + \vec{F}_{\text{g}} \\
ma &= F_{\text{water}} + F_{\text{g}} \\
ma &= F_{\text{water}} + mg \\
m(a-g) &= F_{\text{water}} \\
m &= \frac{F_{\text{water}}}{a-g} \\
&= \frac{320 \text{ N}}{2.6 \text{ m/s}^2 - (-9.81 \text{ m/s}^2)} \\
&= \frac{320 \text{ kg}\bullet\cancel{\frac{\text{m}}{\text{s}^2}}}{12.41\ \cancel{\frac{\text{m}}{\text{s}^2}}} \\
&= 26 \text{ kg}
\end{aligned}$$

Paraphrase

The dolphin has a mass of 26 kg.

(b) ***Analysis and Solution***

From part (a), $ma = F_{\text{water}} + mg$. Solve for the acceleration.

$$\begin{aligned}
a &= \frac{F_{\text{water}}}{m} + g \\
&= \frac{320\ \cancel{\text{kg}}\bullet\frac{\text{m}}{\text{s}^2}}{\left(\frac{25.8}{2}\ \cancel{\text{kg}}\right)} + (-9.81 \text{ m/s}^2) \\
&= 15 \text{ m/s}^2
\end{aligned}$$

$\vec{a} = 15\text{ m/s}^2$ [up]

The dolphin would have an acceleration of 15 m/s^2 [up].

6. *Given*

$m = 80\text{ kg}$

$\vec{F}_{\text{wind}} = 205\text{ N}$ [with the wind]

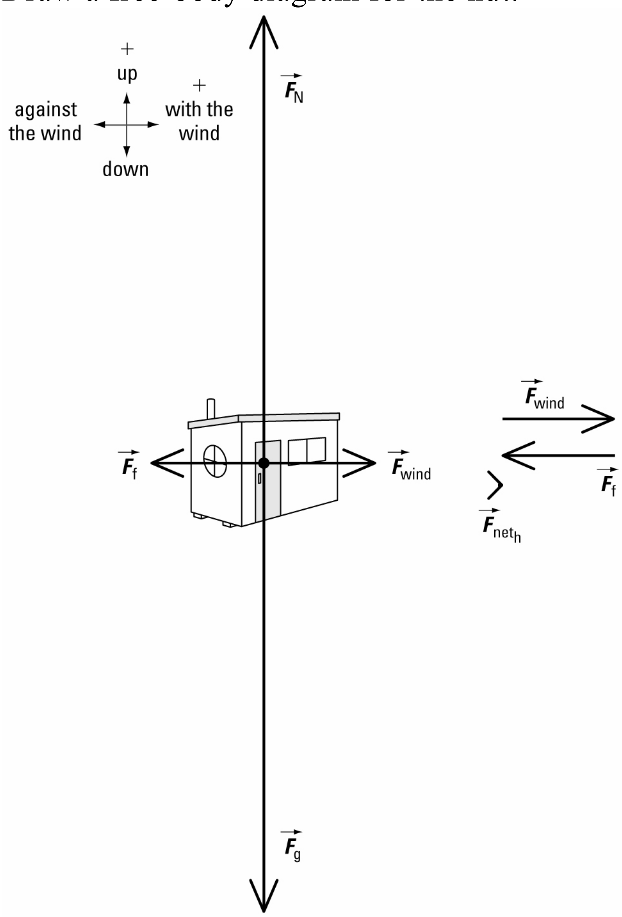
magnitude of $\vec{F}_{\text{f}} = 196\text{ N}$

Required

acceleration of hut ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the hut.



The hut is not accelerating up or down.

So in the vertical direction, $F_{\text{net}_\text{v}} = 0\text{ N}$.

Write equations to find the net force on the hut in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{wind}} + \vec{F}_{\text{f}}$$

$$\begin{aligned} F_{\text{net}_\text{h}} &= F_{\text{wind}} + F_{\text{f}} \\ &= 205\text{ N} + (-196\text{ N}) \\ &= 9\text{ N} \end{aligned}$$

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_{\text{N}} + \vec{F}_{\text{g}}$$

$$F_{\text{net}_\text{v}} = 0$$

Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$$
\begin{aligned}
F_{\text{net}_\text{h}} &= ma \\
a &= \frac{F_{\text{net}_\text{h}}}{m} \\
&= \frac{9\ \text{N}}{80\ \text{kg}} \\
&= \frac{9\ \dfrac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{80\ \cancel{\text{kg}}} \\
&= 0.11\ \text{m/s}^2 \\
\vec{a} &= 0.11\ \text{m/s}^2\ \text{[with the wind]}
\end{aligned}
$$

Paraphrase

The ice hut will have an acceleration of 0.11 m/s^2 [with the wind].

7. (a) ***Given***

$\vec{F}_\text{g}$ = 20 N [down]

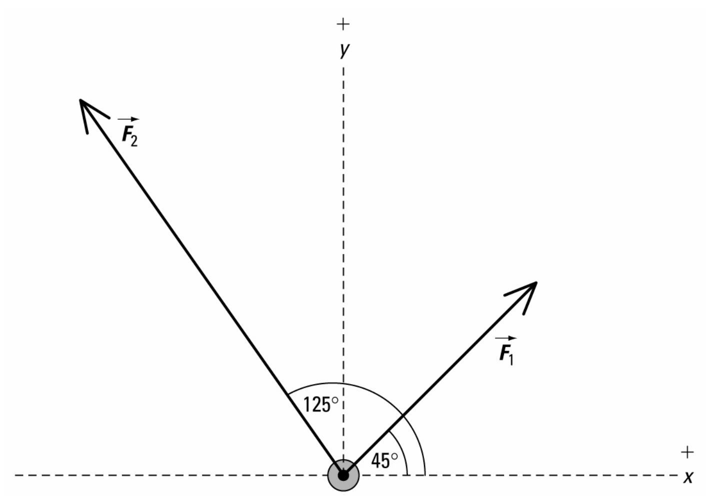
$\vec{F}_1$ = 36 N [45°] $\quad$ $\vec{F}_2$ = 60 N [125°]

Required

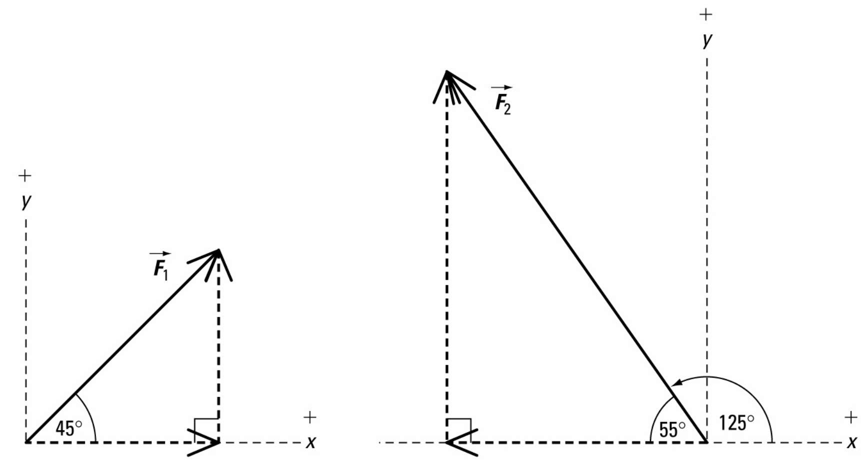
net force on object ($\vec{F}_\text{net}$)

Analysis and Solution

Draw a free-body diagram for the object.



Resolve all forces into x and y components.



Vector	x component	y component
$\vec{F}_1$	(36 N)(cos 45°)	(36 N)(sin 45°)
$\vec{F}_2$	–(60 N)(cos 55°)	(60 N)(sin 55°)

Add the x and y components of all force vectors separately.

x direction

$$\vec{F}_{\text{net}_x} = \vec{F}_{1_x} + \vec{F}_{2_x}$$

$$\begin{aligned} F_{\text{net}_x} &= F_{1_x} + F_{2_x} \\ &= (36\text{ N})(\cos 45°) + \{-(60\text{ N})(\cos 55°)\} \\ &= -8.96\text{ N} \end{aligned}$$

y direction

$$\vec{F}_{\text{net}_y} = \vec{F}_{1_y} + \vec{F}_{2_y}$$

$$\begin{aligned} F_{\text{net}_y} &= F_{1_y} + F_{2_y} \\ &= (36\text{ N})(\sin 45°) + (60\text{ N})(\sin 55°) \\ &= 74.6\text{ N} \end{aligned}$$

Use the Pythagorean theorem to find the magnitude of $\vec{F}_{\text{net}}$.

$$\begin{aligned} F_{\text{net}} &= \sqrt{\left(F_{\text{net}_x}\right)^2 + \left(F_{\text{net}_y}\right)^2} \\ &= \sqrt{(-8.96\text{ N})^2 + (74.6\text{ N})^2} \\ &= 75\text{ N} \end{aligned}$$

Use the tangent function to find the direction of $\vec{F}_{\text{net}}$.

$$\begin{aligned} \tan\theta &= \frac{\text{opposite}}{\text{adjacent}} \\ &= \frac{74.6\ \cancel{\text{N}}}{8.96\ \cancel{\text{N}}} \\ &= 8.328 \\ \theta &= \tan^{-1}(8.328) \\ &= 83° \end{aligned}$$

From the vector addition diagram, this angle is between $\vec{F}_{\text{net}}$ and the negative x-axis. So the direction of $\vec{F}_{\text{net}}$ measured *counterclockwise* from the positive x-axis is 180° – 83° = 97°.

$$\vec{F}_{\text{net}} = 75 \text{ N [97°]}$$

Paraphrase

The net force on the object is 75 N [97°].

(b) ***Analysis and Solution***

Find the mass of the object.

$$\begin{aligned} F_{\text{g}} &= mg \\ m &= \frac{F_{\text{g}}}{g} \\ &= \frac{20 \text{ N}}{9.81 \text{ m/s}^2} \\ &= \frac{20 \text{ kg}\bullet\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{9.81 \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}} \\ &= 2.04 \text{ kg} \end{aligned}$$

The acceleration of the object is in the direction of the net force. So use the scalar form of Newton's second law.

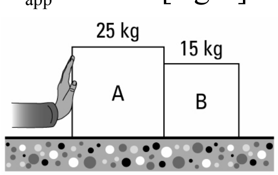
$$\begin{aligned} F_{\text{net}} &= ma \\ a &= \frac{F_{\text{net}}}{m} \\ &= \frac{75.1 \text{ N}}{2.04 \text{ kg}} \\ &= \frac{75.1 \cancel{\text{kg}}\bullet\frac{\text{m}}{\text{s}^2}}{2.04 \cancel{\text{kg}}} \\ &= 37 \text{ m/s}^2 \\ \vec{a} &= 37 \text{ m/s}^2 \text{ [97°]} \end{aligned}$$

The object will have an acceleration of 37 m/s^2 [97°].

8. ***Given***

m_{A} = 25 kg $\qquad$ m_{B} = 15 kg

$\vec{F}_{\text{app}}$ = 30 N [right]



Required

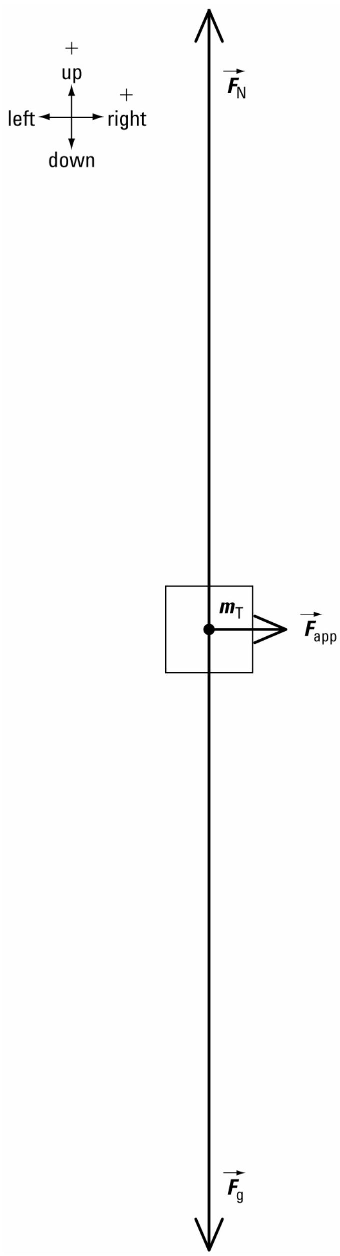
acceleration of the boxes ($\vec{a}$)

Analysis and Solution

Both boxes are a system because they move together as a unit. Find the total mass of the system.

$$
\begin{aligned}
m_T &= m_A + m_B \\
&= 25 \text{ kg} + 15 \text{ kg} \\
&= 40 \text{ kg}
\end{aligned}
$$

Draw a free-body diagram for the system.



The system is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\text{net}_h} = \vec{F}_{\text{app}}$$

$$\begin{aligned} F_{\text{net}_h} &= F_{\text{app}} \\ &= 30 \text{ N} \end{aligned}$$

Apply Newton's second law to the horizontal direction.

$$\begin{aligned} F_{\text{net}_h} &= m_T a \\ a &= \frac{F_{\text{net}_h}}{m_T} \\ &= \frac{30 \text{ N}}{40 \text{ kg}} \\ &= \frac{30 \dfrac{\cancel{\text{kg}} \cdot \text{m}}{\text{s}^2}}{40 \cancel{\text{kg}}} \\ &= 0.75 \text{ m/s}^2 \\ \vec{a} &= 0.75 \text{ m/s}^2 \text{ [right]} \end{aligned}$$

vertical direction

$$\vec{F}_{\text{net}_v} = \vec{F}_N + \vec{F}_g$$

$$F_{\text{net}_v} = 0$$

Calculations in the vertical direction are not required in this problem.

Paraphrase

The boxes will have an acceleration of 0.75 m/s^2 [right].

9. (a) ***Given***

$m_A = 4.0$ kg

$m_B = 2.0$ kg

magnitude of $\vec{F}_f = 11.8$ N

$\vec{g} = 9.81$ m/s^2 [down]

Required

acceleration of the system ($\vec{a}$)

Analysis and Solution

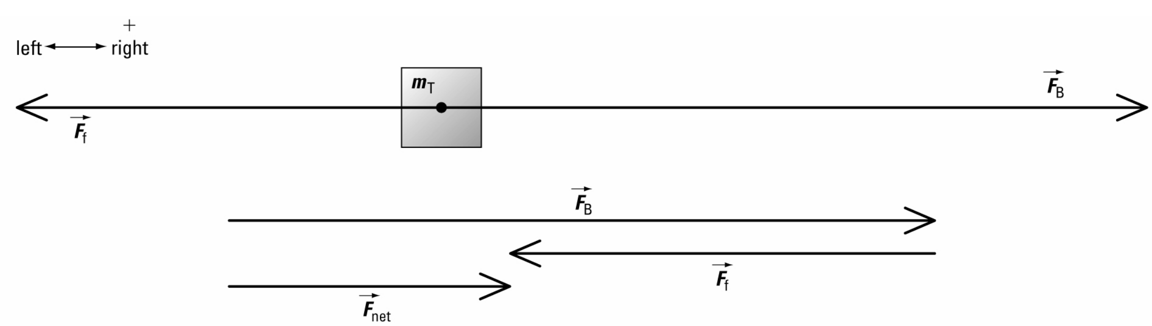
The string has a negligible mass. So the tension in the string is the same on both sides of the pulley.

The string does not stretch. So the magnitude of $\vec{a}_A$ is equal to the magnitude of $\vec{a}_B$.

Find the total mass of both objects.

$$\begin{aligned} m_T &= m_A + m_B \\ &= 4.0 \text{ kg} + 2.0 \text{ kg} \\ &= 6.0 \text{ kg} \end{aligned}$$

Choose an equivalent system in terms of m_T to analyze the motion.



$\vec{F}_B$ is equal to the gravitational force acting on m_B.

Apply Newton's second law to find the net force acting on m_T.

$$\vec{F}_{net} = \vec{F}_B + \vec{F}_f$$

$$\begin{aligned} F_{net} &= F_B + F_f \\ &= m_B g + (-11.8\text{ N}) \\ &= m_B g - 11.8\text{ N} \\ &= (2.0\text{ kg})(9.81\text{ m/s}^2) - 11.8\text{ N} \\ &= 7.82\text{ N} \end{aligned}$$

Use the scalar form of Newton's second law to calculate the magnitude of the acceleration.

$$\begin{aligned} F_{net} &= m_T a \\ a &= \frac{F_{net}}{m_T} \\ &= \frac{7.82\text{ N}}{6.0\text{ kg}} \\ &= \frac{7.82\ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{6.0\ \cancel{\text{kg}}} \\ &= 1.3\text{ m/s}^2 \\ \vec{a}_A &= 1.3\text{ m/s}^2\text{ [toward pulley]} \\ \vec{a}_B &= 1.3\text{ m/s}^2\text{ [down]} \end{aligned}$$

Paraphrase

The 4.0-kg block will have an acceleration of 1.3 m/s^2 [toward pulley] and the 2.0-kg block will have an acceleration of 1.3 m/s^2 [down].

(b) ***Given***

$m_B = 2.0$ kg

$\vec{a}_B = 1.30$ m/s^2 [down] from part (a)

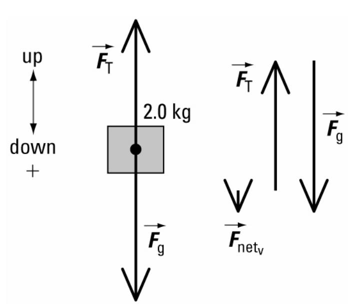
$\vec{g} = 9.81$ m/s^2 [down]

Required

tension in string

Analysis and Solution

Draw a free-body diagram for the 2.0-kg block.



The block is not accelerating left or right.

So in the horizontal direction, $F_{net_h} = 0$ N.

Write equations to find the net force on the block in the vertical direction.

vertical direction

$$\vec{F}_{\text{net}_v} = \vec{F}_T + \vec{F}_g$$

Apply Newton's second law.

$$m_B\vec{a}_B = \vec{F}_T + \vec{F}_g$$

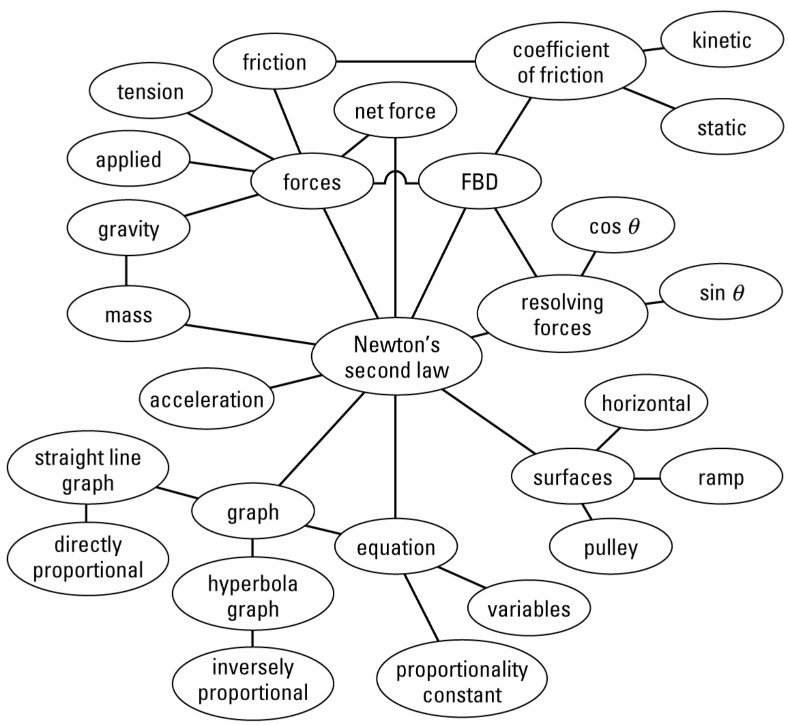
$$\begin{aligned} m_B a_B &= F_T + F_g \\ F_T &= m_B a_B - F_g \\ &= m_B a_B - m_B g \\ &= m_B(a_B - g) \\ &= (2.0\text{ kg})(1.30\text{ m/s}^2 - 9.81\text{ m/s}^2) \\ &= -17\text{ N} \end{aligned}$$

Paraphrase

The tension in the string is 17 N.

Extensions

10.



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Concept Check

The reaction force is always equal in magnitude and opposite in direction to the action force. It is not possible to have just an action force or just a reaction force. If a situation involves an action force, there is always a reaction force as well.

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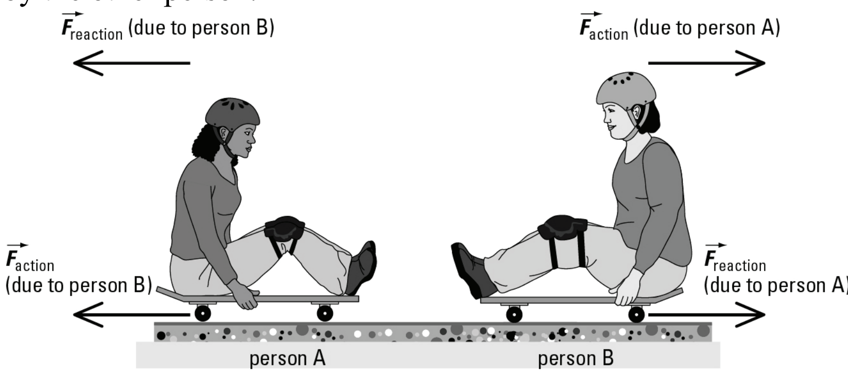
Concept Check

Since the action-reaction forces act on different objects, both objects may accelerate provided there is a non-zero net force acting on each one.
For example, if two people are sitting on skateboards and each person applies a force on the other with their feet, both people will accelerate away from each other. Each person exerts an action force on the other, and each person experiences a reaction force exerted by the other person.



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Example 3.12 Practice Problems

1. ***Given***

$m_A = 8.0$ kg $\quad m_B = 10$ kg $\quad m_C = 5.0$ kg

$\vec{a} = 1.5 \text{ m/s}^2$ [right]

Required

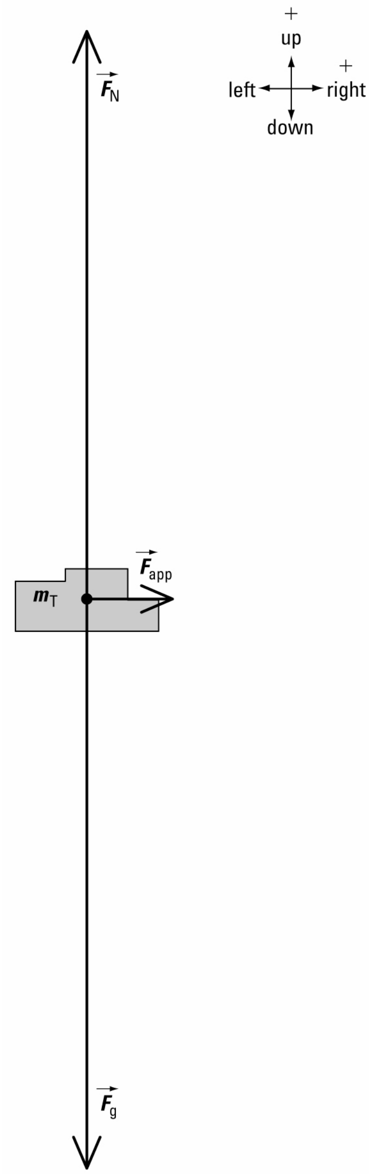
force exerted by box B on box A ($\vec{F}_{\text{B on A}}$)

Analysis and Solution

Since all three boxes have the same acceleration, the boxes are a system. Find the total mass of the system.

$$\begin{aligned} m_T &= m_A + m_B + m_C \\ &= 8.0 \text{ kg} + 10 \text{ kg} + 5.0 \text{ kg} \\ &= 23.0 \text{ kg} \end{aligned}$$

Draw a free-body diagram for the system.



The system is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

For the horizontal direction, write an equation to find the net force on the system.

$$\vec{F}_{net_h} = \vec{F}_{app}$$

Apply Newton's second law.

$$m_T\vec{a} = \vec{F}_{app}$$

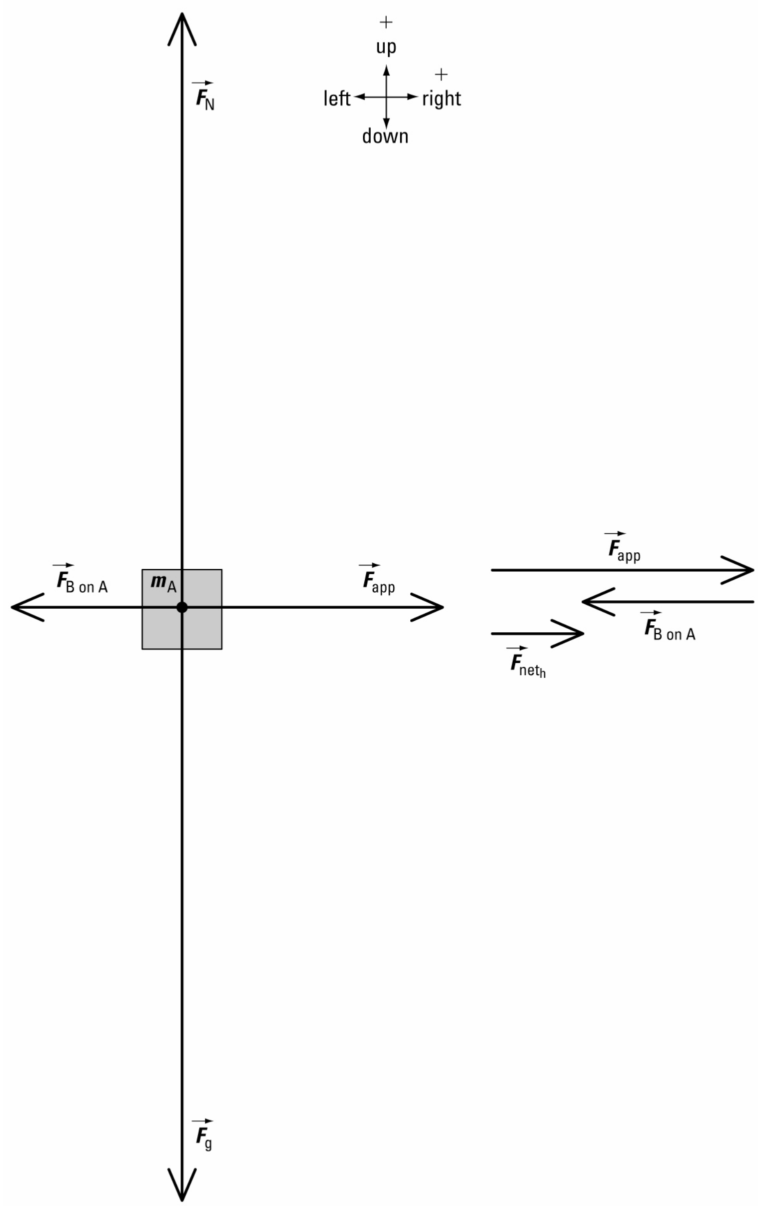
$$m_T a = F_{app}$$

$$F_{app} = (23.0\text{ kg})(1.5\text{ m/s}^2)$$

$$= 34.5\text{ N}$$

$$\vec{F}_{app} = 34.5\text{ N [right]}$$

Draw a free-body diagram for box A.



Box A is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on box A in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_{app} + \vec{F}_{B \text{ on } A}$$

$$F_{net_h} = F_{app} + F_{B \text{ on } A}$$

Apply Newton's second law.

$$m_A a = F_{app} + F_{B \text{ on } A}$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$

$$F_{net_v} = 0$$

Calculations in the vertical direction are not required in this problem.

$F_{\text{B on A}} = m_A a - F_{app}$
$= (8.0 \text{ kg})(1.5 \text{ m/s}^2) - 34.5 \text{ N}$
$= -23 \text{ N}$
$\vec{F}_{\text{B on A}} = 23 \text{ N [left]}$

Paraphrase

The force exerted by box B on box A is 23 N [left].

2. ***Given***

$m_A = 5.0 \text{ kg}$ $m_B = 5.0 \text{ kg}$
$\vec{F}_T = 60 \text{ N [along rope]}$
$\vec{a} = 2.19 \text{ m/s}^2$ [up] from Example 3.9 Practice Problem 1
$\vec{g} = 9.81 \text{ m/s}^2$ [down]

Required

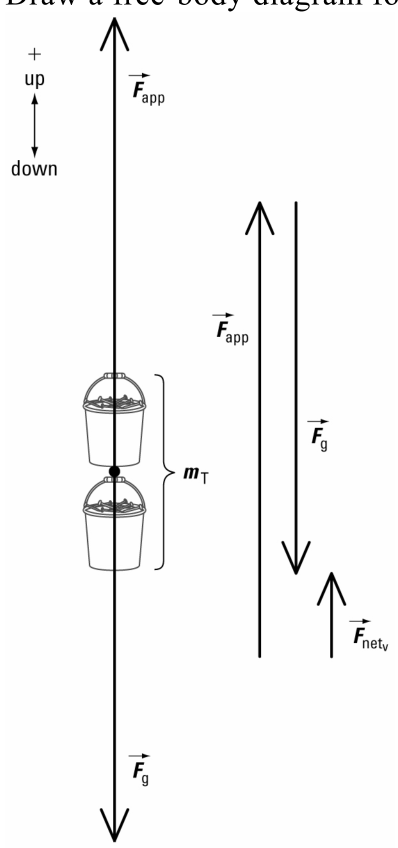
applied force ($\vec{F}_{app}$)

Analysis and Solution

The two buckets move together as a unit with the same acceleration. So the buckets are a system. Find the total mass of the system.

$$m_T = m_A + m_B = 5.0 \text{ kg} + 5.0 \text{ kg} = 10.0 \text{ kg}$$

Draw a free-body diagram for the system.



The system is not accelerating left or right.
So in the horizontal direction, $F_{net_h} = 0 \text{ N}$.

For the vertical direction, write an equation to find the net force on the system.

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_{\text{app}} + \vec{F}_{\text{g}}$$

Apply Newton's second law.

$$\begin{aligned} m_\text{T}\vec{a} &= \vec{F}_{\text{app}} + \vec{F}_{\text{g}} \\ m_\text{T}a &= F_{\text{app}} + F_{\text{g}} \\ m_\text{T}a &= F_{\text{app}} + m_\text{T}g \\ F_{\text{app}} &= m_\text{T}(a - g) \\ &= (10.0\text{ kg})\{2.19\text{ m/s}^2 - (-9.81\text{ m/s}^2)\} \\ &= (10.0\text{ kg})\{2.19\text{ m/s}^2 + 9.81\text{ m/s}^2\} \\ &= 1.2 \times 10^2\text{ N} \\ \vec{F}_{\text{app}} &= 1.2 \times 10^2\text{ N [up]} \end{aligned}$$

Paraphrase

An applied force of 1.2×10^2 N [up] would cause both buckets to have an acceleration of 2.2 m/s^2 [up].

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Example 3.13 Practice Problem

1. (a) ***Given***

$m_\text{A} = 150$ kg $\quad m_\text{B} = 250$ kg

$\vec{F}_{\text{app}} = 2600$ N [forward]

magnitude of $\vec{F}_\text{f} = 2400$ N

Required

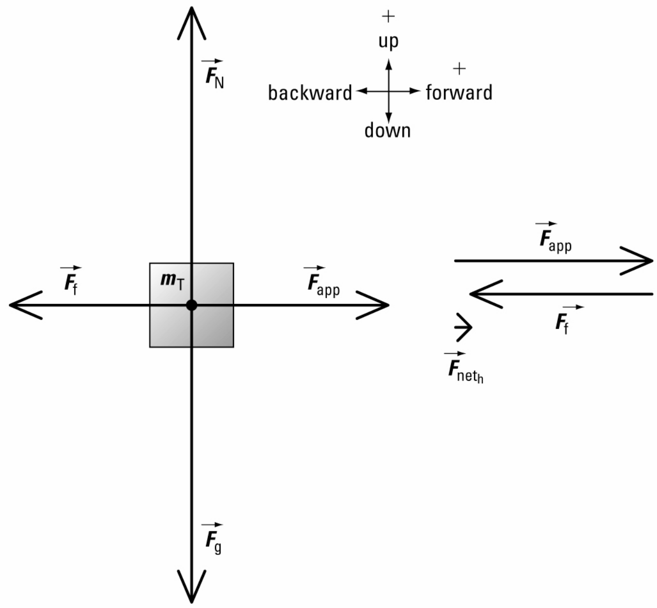
acceleration of the logs ($\vec{a}$)

Analysis and Solution

Both logs are a system because they move together as a unit. Find the total mass of the system.

$$\begin{aligned} m_\text{T} &= m_\text{A} + m_\text{B} \\ &= 150\text{ kg} + 250\text{ kg} \\ &= 400\text{ kg} \end{aligned}$$

Draw a free-body diagram for the system.



The system is not accelerating up or down.
So in the vertical direction, F_{net_v} = 0 N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_{app} + \vec{F}_f$$
$$\begin{aligned} F_{net_h} &= F_{app} + F_f \\ &= 2600 \text{ N} + (-2400 \text{ N}) \\ &= 2600 \text{ N} - 2400 \text{ N} \\ &= 200 \text{ N} \end{aligned}$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = 0$$

Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$$\begin{aligned} F_{net_h} &= m_T a \\ a &= \frac{F_{net\,h}}{m_T} \\ &= \frac{200 \text{ N}}{400 \text{ kg}} \\ &= \frac{200 \ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{400 \ \cancel{\text{kg}}} \\ &= 0.500 \text{ m/s}^2 \\ \vec{a} &= 0.500 \text{ m/s}^2 \text{ [forward]} \end{aligned}$$

Paraphrase

The logs will have an acceleration of 0.500 m/s^2 [forward].

(b) ***Given***

m_A = 150 kg
m_B = 250 kg
$\vec{F}_{app}$ = 2600 N [forward]
$\vec{F}_{f \text{ on } A}$ = 900 N [backward]

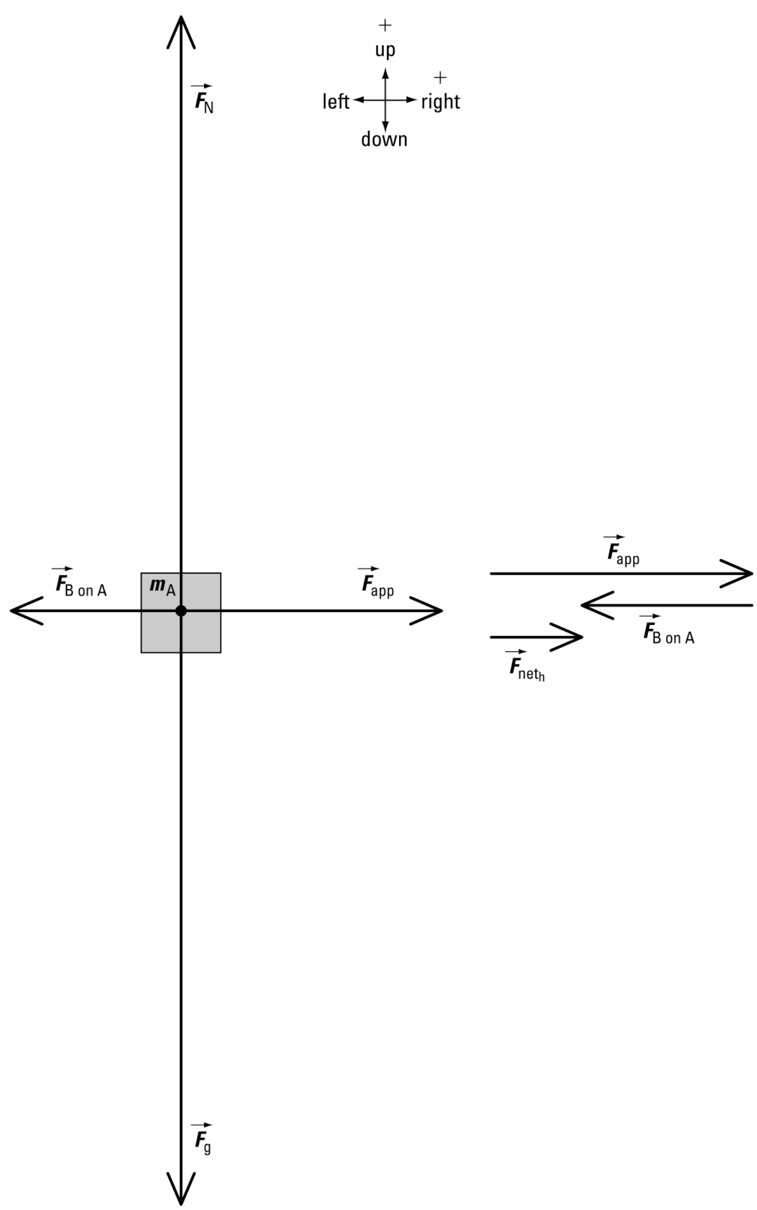
$\vec{a}$ = 0.500 m/s^2 [forward] from part (a)

Required

force exerted by log B on log A ($\vec{F}_{\text{B on A}}$)

Analysis and Solution

Draw a free-body diagram for log A.



Log A is not accelerating up or down.
So in the vertical direction, F_{net_v} = 0 N.

Write equations to find the net force on log A in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{app}} + \vec{F}_{\text{B on A}} + \vec{F}_{\text{f on A}}$$

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_{\text{N}} + \vec{F}_{\text{g}}$$

$F_{\text{net}_h} = F_{\text{app}} + F_{\text{B on A}} + F_{\text{f on A}}$ $\qquad F_{\text{net}_v} = 0$

Apply Newton's second law.

Calculations in the vertical direction are not required in this problem.

$$\begin{aligned}
m_A a &= F_{\text{app}} + F_{\text{B on A}} + F_{\text{f on A}} \\
F_{\text{B on A}} &= m_A a - F_{\text{app}} - F_{\text{f on A}} \\
&= (150 \text{ kg})(0.500 \text{ m/s}^2) - 2600 \text{ N} - (-900 \text{ N}) \\
&= -1.63 \times 10^3 \text{ N} \\
\vec{F}_{\text{B on A}} &= 1.63 \times 10^3 \text{ N [backward]}
\end{aligned}$$

Paraphrase

Log B exerts a force of 1.63×10^3 N [backward] on log A.

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3.4 Check and Reflect

Knowledge

1. Newton's third law states that if one object exerts a force on a second object, the second object exerts a force back on the first object that is equal in magnitude and opposite in direction.

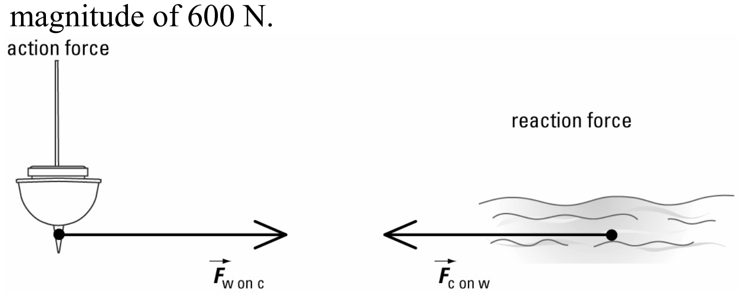
2. (a) The swimmer at the edge of the pool exerts an action force directed toward the wall of the pool. The wall, in turn, exerts a reaction force directed toward the swimmer. This reaction force causes the swimmer to accelerate away from the wall.

(b) The person in the canoe exerts an action force on the package directed toward the shore. The package, in turn, exerts a reaction force directed on the person. Since the person is in the canoe, the reaction force on the person also acts on the canoe, so the canoe moves away from shore.

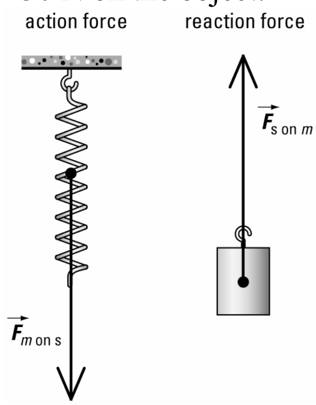
3. In order for a car to accelerate, the tires must exert a force of friction directed backward on the ground. The ground will, in turn, exert a reaction force directed forward on the tires causing the car to accelerate forward.

If the ground is icy, the tires will not be able to exert a great enough force of friction on the ice, no matter how powerful the car engine. If the driver presses the accelerator too hard, the tires will spin, causing the ice beneath the tires to melt. This watery layer will make it even more difficult for the tires to exert any frictional force on the icy surface. In general, it is better to use lower gears and to gently press the accelerator so that the tires can exert the maximum force of friction on snow and ice.

4. (a) The action force is the water pushing against the centreboard with a magnitude of 600 N. The reaction force is the centreboard pushing against the water with a magnitude of 600 N.



(b) The action force is the object exerting a downward force of magnitude 30 N on the spring. The reaction force is the spring exerting an upward force of magnitude 30 N on the object.



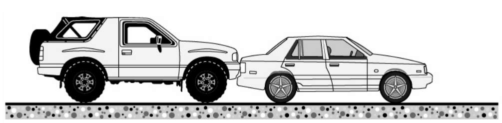
Applications

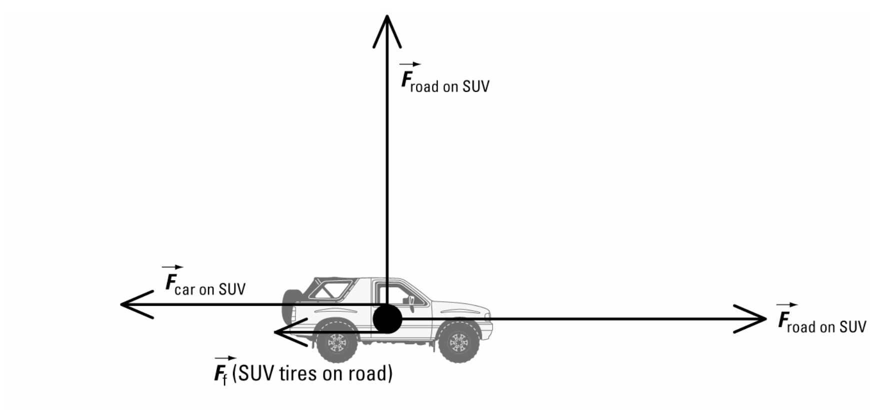
5. The normal force $\vec{F}_{\text{N}}$ and the gravitational force $\vec{F}_{\text{g}}$ acting on an object are *not* action-reaction forces, because both of these forces act on the same object.

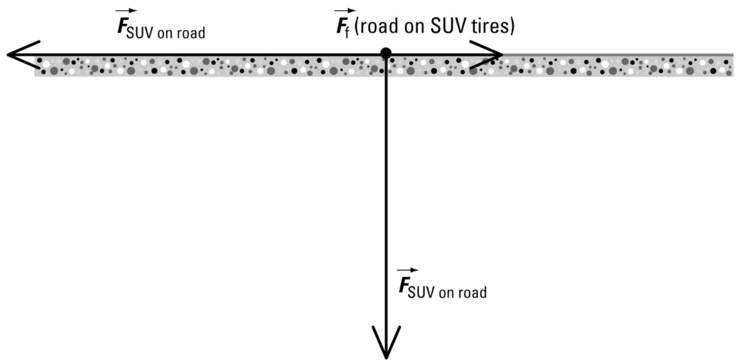
The normal force is exerted by the contact surface on the object and is directed perpendicular to the contact surface. The reaction force to $\vec{F}_{\text{N}}$ is the force exerted by the object on the contact surface, and is directed toward the contact surface.

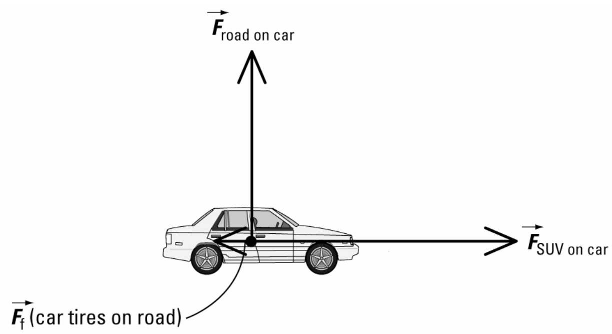
The gravitational force is the force exerted by Earth on the object, and is directed toward Earth's centre. The reaction force to $\vec{F}_{\text{g}}$ is the force exerted by the object on Earth, and is directed toward the object.

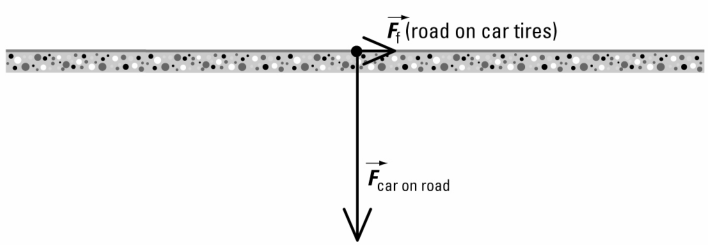
6.











7. For example, label the spring scale on the right as A and the one on the left as B. The person exerts a force of 10 N [right] on A. From Newton's third law, A exerts a force of 10 N [left] on the person. But A also exerts a force of 10 N [right] on B. From Newton's third law, B exerts a force of 10 N [left] on A. B, in turn, exerts a force of 10 N [right] on the wall, and the wall exerts a force of 10 N [left] on B.
So the net force in the horizontal direction is zero and the spring scales remain stationary. The reading on B is 10 N, and the wall exerts a force of 10 N [left] on the anchored spring scale.

8. (a) ***Given***

m_{X} = 10 kg $\qquad$ m_{Y} = 5.0 kg

$\vec{F}_{\text{app}}$ = 36 N [right]

Required

force exerted by block X on block Y ($\vec{F}_{\text{X on Y}}$)

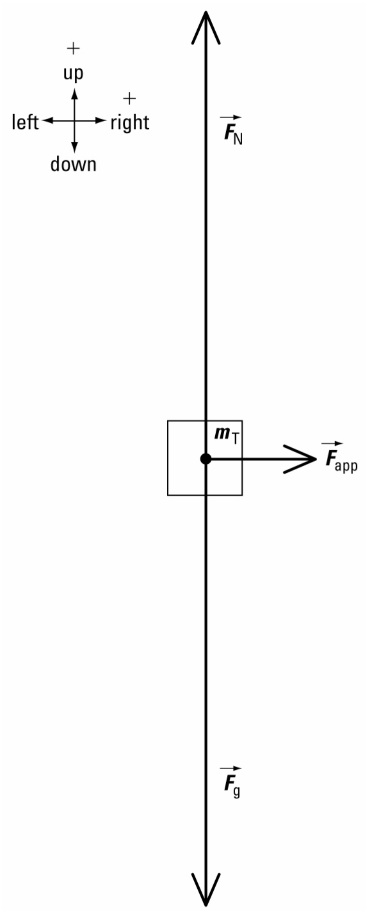
force exerted by block Y on block X ($\vec{F}_{\text{Y on X}}$)

Analysis and Solution

Blocks X and Y are a system because they move together as a unit. Find the total mass of the system.

$m_T = m_X + m_Y$
$= 10 \text{ kg} + 5.0 \text{ kg}$
$= 15.0 \text{ kg}$

Draw a free-body diagram for the system.



The system is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$\vec{F}_{net_h} = \vec{F}_{app}$

$F_{net_h} = F_{app}$
$= 36 \text{ N}$

vertical direction

$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$

$F_{net_v} = 0$

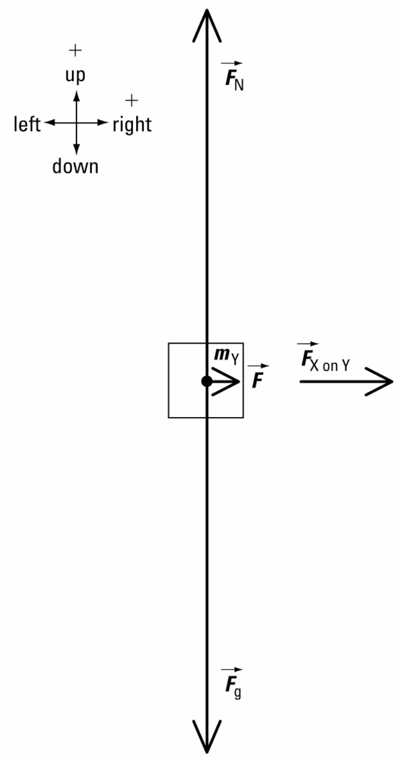
Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$F_{net_h} = m_T a$

$$
\begin{aligned}
a &= \frac{F_{\text{net}_\text{h}}}{m_\text{T}} \\
&= \frac{36\ \text{N}}{15.0\ \text{kg}} \\
&= \frac{36\ \frac{\cancel{\text{kg}}\cdot\text{m}}{\text{s}^2}}{15.0\ \cancel{\text{kg}}} \\
&= 2.40\ \text{m/s}^2 \\
\vec{a} &= 2.40\ \text{m/s}^2\ [\text{right}]
\end{aligned}
$$

Draw a free-body diagram for block Y.



Block Y is not accelerating up or down.
So in the vertical direction, $F_{\text{net}_\text{v}} = 0$ N.

Write equations to find the net force on block Y in both the horizontal and vertical directions.

horizontal direction

$$
\begin{aligned}
\vec{F}_{\text{net}_\text{h}} &= \vec{F}_{\text{X on Y}} \\
F_{\text{net}_\text{h}} &= F_{\text{X on Y}}
\end{aligned}
$$

Apply Newton's second law.

$$
\begin{aligned}
m_\text{Y}a &= F_{\text{X on Y}} \\
F_{\text{X on Y}} &= (5.0\ \text{kg})(2.40\ \text{m/s}^2) \\
&= 12\ \text{N} \\
\vec{F}_{\text{X on Y}} &= 12\ \text{N}\ [\text{right}]
\end{aligned}
$$

vertical direction

$$
\begin{aligned}
\vec{F}_{\text{net}_\text{v}} &= \vec{F}_\text{N} + \vec{F}_\text{g} \\
F_{\text{net}_\text{v}} &= 0
\end{aligned}
$$

Calculations in the vertical direction are not required in this problem.

Apply Newton's third law.

$$\vec{F}_{\text{Y on X}} = -\vec{F}_{\text{X on Y}}$$
$$= 12 \text{ N [left]}$$

Paraphrase

The force exerted by block X on block Y is 12 N [right] and block Y exerts a force of 12 N [left] on block X.

(b) ***Given***

$m_X = 10$ kg $m_Y = 5.0$ kg

$\vec{F}_{\text{f on X}} = 8.0$ N [left] $\vec{F}_{\text{f on Y}} = 4.0$ N [left]

$\vec{F}_{\text{app}} = 36$ N [right]

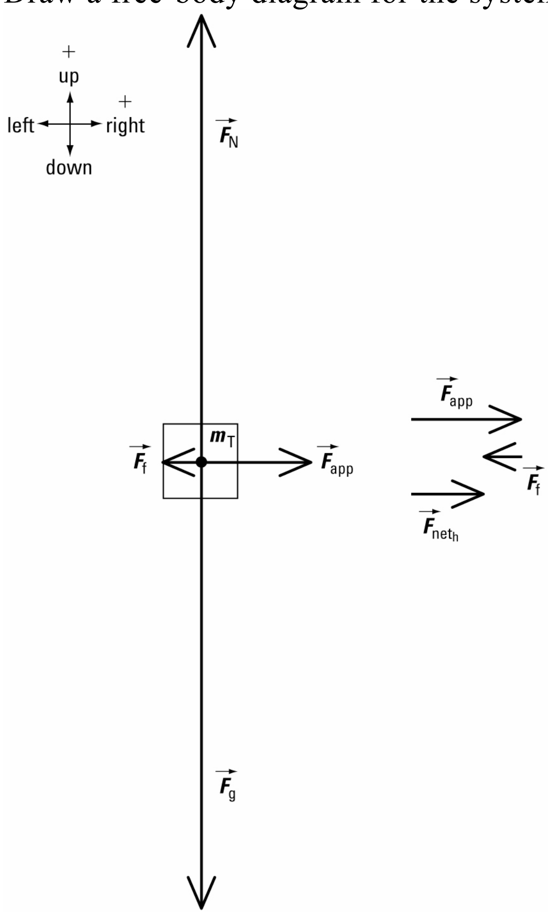
Required

force exerted by block X on block Y ($\vec{F}_{\text{X on Y}}$)

force exerted by block Y on block X ($\vec{F}_{\text{Y on X}}$)

Analysis and Solution

Draw a free-body diagram for the system.



The system is not accelerating up or down.

So in the vertical direction, $F_{\text{net}_v} = 0$ N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{app}} + \vec{F}_{\text{f}}$

$F_{\text{net}_\text{h}} = F_{\text{app}} + F_{\text{f}}$

$= F_{\text{app}} + F_{\text{f on X}} + F_{\text{f on Y}}$

$= 36\text{ N} + (-8.0\text{ N}) + (-4.0\text{ N})$

$= 36\text{ N} - 8.0\text{ N} - 4.0\text{ N}$

$= 24.0\text{ N}$

vertical direction

$\vec{F}_{\text{net}_\text{v}} = \vec{F}_{\text{N}} + \vec{F}_{\text{g}}$

$F_{\text{net}_\text{v}} = 0$

Calculations in the vertical direction are not required in this problem.

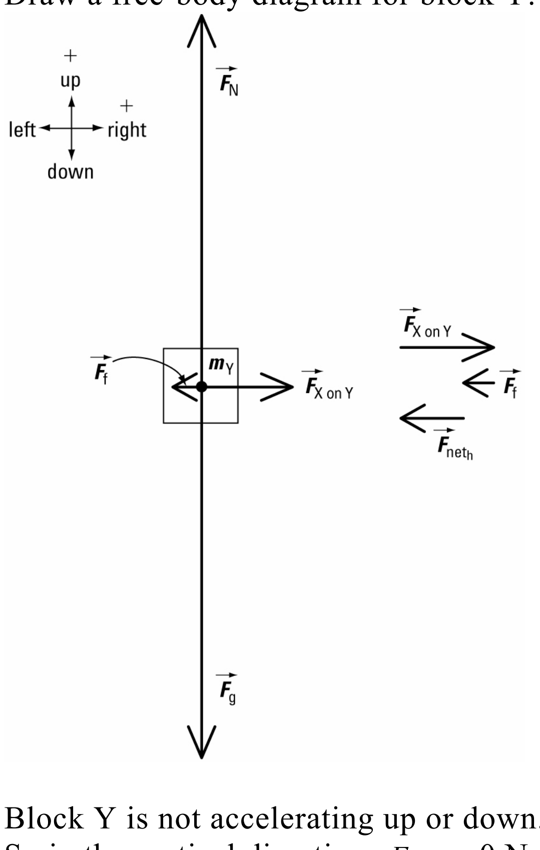
Apply Newton's second law to the horizontal direction.

$F_{\text{net}_\text{h}} = m_{\text{T}}\, a$

$$a = \frac{F_{\text{net}_\text{h}}}{m_{\text{T}}} = \frac{24.0\text{ N}}{15.0\text{ kg}} = \frac{24.0\ \frac{\cancel{\text{kg}}\cdot\text{m}}{\text{s}^2}}{15.0\ \cancel{\text{kg}}} = 1.60\text{ m/s}^2$$

$\vec{a} = 1.60\text{ m/s}^2$ [right]

Draw a free-body diagram for block Y.



Block Y is not accelerating up or down.
So in the vertical direction, $F_{\text{net}_\text{v}} = 0$ N.

Write equations to find the net force on block Y in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{X on Y}} + \vec{F}_{\text{f on Y}}$$

$$F_{\text{net}_\text{h}} = F_{\text{X on Y}} + F_{\text{f on Y}}$$

Apply Newton's second law.

$$\begin{aligned} m_\text{Y}a &= F_{\text{X on Y}} + F_{\text{f on Y}} \\ F_{\text{X on Y}} &= m_\text{Y}a - F_{\text{f on Y}} \\ &= (5.0 \text{ kg})(1.60 \text{ m/s}^2) - (-4.0 \text{ N}) \\ &= 8.0 \text{ N} + 4.0 \text{ N} \\ &= 12 \text{ N} \\ \vec{F}_{\text{X on Y}} &= 12 \text{ N [right]} \end{aligned}$$

Apply Newton's third law.

$$\begin{aligned} \vec{F}_{\text{Y on X}} &= -\vec{F}_{\text{X on Y}} \\ &= 12 \text{ N [left]} \end{aligned}$$

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_\text{N} + \vec{F}_\text{g}$$

$$F_{\text{net}_\text{v}} = 0$$

Calculations in the vertical direction are not required in this problem.

Paraphrase

The force exerted by block X on block Y is 12 N [right] and block Y exerts a force of 12 N [left] on block X.

9. The box will begin to move in a direction opposite to the water flow out of the holes. Since the holes are diagonally opposite each other, the box will rotate. This motion can be explained using Newton's third law. The side of the box opposite each hole exerts a force on the water to accelerate it out of the hole. From Newton's third law, the water exerts a reaction force on the side of the box. This net force accelerates the box in a direction opposite to the direction in which the water is flowing.

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Example 3.14 Practice Problems

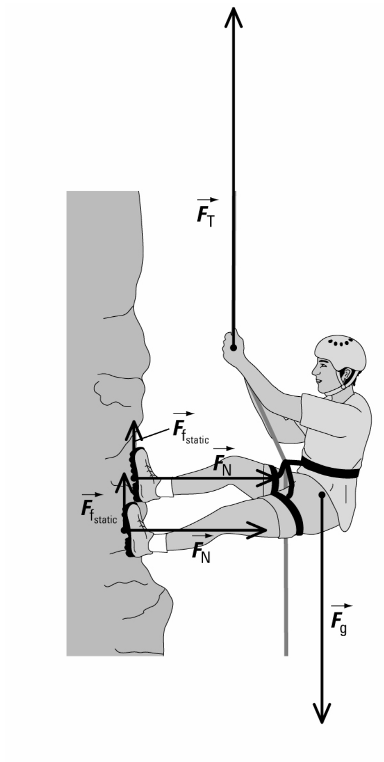
1. ***Analysis and Solution***

From Example 3.14, $F_{\text{f}_\text{static}} \propto \cos\theta$.

(a) To maximize $F_{\text{f}_\text{static}}$, $\cos\theta = 1$. So $\theta = 0°$.

(b) To minimize $F_{\text{f}_\text{static}}$, $\cos\theta = 0$. So $\theta = 90.0°$.

2.



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Example 3.15 Practice Problems

1. ***Given***

$m_{\mathrm{A}} = 7.0$ g or 7.0×10^{-3} kg
$m_{\mathrm{B}} = 7.3$ g or 7.3×10^{-3} kg
$\theta = 30.0°$
$g = 9.81\ \mathrm{m/s^2}$

Required

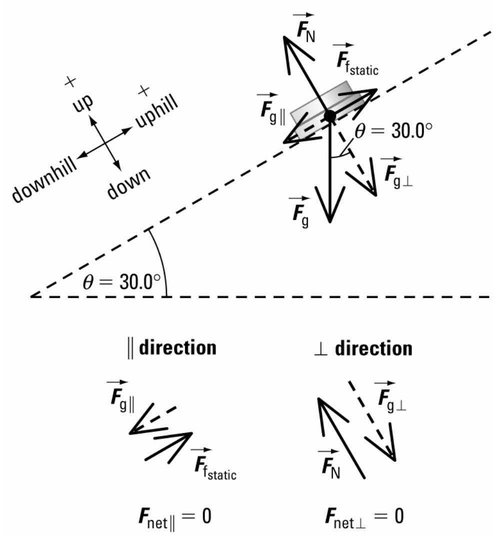
force of static friction ($\vec{F}_{\mathrm{f_{static}}}$)

Analysis and Solution

Since the two coins are stacked, the coins are a system. Find the total mass of the system.

$$\begin{aligned} m_{\mathrm{T}} &= m_{\mathrm{A}} + m_{\mathrm{B}} \\ &= 7.0 \times 10^{-3}\ \mathrm{kg} + 7.3 \times 10^{-3}\ \mathrm{kg} \\ &= 1.4 \times 10^{-2}\ \mathrm{kg} \end{aligned}$$

Draw a free-body diagram for the system.



Since the system is not accelerating, $\vec{F}_{net}$ = 0 N both parallel and perpendicular to the incline.

Write equations to find the net force on the system in both directions.

$\perp$ direction

$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$

$F_{net\perp} = 0$

Calculations in the $\perp$ direction are not required in this problem.

$\parallel$ direction

$$\begin{aligned}
\vec{F}_{net\,\parallel} &= \vec{F}_{g\,\parallel} + \vec{F}_{f_{static}} \\
F_{net\,\parallel} &= F_{g\,\parallel} + F_{f_{static}} \\
0 &= F_{g\,\parallel} + F_{f_{static}} \\
F_{f_{static}} &= -F_{g\,\parallel} \\
\text{Now, } F_{g\,\parallel} &= -m_T g \sin\theta \\
\text{So, } F_{f_{static}} &= -(-m_T g \sin\theta) \\
&= m_T g \sin\theta \\
&= (1.4 \times 10^{-2}\text{ kg})(9.81\text{ m/s}^2)(\sin 30.0°) \\
&= 7.0 \times 10^{-2}\text{ N}
\end{aligned}$$

$\vec{F}_{f_{static}}$ prevents the system from sliding downhill. The positive value for $F_{f_{static}}$ indicates that the direction of $\vec{F}_{f_{static}}$ is uphill.

$\vec{F}_{f_{static}} = 7.0 \times 10^{-2}$ N [uphill]

Paraphrase

The force of static friction acting on the loonie-toonie combination is 7.0×10^{-2} N [uphill].

2. ***Given***

m = 7.00 g or 7.00×10^{-3} kg

magnitude of $\vec{F}_{f_{static}} = 4.40 \times 10^{-2}$ N

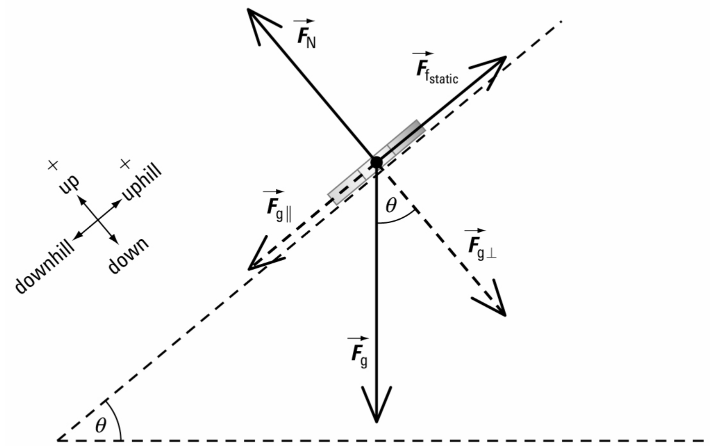
g = 9.81 m/s^2

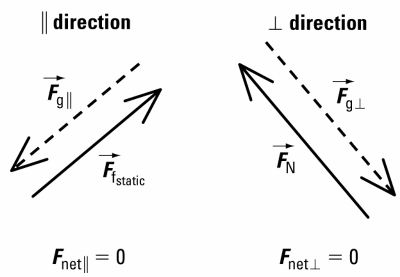
Required

maximum angle of the incline (θ)

Analysis and Solution

Draw a free-body diagram for the loonie.





Since the loonie is not accelerating, $\vec{F}_{net}$ = 0 N both parallel and perpendicular to the incline.

$\vec{F}_{f_{static}}$ prevents the loonie from sliding downhill. So $\vec{F}_{f_{static}}$ is directed uphill.

Write equations to find the net force on the loonie in both directions.

⊥ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$

$$F_{net\perp} = 0$$

Calculations in the ⊥ direction are not required in this problem.

|| direction

$$\begin{aligned}
\vec{F}_{net\parallel} &= \vec{F}_{g\parallel} + \vec{F}_{f_{static}} \\
F_{net\parallel} &= F_{g\parallel} + F_{f_{static}} \\
0 &= F_{g\parallel} + F_{f_{static}} \\
F_{f_{static}} &= -F_{g\parallel} \\
\text{Now, } F_{g\parallel} &= -mg\sin\theta \\
\text{So, } F_{f_{static}} &= -(-mg\sin\theta) \\
&= mg\sin\theta \\
\sin\theta &= \frac{F_{f_{static}}}{mg} \\
&= \frac{4.40\times10^{-2}\text{ N}}{(7.00\times10^{-3}\text{ kg})(9.81\text{ m/s}^2)} \\
&= 0.6407 \\
\theta &= \sin^{-1}(0.6407) \\
&= 39.8°
\end{aligned}$$

Paraphrase
The maximum angle that the book can be inclined is 39.8°.

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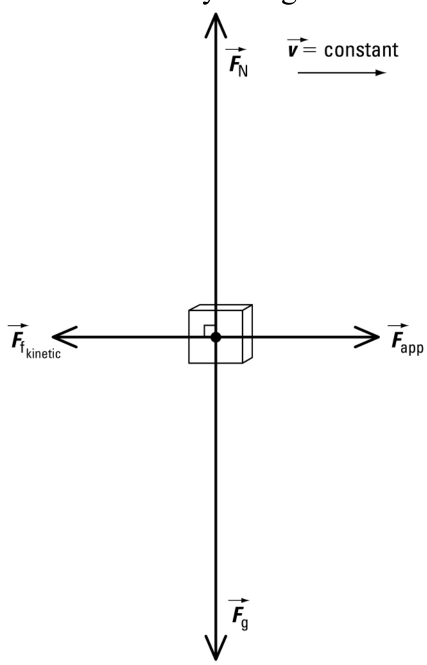
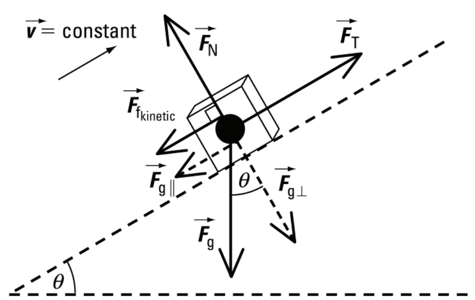
Concept Check

The angle between the normal force and the force of friction is always 90º, whether or not the object is on a horizontal surface.
The free-body diagram below shows the forces acting on an object being pulled at constant velocity along a horizontal, rough surface.



The free-body diagram below shows the same object being pulled up a rough incline at constant velocity with $\vec{F}_{app}$ acting parallel to the incline.



Example 3.16 Practice Problems

1. ***Given***

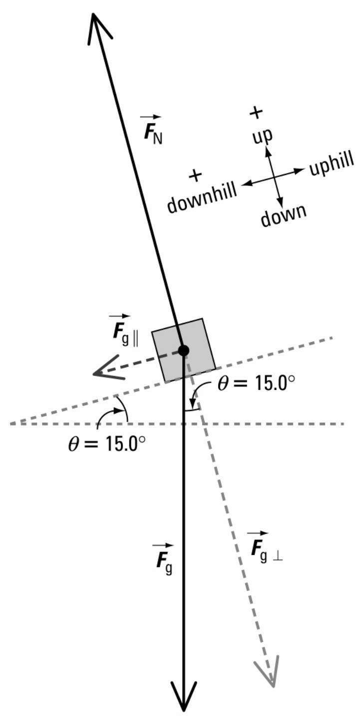
$m = 3.5$ kg
$\theta = 15.0°$
$g = 9.81$ m/s^2

Required

acceleration of block ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the block.



Since the block is accelerating downhill, $\vec{F}_{net} \neq 0$ N parallel to the incline, but $\vec{F}_{net} = 0$ N perpendicular to the incline.

Write equations to find the net force on the block in both directions.

$\perp$ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$

$$F_{net\perp} = 0$$

Calculations in the $\perp$ direction are not required in this problem.

$\parallel$ direction

$$\vec{F}_{net\parallel} = \vec{F}_{g\parallel}$$

$$F_{net\parallel} = F_{g\parallel}$$

$$ma = F_{g\parallel}$$

Now, $F_{g\parallel} = mg \sin\theta$

So, $\cancel{m}a = \cancel{m}g\sin\theta$

$= g \sin\theta$

$$a = (9.81\ \text{m/s}^2)(\sin 15.0°) = 2.5\ \text{m/s}^2$$

The positive value for a indicates that the direction of $\vec{a}$ is downhill.

$\vec{a} = 2.5\ \text{m/s}^2$ [downhill]

Paraphrase

The acceleration of the block will be 2.5 m/s^2 [downhill].

2. ***Given***

$m = 55.0$ kg

$\theta = 35.0°$

magnitude of $\vec{a} = 4.41\ \text{m/s}^2$

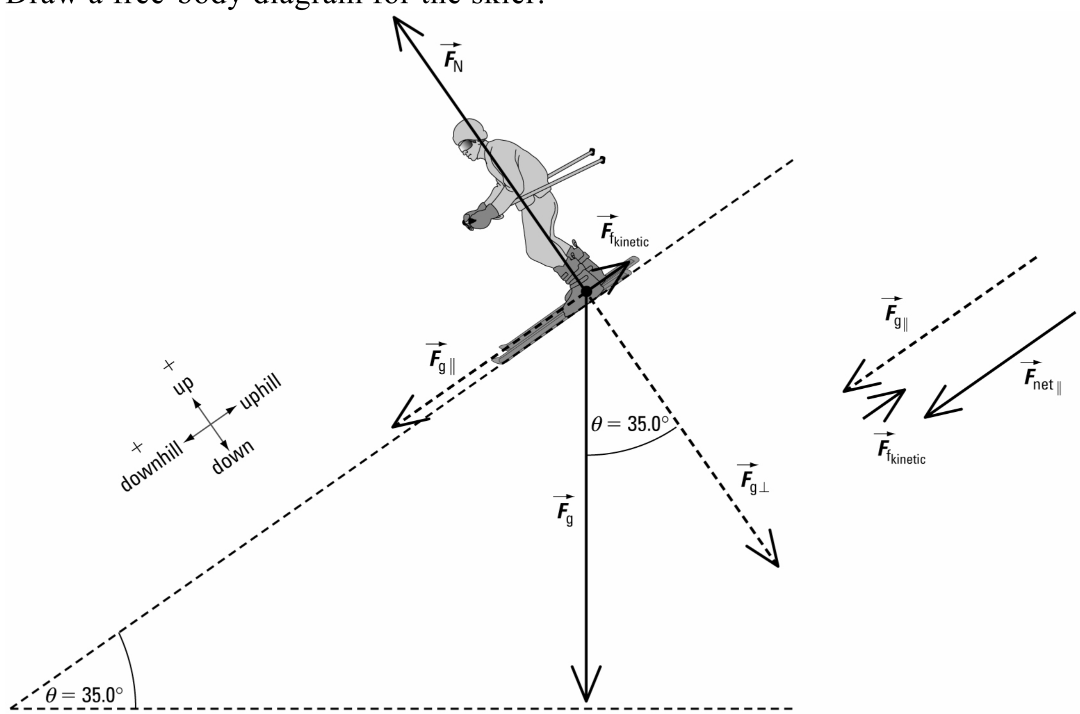
$g = 9.81\ \text{m/s}^2$

Required

force of kinetic friction ($\vec{F}_{f_{kinetic}}$)

Analysis and Solution

Draw a free-body diagram for the skier.



Since the skier is accelerating downhill, $\vec{F}_{net} \neq 0$ N parallel to the incline, but $\vec{F}_{net} = 0$ N perpendicular to the incline.

Write equations to find the net force on the skier in both directions.

$\perp$ direction	$\parallel$ direction
$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$	$\vec{F}_{net\parallel} = \vec{F}_{g\parallel} + \vec{F}_{f_{kinetic}}$
$F_{net\perp} = 0$	$F_{net\parallel} = F_{g\parallel} + F_{f_{kinetic}}$
Calculations in the $\perp$	$ma = F_{g\parallel} + F_{f_{kinetic}}$
direction are not required	Now, $F_{g\parallel} = mg \sin\theta$
in this problem.	So, $ma = mg\sin\theta + F_{f_{kinetic}}$

$$F_{\mathrm{f}_{\mathrm{kinetic}}} = m(a - g \sin \theta)$$
$$= (55.0\ \text{kg})\{4.41\ \text{m/s}^2 - (9.81\ \text{m/s}^2)(\sin 35.0°)\}$$
$$= -66.9\ \text{N}$$

The negative value for $F_{\mathrm{f}_{\mathrm{kinetic}}}$ indicates that the direction of $\vec{F}_{\mathrm{f}_{\mathrm{kinetic}}}$ is uphill.

$\vec{F}_{\mathrm{f}_{\mathrm{kinetic}}} = 66.9$ N [uphill]

Paraphrase

The force of kinetic friction on the skier is 66.9 N [uphill].

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Concept Check

If the magnitude of the force of kinetic friction were greater than the maximum magnitude of the force of static friction, an object would be unable to move.

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Example 3.17 Practice Problems

1. ***Given***

$\vec{F}_{\text{app}} = 24$ N [forward]

$\vec{g} = 9.81\ \text{m/s}^2$ [down]

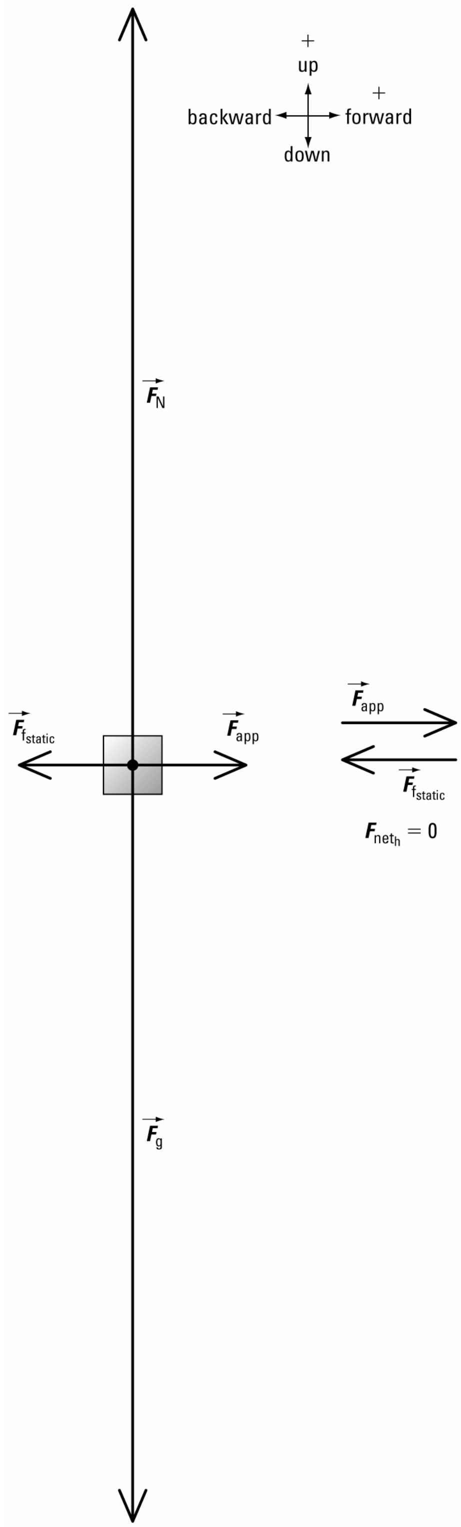
$\mu_{\text{s}} = 0.15$ from Table 3.4 (steel on greased steel)

Required

mass of block (m)

Analysis and Solution

Draw a free-body diagram for the block.



Since the block is not accelerating, $\vec{F}_{net} = 0$ N in both the horizontal and vertical directions.
Write equations to find the net force on the block in both directions.

horizontal direction

$$\begin{aligned}\vec{F}_{\text{net}_h} &= \vec{F}_{\text{app}} + \vec{F}_{\text{f}_{\text{static}}} \\ F_{\text{net}_h} &= F_{\text{app}} + F_{\text{f}_{\text{static}}} \\ 0 &= F_{\text{app}} + F_{\text{f}_{\text{static}}} \\ &= F_{\text{app}} + (-\mu_s F_N) \\ &= F_{\text{app}} - \mu_s F_N \\ F_{\text{app}} &= \mu_s F_N\end{aligned}$$

vertical direction

$$\begin{aligned}\vec{F}_{\text{net}_v} &= \vec{F}_N + \vec{F}_g \\ F_{\text{net}_v} &= F_N + F_g \\ 0 &= F_N + (-mg) \\ &= F_N - mg \\ F_N &= mg\end{aligned}$$

Substitute $F_N = mg$ into equation for F_{app}.

$$\begin{aligned}F_{\text{app}} &= \mu_s mg \\ m &= \frac{F_{\text{app}}}{\mu_s g} \\ &= \frac{24\ \text{N}}{(0.15)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)} \\ &= \frac{24\ \text{kg}\bullet\cancel{\frac{\text{m}}{\text{s}^2}}}{(0.15)\left(9.81\ \cancel{\frac{\text{m}}{\text{s}^2}}\right)} \\ &= 16\ \text{kg}\end{aligned}$$

Paraphrase

The mass of the steel block is 16 kg.

2. ***Given***

$\vec{F}_{\text{app}}$ = 125 N [forward]

$\vec{g}$ = 9.81 m/s^2 [down]

μ_s = 0.20 from Table 3.4 (waxed hickory skis on wet snow)

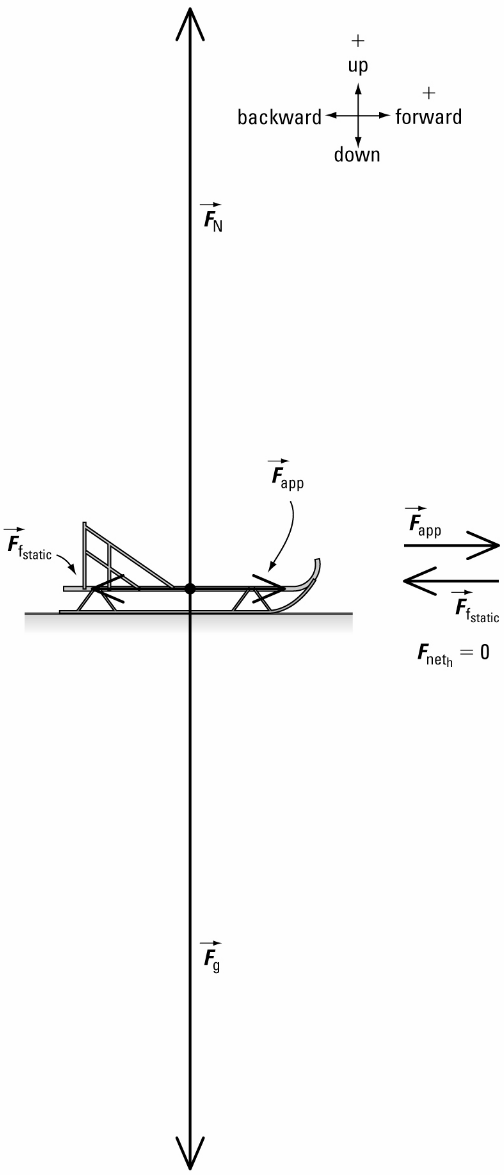
m = 78 kg from Example 3.17

Required

determine if sled will move

Analysis and Solution

Draw a free-body diagram for the sled.



Since the sled is not accelerating in the vertical direction, $F_{net_h} = 0$ N.

Write equations to find the net force on the sled in both directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_{app} + \vec{F}_{f_{static}}$$
$$\begin{aligned} F_{net_h} &= F_{app} + F_{f_{static}} \\ &= F_{app} + F_{f_{static}} \\ &= F_{app} + (-\mu_s F_N) \\ &= F_{app} - \mu_s F_N \end{aligned}$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$\begin{aligned} F_{net_v} &= F_N + F_g \\ 0 &= F_N + (-mg) \\ &= F_N - mg \\ F_N &= mg \end{aligned}$$

Substitute $F_N = mg$ into equation for F_{net_h}.

$$\begin{aligned} F_{net_h} &= F_{app} - \mu_s mg \\ &= 125 \text{ N} - (0.20)(78 \text{ kg})(9.81 \text{ m/s}^2) \\ &= -28 \text{ N} \end{aligned}$$

Since $\vec{F}_{\text{net}_\text{h}}$ is negative, $F_{\text{f}_\text{static}} > F_{\text{app}}$.

Paraphrase

The sled will not move on a wet snowy surface if an applied force of 125 N acts on it.

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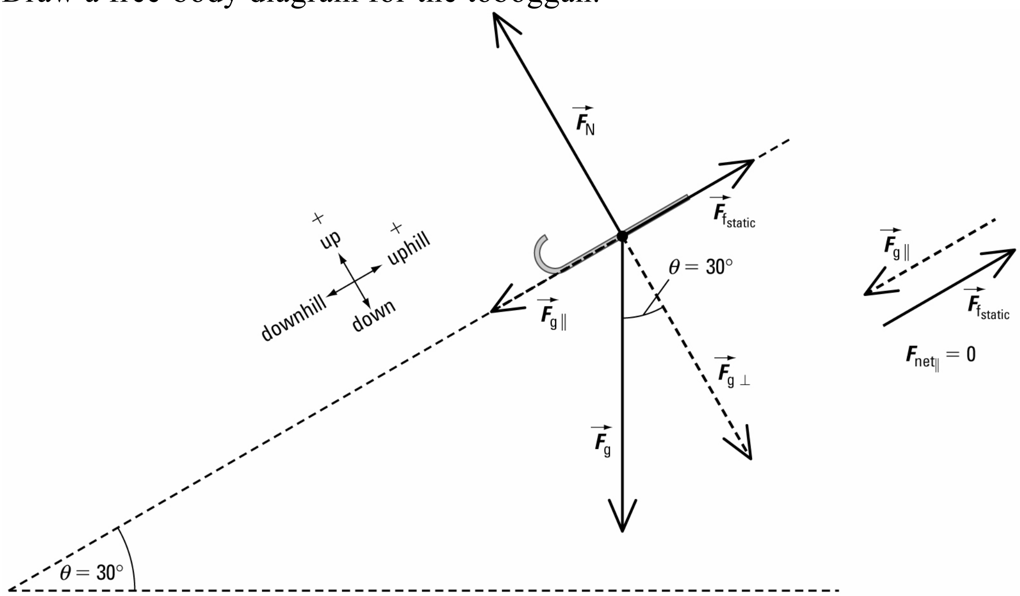
Example 3.18 Practice Problems

1. ***Analysis and Solution***

Draw a free-body diagram for the toboggan.



From Example 3.18, μ_s depends on the angle of the hill, not the mass of the toboggan.

Substitute $\theta = 30.0°$ into equation for μ_s.

$$\begin{aligned}\mu_\text{s} &= \tan\theta \\ &= \tan 30.0° \\ &= 0.58\end{aligned}$$

The coefficient of static friction for the toboggan on the snow is 0.58.

2. ***Given***

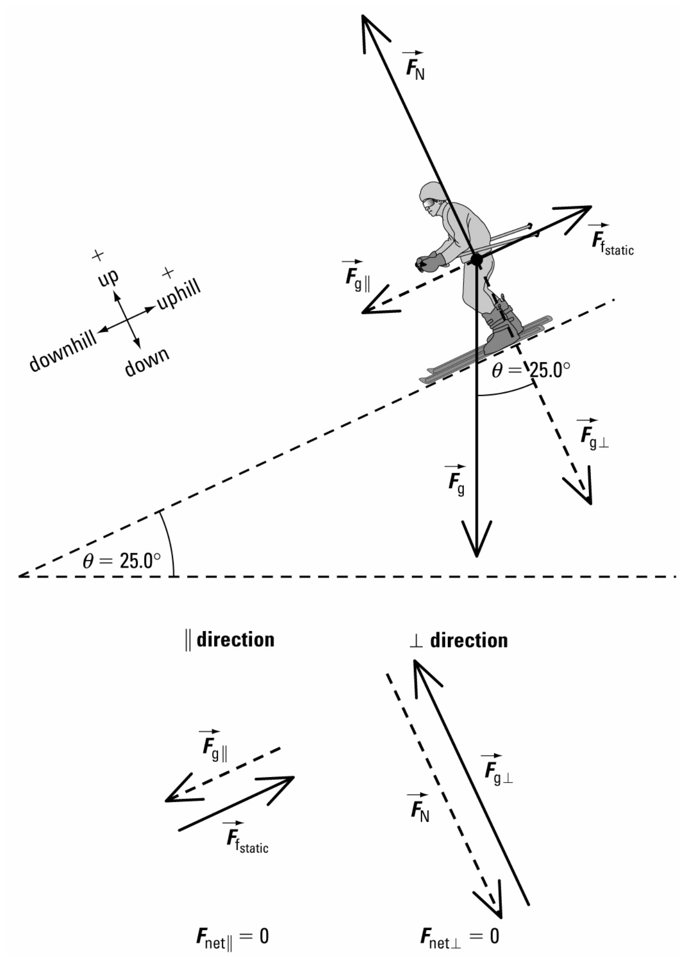
m = 80 kg
θ = 25.0°
g = 9.81 m/s^2

Required

(a) coefficient of static friction (μ_s)
(b) maximum force of static friction ($\vec{F}_{\text{f}_\text{static}}$)

Analysis and Solution

(a) Draw a free-body diagram for the skier.



When the angle of the incline is just enough for the skier to start moving, the surface of the incline is exerting the maximum magnitude of the force of static friction on the skier.

Just before the skier begins to slide, $\vec{F}_{net}$ = 0 N in both the parallel and perpendicular directions to the incline.

Write equations to find the net force on the skier in both directions.

$\perp$ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$
$$F_{net\perp} = F_N + F_{g\perp}$$
$$0 = F_N + F_{g\perp}$$
$$F_N = -F_{g\perp}$$

Now, $F_{g\perp} = -mg\cos\theta$

So, $F_N = -(-mg\cos\theta)$

$$= mg\cos\theta$$

$\parallel$ direction

$$\vec{F}_{net\parallel} = \vec{F}_{g\parallel} + \vec{F}_{f_{static}}$$
$$F_{net\parallel} = F_{g\parallel} + F_{f_{static}}$$
$$0 = F_{g\parallel} + F_{f_{static}}$$
$$F_{f_{static}} = -F_{g\parallel}$$
$$F_{g\parallel} = -mg\sin\theta$$
$$F_{f_{static}} = -(-mg\sin\theta)$$
$$= mg\sin\theta$$
$$\mu_s F_N = mg\sin\theta$$

Substitute $F_N = mg\cos\theta$ into the last equation for the $\parallel$ direction.

$$
\begin{aligned}
\mu_s(\cancel{mg}\cos\theta) &= \cancel{mg}\sin\theta \\
\mu_s\cos\theta &= \sin\theta \\
\mu_s &= \frac{\sin\theta}{\cos\theta} \\
&= \tan\theta \\
&= \tan 25.0° \\
&= 0.47
\end{aligned}
$$

(b) Substitute μ_s into the equation $F_{f_{static}} = \mu_s F_N$.

$$
\begin{aligned}
F_{f_{static}} &= \mu_s mg\cos\theta \\
&= (0.47)(80\text{ kg})(9.81\text{ m/s}^2)(\cos 25.0°) \\
&= 3.3\times10^2\text{ N} \\
\vec{F}_{f_{static}} &= 3.3\times10^2\text{ N [uphill]}
\end{aligned}
$$

Paraphrase

(a) The coefficient of static friction for the skier on the snow is 0.47.

(b) The maximum force of static friction on the skier is 3.3×10^2 N [uphill].

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Example 3.19 Practice Problems

1. ***Given***

$\vec{F}_{app}$ = 450 N [forward]

$\vec{g}$ = 9.81 m/s^2 [down]

m = 1000 kg

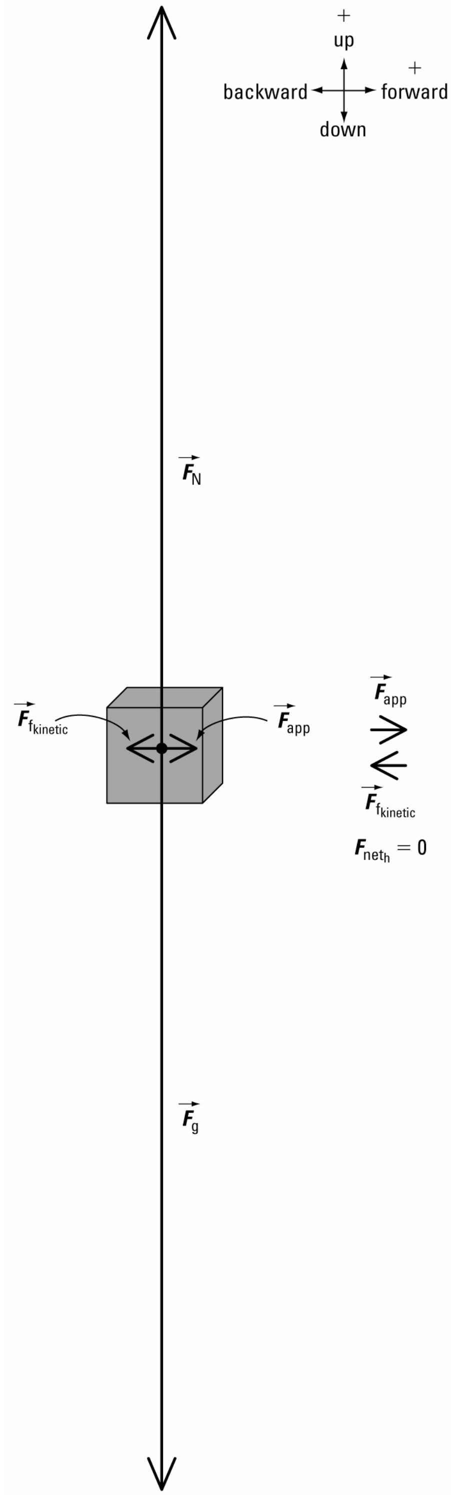
$\vec{a}$ = 0 m/s^2

Required

coefficient of kinetic friction (μ_k)

Analysis and Solution

Draw a free-body diagram for the crate.



Since the crate is moving at constant speed, $\vec{F}_{net}$ = 0 N in both the horizontal and vertical directions.
Write equations to find the net force on the crate in both directions.

horizontal direction

$$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{app}} + \vec{F}_{\text{f}_\text{kinetic}}$$

$$F_{\text{net}_\text{h}} = F_{\text{app}} + F_{\text{f}_\text{kinetic}}$$

$$\begin{aligned} 0 &= 450 \text{ N} + (-\mu_\text{k} F_\text{N}) \\ &= 450 \text{ N} - \mu_\text{k} F_\text{N} \\ \mu_\text{k} F_\text{N} &= 450 \text{ N} \end{aligned}$$

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_\text{N} + \vec{F}_\text{g}$$

$$F_{\text{net}_\text{v}} = F_\text{N} + F_\text{g}$$

$$\begin{aligned} 0 &= F_\text{N} + (-mg) \\ &= F_\text{N} - mg \\ F_\text{N} &= mg \end{aligned}$$

Substitute $F_\text{N} = mg$ into the last equation for the horizontal direction.

$$\begin{aligned} \mu_\text{k} mg &= 450 \text{ N} \\ \mu_\text{k} &= \frac{450 \text{ N}}{mg} \\ &= \frac{450 \text{ N}}{(1000 \text{ kg})\left(9.81 \dfrac{\text{m}}{\text{s}^2}\right)} \\ &= \frac{450 \ \cancel{\text{kg}} \bullet \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{\left(1000 \ \cancel{\text{kg}}\right)\left(9.81 \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)} \\ &= 4.59 \times 10^{-2} \end{aligned}$$

Paraphrase

The coefficient of kinetic friction for the crate on the floor is 4.59×10^{-2}.

2. ***Given***

$m = 1640$ kg

$\theta = 15.0°$

$\vec{a} = 0$ m/s^2

$g = 9.81$ m/s^2

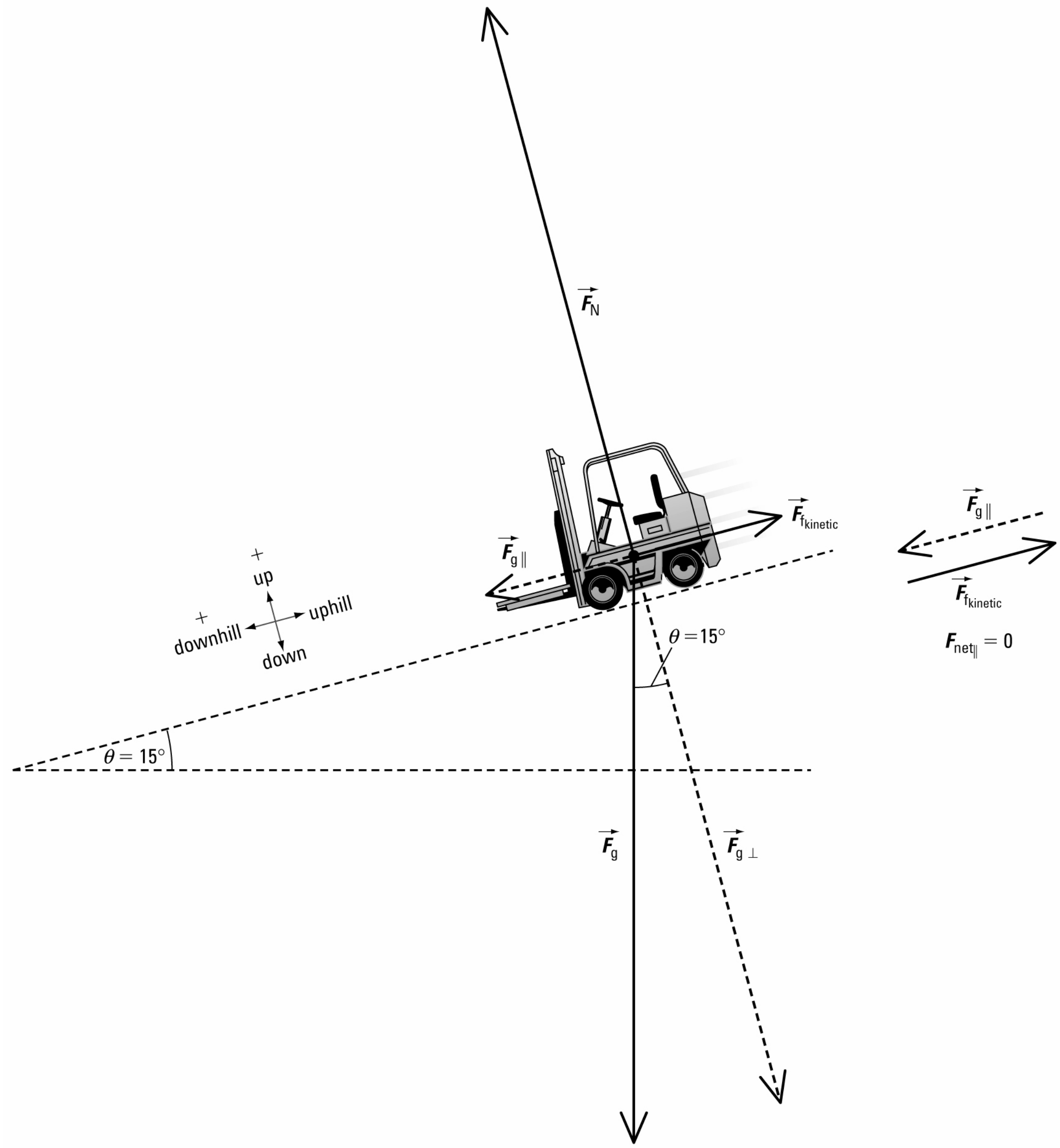
$\mu_\text{k} = 0.5$ from Table 3.4 (rubber tires on wet concrete)

Required

force of kinetic friction ($\vec{F}_{\text{f}_\text{kinetic}}$)

Analysis and Solution

Draw a free-body diagram for the lift truck.



Since the lift truck is moving at constant speed downhill, $\vec{F}_{net}$ = 0 N both parallel and perpendicular to the incline.
Write equations to find the net force on the lift truck in both directions.

$\perp$ direction

$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$

$F_{net\perp} = 0$

Calculations in the $\perp$ direction are not required in this problem.

$\parallel$ direction

$\vec{F}_{net\parallel} = \vec{F}_{g\parallel} + \vec{F}_{f_{kinetic}}$

$F_{net\parallel} = F_{g\parallel} + F_{f_{kinetic}}$

$0 = F_{g\parallel} + F_{f_{kinetic}}$

$F_{f_{kinetic}} = -F_{g\parallel}$

Now, $F_{g\parallel} = mg \sin\theta$

$$\text{So, } F_{f_{\text{kinetic}}} = -mg \sin \theta$$
$$= -(1640 \text{ kg})(9.81 \text{ m/s}^2)(\sin 15.0°)$$
$$= -4.16 \times 10^3 \text{ N}$$

The negative value for $F_{f_{\text{kinetic}}}$ indicates that the direction of $\vec{F}_{f_{\text{kinetic}}}$ is uphill.

$\vec{F}_{f_{\text{kinetic}}} = 4.16 \times 10^3$ N [uphill]

Paraphrase

The force of kinetic friction on the lift truck is 4.16×10^3 N [uphill].

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Example 3.20 Practice Problem

1. (a) ***Given***

$m_A = 15$ kg $\qquad m_B = 15$ kg

$\mu_k = 0.50 \qquad g = 9.81$ m/s^2

$\vec{a} = 0$ m/s^2

Required

applied force on bundles ($\vec{F}_{\text{app}}$)

Analysis and Solution

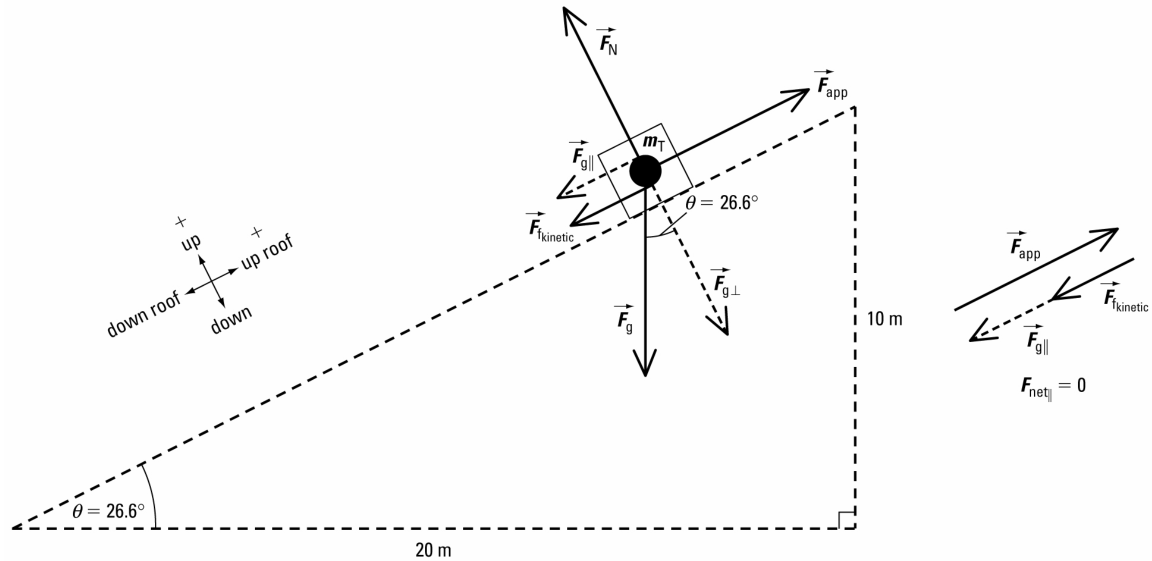
Calculate the angle of the roof.

$$\tan \theta = \frac{1.0 \cancel{\text{m}}}{2.0 \cancel{\text{m}}}$$
$$= 0.5000$$
$$\theta = \tan^{-1}(0.5000)$$
$$= 26.6°$$

Both bundles are a system because they move together as a unit. Find the total mass of the system.

$$m_T = m_A + m_B$$
$$= 15 \text{ kg} + 15 \text{ kg}$$
$$= 30 \text{ kg}$$

Draw a free-body diagram for the system.



Since the system is moving at constant speed up the roof, $\vec{F}_{net}$ = 0 N both parallel and perpendicular to the roof.
Write equations to find the net force on the system in both directions.

$\perp$ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$
$$F_{net\perp} = F_N + F_{g\perp}$$
$$0 = F_N + F_{g\perp}$$
$$F_N = -F_{g\perp}$$

Now, $F_{g\perp} = -m_T g \cos\theta$

So, $F_N = -(-m_T g\cos\theta) = m_T g\cos\theta$

$\parallel$ direction

$$\vec{F}_{net\parallel} = \vec{F}_{app} + \vec{F}_{g\parallel} + \vec{F}_{f_{kinetic}}$$
$$F_{net\parallel} = F_{app} + F_{g\parallel} + F_{f_{kinetic}}$$
$$0 = F_{app} + F_{g\parallel} + F_{f_{kinetic}}$$
$$F_{app} = -F_{g\parallel} - F_{f_{kinetic}}$$

$F_{g\parallel} = -m_T g\sin\theta$ and $F_{f_{kinetic}} = -\mu_k F_N$

$$F_{app} = -(-m_T g\sin\theta) - (-\mu_k F_N) = m_T g\sin\theta + \mu_k F_N$$

Substitute $F_N = m_T g\cos\theta$ into the equation for F_{app}.

$$\begin{aligned} F_{app} &= m_T g\sin\theta + \mu_k m_T g\cos\theta \\ &= m_T g(\sin\theta + \mu_k\cos\theta) \\ &= (30\text{ kg})(9.81\text{ m/s}^2)\{\sin 26.6° + (0.50)(\cos 26.6°)\} \\ &= 2.6\times10^2\text{ N} \end{aligned}$$

The positive value for F_{app} indicates that the direction of $\vec{F}_{app}$ is up the roof.

$$\vec{F}_{app} = 2.6\times10^2\text{ N [up roof]}$$

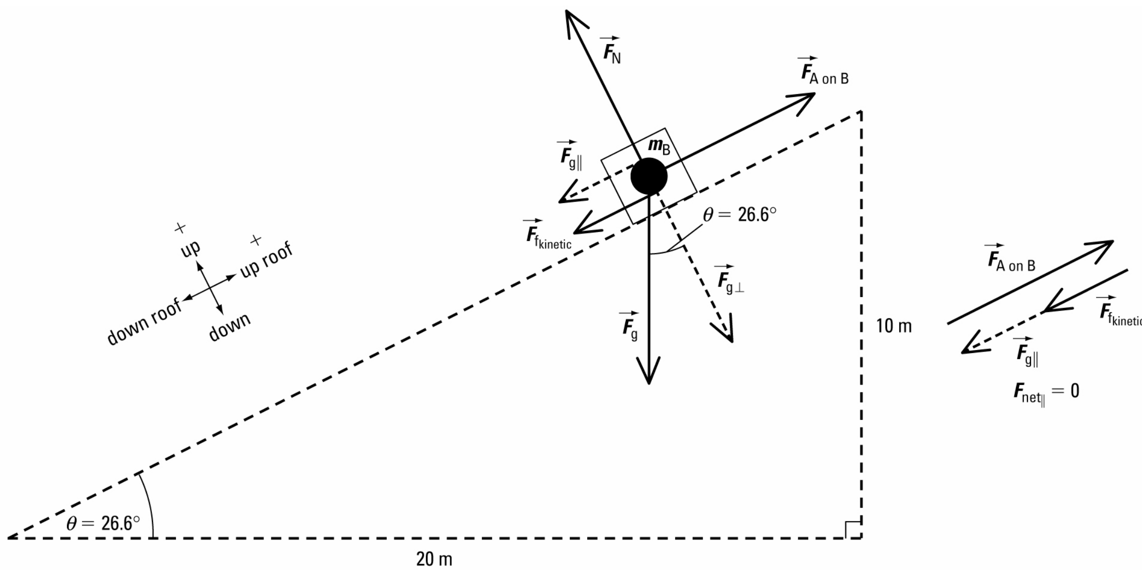
Paraphrase

The roofer must apply a force of 2.6×10^2 N [up roof] to drag the bundles at constant speed.

(b) ***Given***

$m_A = 15$ kg $\quad m_B = 15$ kg
$\mu_k = 0.50 \quad g = 9.81\text{ m/s}^2$
$\vec{a} = 0\text{ m/s}^2$

Required
force exerted by bundle A on bundle B ($\vec{F}_{\text{A on B}}$)
Analysis and Solution
Draw a free-body diagram for bundle B.



Since bundle B is moving at constant speed up the roof, $\vec{F}_{\text{net}}$ = 0 N both parallel and perpendicular to the roof.
Write equations to find the net force on bundle B in both directions.

$\perp$ direction

$$\vec{F}_{\text{net}\perp} = \vec{F}_{\text{N}} + \vec{F}_{\text{g}\perp}$$
$$F_{\text{net}\perp} = F_{\text{N}} + F_{\text{g}\perp}$$
$$0 = F_{\text{N}} + F_{\text{g}\perp}$$
$$F_{\text{N}} = -F_{\text{g}\perp}$$

Now, $F_{\text{g}\perp} = -m_{\text{B}}g \cos\theta$

So, $F_{\text{N}} = -(-m_{\text{B}}g\cos\theta)$
$= m_{\text{B}}g\cos\theta$

$\parallel$ direction

$$\vec{F}_{\text{net}\parallel} = \vec{F}_{\text{A on B}} + \vec{F}_{\text{g}\parallel} + \vec{F}_{\text{f}_{\text{kinetic}}}$$
$$F_{\text{net}\parallel} = F_{\text{A on B}} + F_{\text{g}\parallel} + F_{\text{f}_{\text{kinetic}}}$$
$$0 = F_{\text{A on B}} + F_{\text{g}\parallel} + F_{\text{f}_{\text{kinetic}}}$$
$$F_{\text{A on B}} = -F_{\text{g}\parallel} - F_{\text{f}_{\text{kinetic}}}$$

$F_{\text{g}\parallel} = -m_{\text{B}}g\sin\theta$ and $F_{\text{f}_{\text{kinetic}}} = -\mu_{\text{k}}F_{\text{N}}$

$F_{\text{A on B}} = -(-m_{\text{B}}g\sin\theta) - (-\mu_{\text{k}}F_{\text{N}})$
$= m_{\text{B}}g\sin\theta + \mu_{\text{k}}F_{\text{N}}$

Substitute $F_{\text{N}} = m_{\text{B}}g\cos\theta$ into equation for F_{app}.

$$\begin{aligned} F_{\text{A on B}} &= m_{\text{B}}g\sin\theta + \mu_{\text{k}}m_{\text{B}}g\cos\theta \\ &= m_{\text{B}}g(\sin\theta + \mu_{\text{k}}\cos\theta) \\ &= (15\text{ kg})(9.81\text{ m/s}^2)\{\sin 26.6° + (0.50)(\cos 26.6°)\} \\ &= 1.3 \times 10^2\text{ N} \end{aligned}$$

The positive value for $F_{\text{A on B}}$ indicates that the direction of $\vec{F}_{\text{A on B}}$ is up the roof.

$$\vec{F}_{\text{A on B}} = 1.3 \times 10^2\text{ N [up roof]}$$

Paraphrase
Bundle A exerts a force of 1.3×10^2 N [up roof] on bundle B.

(c) ***Given***

$m_A = 15$ kg $\qquad m_B = 15$ kg

$\mu_k = 0.50 \qquad g = 9.81$ m/s^2

$\vec{a} = 2.0$ m/s^2 [up roof]

Required

applied force on bundles ($\vec{F}_{app}$)

Analysis and Solution

Since the system is accelerating up the roof, $\vec{F}_{net} \neq 0$ N parallel to the roof, but $\vec{F}_{net} = 0$ N perpendicular to the roof.

Write equations to find the net force on the system in both directions.

$\perp$ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$
$$F_{net\perp} = F_N + F_{g\perp}$$
$$0 = F_N + F_{g\perp}$$
$$F_N = -F_{g\perp}$$

Now, $F_{g\perp} = -m_T g \cos\theta$

So, $F_N = -(-m_T g \cos\theta)$
$= m_T g \cos\theta$

$\|$ direction

$$\vec{F}_{net\|} = \vec{F}_{app} + \vec{F}_{g\|} + \vec{F}_{f_{kinetic}}$$
$$F_{net\|} = F_{app} + F_{g\|} + F_{f_{kinetic}}$$
$$m_T a = F_{app} + F_{g\|} + F_{f_{kinetic}}$$
$$F_{app} = m_T a - F_{g\|} - F_{f_{kinetic}}$$

$F_{g\|} = -m_T g \sin\theta$ and $F_{f_{kinetic}} = -\mu_k F_N$

$F_{app} = m_T a - (-m_T g \sin\theta) - (-\mu_k F_N)$
$= m_T a + m_T g \sin\theta + \mu_k F_N$

Substitute $F_N = m_T g \cos\theta$ into equation for F_{app}.

$$\begin{aligned} F_{app} &= m_T a + m_T g \sin\theta + \mu_k m_T g \cos\theta \\ &= m_T a + m_T g(\sin\theta + \mu_k \cos\theta) \\ &= (30\text{ kg})(2.0\text{ m/s}^2) + (30\text{ kg})(9.81\text{ m/s}^2)\{\sin 26.6° \\ &\quad + (0.50)(\cos 26.6°)\} \\ &= 3.2 \times 10^2\text{ N} \end{aligned}$$

The positive value for F_{app} indicates that the direction of $\vec{F}_{app}$ is up the roof.

$\vec{F}_{app} = 3.2 \times 10^2$ N [up roof]

Paraphrase

The roofer must apply a force of 3.2×10^2 N [up roof] to accelerate the bundles.

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3.5 Check and Reflect

Knowledge

1. Friction is the force that opposes the motion of an object, or the direction the object would be moving if there were no friction, that is in contact with another material.

2. Friction can be ignored if an object is in a vacuum, or on an air track or air table.

3. Static friction is the force that opposes an applied force on a stationary object.
The magnitude of static friction varies from zero to a maximum value.
Kinetic friction is the force that opposes the motion of an object. The magnitude of kinetic friction is usually less than the maximum value of static friction.

Applications

4. ***Given***

$\vec{F}_g$ = 15 N [down]

μ_s = 0.06 from Table 3.4 (waxed hickory skis on dry snow)

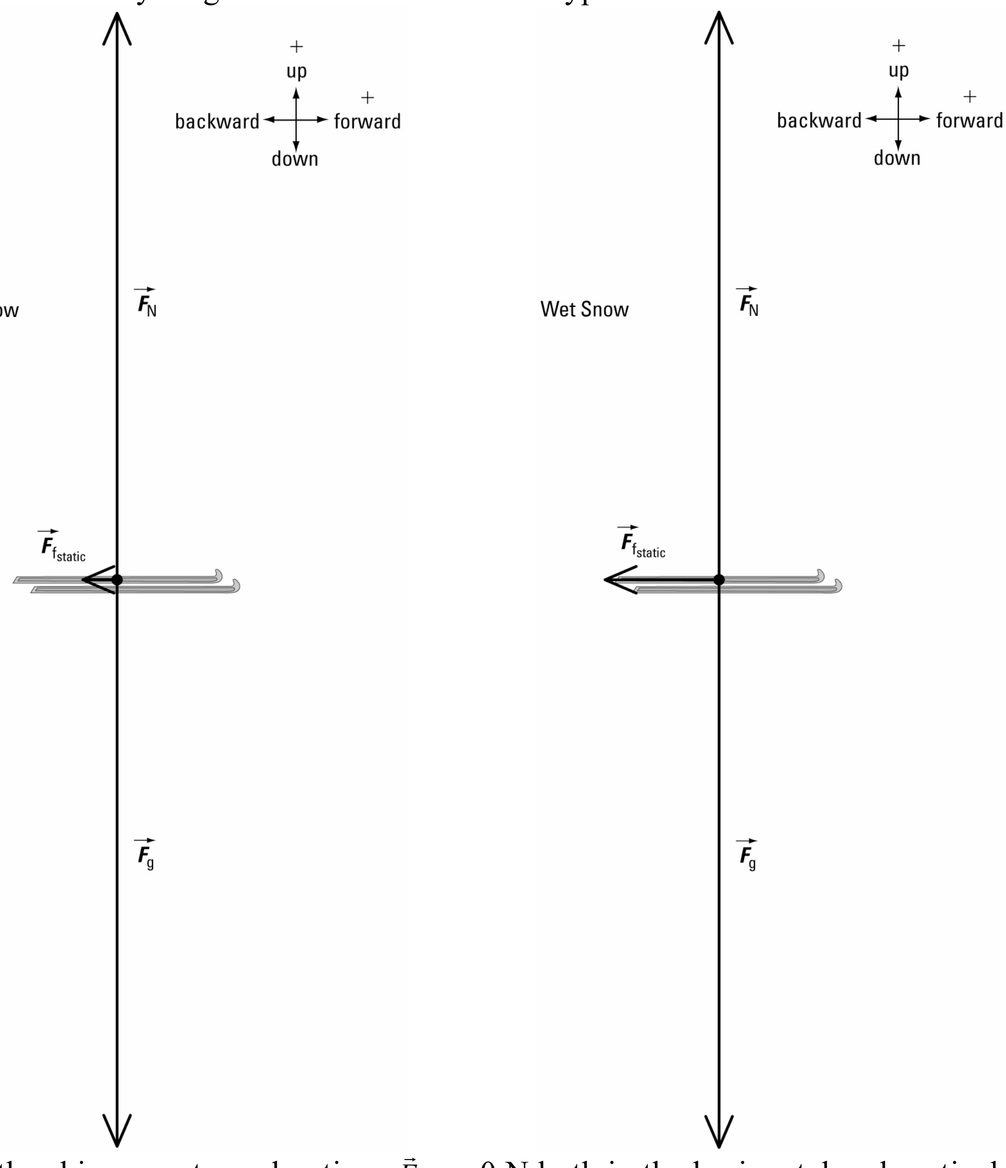
μ_s = 0.20 from Table 3.4 (waxed hickory skis on wet snow)

Required

difference in the maximum force of static friction on wet and dry snow ($\Delta \vec{F}_{f_{static}}$)

Analysis and Solution

Draw a free-body diagram for the skis on each type of surface.



Since the skis are not accelerating, $\vec{F}_{net}$ = 0 N both in the horizontal and vertical directions.

Calculate $F_{f_{static}}$ on each surface.

$$F_{f_{static}} = \mu_s F_N$$
$$= \mu_s mg$$

Dry Snow

$$F_{f_{static}} = \mu_s mg$$
$$= (0.06)(15\text{ N})$$
$$= 0.90\text{ N}$$
$$\vec{F}_{f_{static}} = 0.90\text{ N [backward]}$$

Wet Snow

$$F_{f_{static}} = \mu_s mg$$
$$= (0.20)(15\text{ N})$$
$$= 3.0\text{ N}$$
$$\vec{F}_{f_{static}} = 3.0\text{ N [backward]}$$

Calculate the difference between the two values of $F_{f_{static}}$.

$$\Delta F_{f_{static}} = 3.0\text{ N} - 0.90\text{ N}$$
$$= 2\text{ N}$$
$$\Delta \vec{F}_{f_{static}} = 2\text{ N [backward]}$$

Paraphrase

The difference in the maximum force of static friction on wet and dry snow is 2 N [backward].

5. ***Given***

$\vec{F}_{app} = 31$ N [forward]

$\vec{g} = 9.81$ m/s^2 [down]

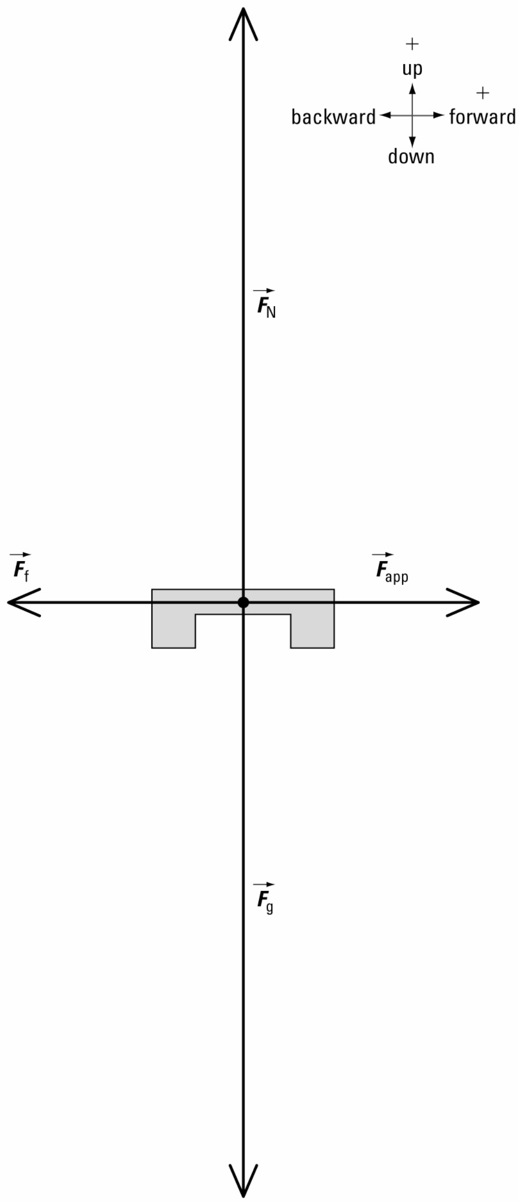
$m = 8.0$ kg

Required

coefficient of static friction (μ_s)

Analysis and Solution

Draw a free-body diagram for the steel slider.



Since the slider is not accelerating, $\vec{F}_{net} = 0$ N in both the horizontal and vertical directions.

Write equations to find the net force on the slider in both directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_{app} + \vec{F}_{f_{static}}$$
$$F_{net_h} = F_{app} + F_{f_{static}}$$
$$0 = 31\text{ N} + (-\mu_s F_N)$$
$$= 31\text{ N} - \mu_s F_N$$
$$\mu_s F_N = 31\text{ N}$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = F_N + F_g$$
$$0 = F_N + (-mg)$$
$$= F_N - mg$$
$$F_N = mg$$

Substitute $F_N = mg$ into the last equation for the horizontal direction.

$$\mu_s mg = 31\ \text{N}$$

$$\mu_s = \frac{31\ \text{N}}{mg}$$

$$= \frac{31\ \text{N}}{(8.0\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}$$

$$= \frac{31\ \cancel{\text{kg}} \bullet \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}}{\left(8.0\ \cancel{\text{kg}}\right)\left(9.81\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}$$

$$= 0.40$$

Paraphrase

The coefficient of static friction for the steel slider on the steel rail is 0.40.

6. ***Given***

$\vec{F}_g$ = 2350 N [down] $\qquad$ $\vec{g}$ = 9.81 m/s^2 [down]

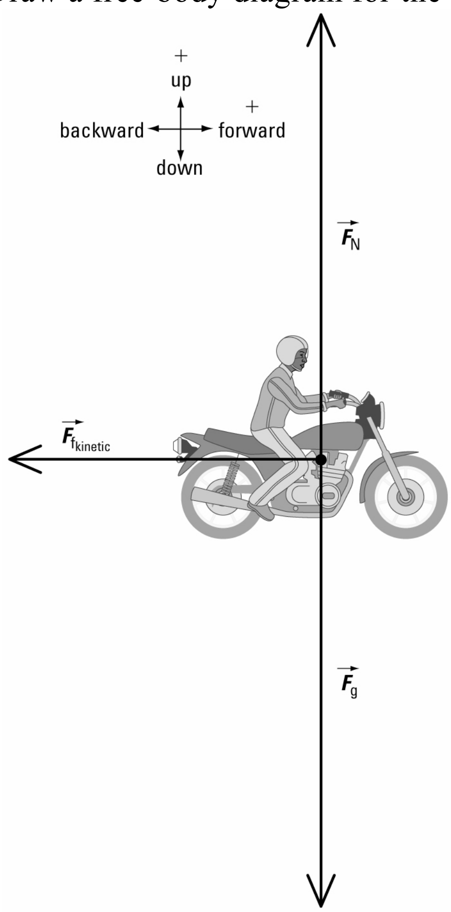
μ_k = 0.7 from Table 3.4 (rubber tires on dry concrete)

Required

force of kinetic friction ($\vec{F}_{f_{kinetic}}$)

Analysis and Solution

Draw a free-body diagram for the biker-bike system.



Since the system is skidding, $\vec{F}_{net} \neq 0$ N in the horizontal direction, but $\vec{F}_{net} = 0$ N in the vertical direction.

Calculate $F_{f_{kinetic}}$.

$$
\begin{aligned}
F_{f_{kinetic}} &= \mu_k F_N \\
&= \mu_k mg \\
&= (0.7)(2350 \text{ N}) \\
&= 2 \times 10^3 \text{ N} \\
\vec{F}_{f_{kinetic}} &= 2 \times 10^3 \text{ N [backward]}
\end{aligned}
$$

Paraphrase

The force of kinetic friction on the biker-bike system is 2×10^3 N [backward].

7. ***Given***

$m = 15$ kg

$\mu_s = 0.45$

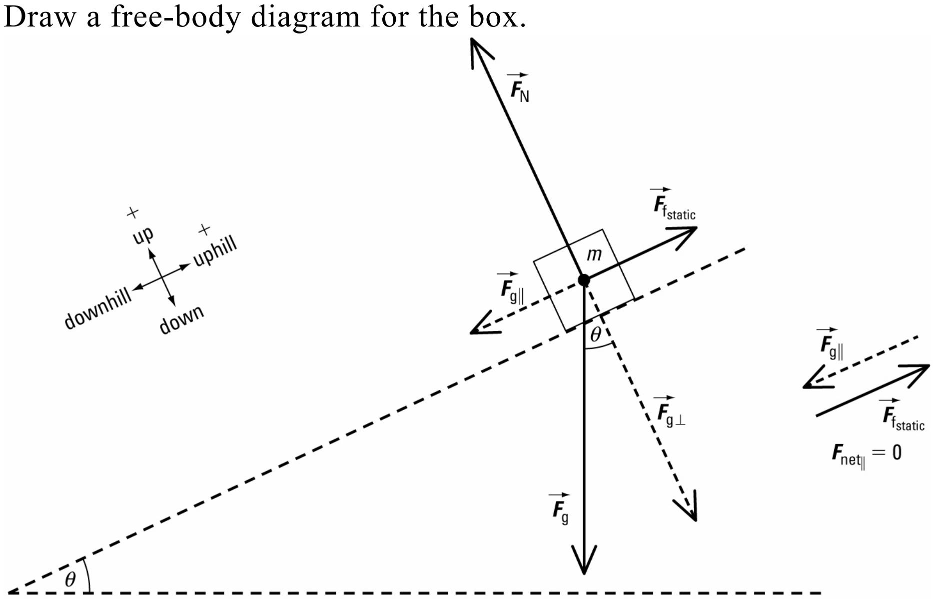
$g = 9.81$ m/s^2

Required

maximum angle of the incline (θ)

Analysis and Solution

Draw a free-body diagram for the box.



Since the box is not accelerating, $\vec{F}_{net} = 0$ N both parallel and perpendicular to the incline.

$\vec{F}_{f_{static}}$ prevents the box from sliding downhill. So $\vec{F}_{f_{static}}$ is directed uphill.

Write equations to find the net force on the box in both directions.

$\perp$ direction

$$
\begin{aligned}
\vec{F}_{net\perp} &= \vec{F}_N + \vec{F}_{g\perp} \\
F_{net\perp} &= F_N + F_{g\perp} \\
0 &= F_N + F_{g\perp}
\end{aligned}
$$

$\parallel$ direction

$$
\begin{aligned}
\vec{F}_{net\parallel} &= \vec{F}_{g\parallel} + \vec{F}_{f_{static}} \\
F_{net\parallel} &= F_{g\parallel} + F_{f_{static}} \\
0 &= F_{g\parallel} + F_{f_{static}}
\end{aligned}
$$

$$F_N = -F_{g\perp} \qquad F_{f_{static}} = -F_{g\parallel}$$

Now, $F_{g\perp} = -mg\cos\theta \qquad F_{g\parallel} = -mg\sin\theta$ and $F_{f_{static}} = \mu_s F_N$

So, $F_N = -(-mg\cos\theta) = mg\cos\theta \qquad \mu_s F_N = -(-mg\sin\theta) = mg\sin\theta$

Substitute $F_N = mg\cos\theta$ into the last equation for the || direction.

$$\mu_s(\cancel{mg}\cos\theta) = \cancel{mg}\sin\theta$$

$$\mu_s\cos\theta = \sin\theta$$

$$\mu_s = \frac{\sin\theta}{\cos\theta}$$

$$\mu_s = \tan\theta$$

$$0.45 = \tan\theta$$

$$\theta = \tan^{-1}(0.45) = 24°$$

Paraphrase

The maximum angle of the incline before the box starts to move is 24°.

8. ***Given***

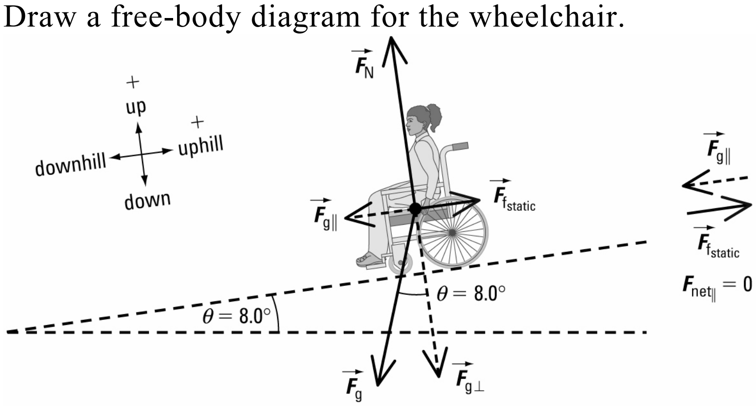
$\mu_s = 0.10$
$m = 85$ kg
$\theta = 8.0°$
$g = 9.81$ m/s^2

Required

determine if wheelchair will move

Analysis and Solution

Draw a free-body diagram for the wheelchair.



Since the wheelchair is not accelerating, $\vec{F}_{net} = 0$ N both parallel and perpendicular to the incline.

$\vec{F}_{f_{static}}$ prevents the wheelchair from sliding downhill. So $\vec{F}_{f_{static}}$ is directed uphill.

Write equations to find the net force on the wheelchair in both directions.

$\perp$ direction

$$\vec{F}_{net\perp} = \vec{F}_N + \vec{F}_{g\perp}$$

$$F_{net\perp} = F_N + F_{g\perp}$$

|| direction

$$\vec{F}_{net\parallel} = \vec{F}_{g\parallel} + \vec{F}_{f_{static}}$$

$$F_{net\parallel} = F_{g\parallel} + F_{f_{static}}$$

$$0 = F_N + F_{g\perp} \qquad\qquad 0 = F_{g\parallel} + F_{f_{static}}$$

$$F_N = -F_{g\perp} \qquad\qquad F_{f_{static}} = -F_{g\parallel}$$

Now, $F_{g\perp} = -mg\cos\theta$ $\qquad$ $F_{g\parallel} = -mg\sin\theta$ and $F_{f_{static}} = \mu_s F_N$

So, $\quad F_N = -(-mg\cos\theta) = mg\cos\theta$ $\qquad$ $\mu_s F_N = -(-mg\sin\theta) = mg\sin\theta$

Substitute $F_N = mg\cos\theta$ into the last equation for the || direction.

$$\mu_s(\cancel{mg}\cos\theta) = \cancel{mg}\sin\theta$$

$$\mu_s\cos\theta = \sin\theta$$

$$\mu_s = \frac{\sin\theta}{\cos\theta}$$

$$\mu_s = \tan\theta$$

$$0.10 = \tan\theta$$

$$\theta = \tan^{-1}(0.10) = 5.7°$$

In order for the wheelchair to remain stationary, $\theta \leq 5.7°$. The given value of θ is greater than 5.7°.

Paraphrase

An angle of 8.0° will not prevent the wheelchair from moving.

9. ***Given***

m

$\theta = 10.0°$

$\mu_s = 0.30$

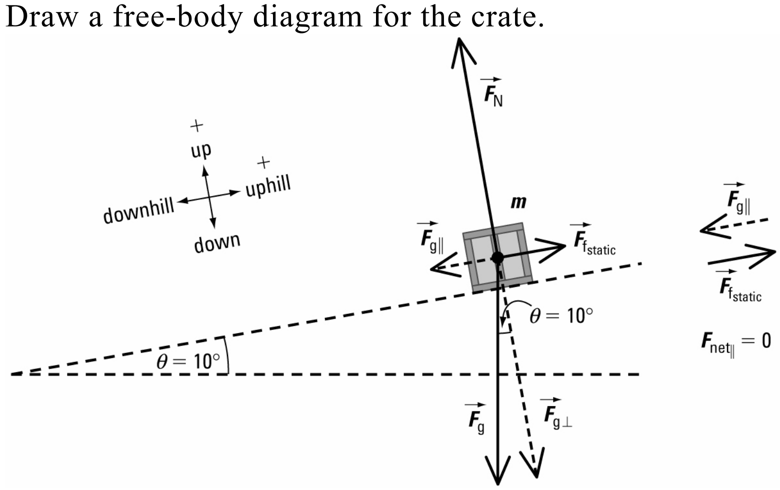
$g = 9.81 \text{ m/s}^2$

Required

maximum acceleration uphill ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the crate.



Since the crate is not accelerating, $\vec{F}_{net} = 0$ N both parallel and perpendicular to the incline.

Write equations to find the net force on the crate in both directions.

$\perp$ direction

$$\vec{F}_{\text{net}\perp} = \vec{F}_{\text{N}} + \vec{F}_{\text{g}\perp}$$
$$F_{\text{net}\perp} = F_{\text{N}} + F_{\text{g}\perp}$$
$$0 = F_{\text{N}} + F_{\text{g}\perp}$$
$$F_{\text{N}} = -F_{\text{g}\perp}$$

Now, $F_{\text{g}\perp} = -mg\cos\theta$

So, $F_{\text{N}} = -(-mg\cos\theta)$
$= mg\cos\theta$

|| direction

$$\vec{F}_{\text{net}\,||} = \vec{F}_{\text{g}\,||} + \vec{F}_{\text{f}_{\text{static}}}$$
$$F_{\text{net}\,||} = F_{\text{g}\,||} + F_{\text{f}_{\text{static}}}$$
$$ma = F_{\text{g}\,||} + F_{\text{f}_{\text{static}}}$$

$F_{\text{g}\,||} = -mg\sin\theta$ and $F_{\text{f}_{\text{static}}} = \mu_{\text{s}}F_{\text{N}}$

$ma = -mg\sin\theta + \mu_{\text{s}}F_{\text{N}}$

Substitute $F_{\text{N}} = mg\cos\theta$ into the last equation for the || direction.

$$\cancel{m}\,a = -\cancel{m}\,g\sin\theta + \mu_{\text{s}}\cancel{m}\,g\cos\theta$$
$$a = g(\mu_{\text{s}}\cos\theta - \sin\theta)$$
$$= (9.81\ \text{m/s}^2)\{(0.30)(\cos 10.0°) - \sin 10.0°\}$$
$$= 1.2\ \text{m/s}^2$$
$$\vec{a} = 1.2\ \text{m/s}^2\ [\text{uphill}]$$

Paraphrase

The maximum acceleration uphill is 1.2 m/s^2 [uphill].

10. ***Given***

$m = 400$ kg

$\vec{g} = 9.81\ \text{m/s}^2$ [down]

$\vec{v}_{\text{i}} = 4.0$ m/s [N]

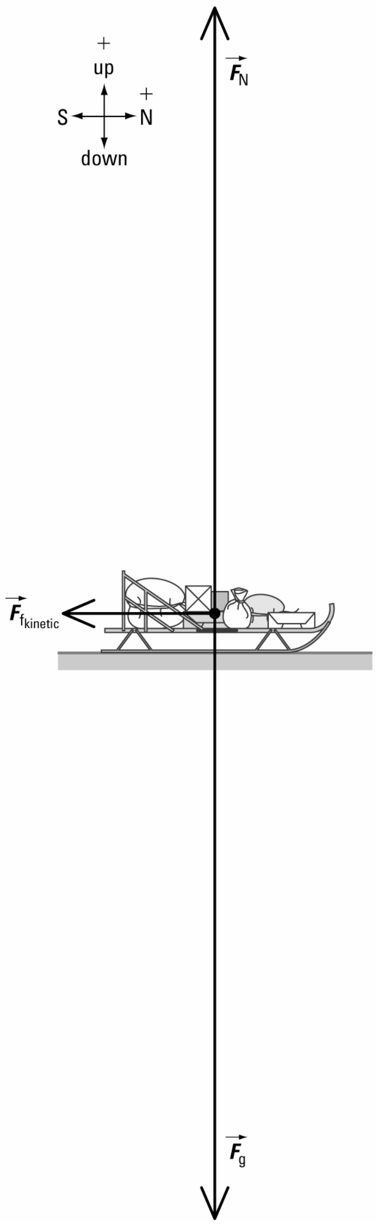
$\mu_{\text{k}} = 0.0500$

Required

coasting distance of sled (d)

Analysis and Solution

Draw a free-body diagram for the sled.



Since the sled is coasting, $\vec{F}_{net} \neq 0$ N in the horizontal direction, but $\vec{F}_{net} = 0$ N in the vertical direction.

Write equations to find the net force on the sled in both directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_{f_{kinetic}}$$
$$F_{net_h} = F_{f_{kinetic}}$$
$$ma = -\mu_k F_N$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = F_N + F_g$$
$$0 = F_N + (-mg)$$
$$= F_N - mg$$
$$F_N = mg$$

Substitute $F_N = mg$ into the last equation for the horizontal direction.

$$\cancel{m}a = -\mu_k \cancel{m} g$$

$$\begin{aligned} a &= -\mu_k g \\ &= -(0.0500)(9.81\ \text{m/s}^2) \\ &= -0.49\ \text{m/s}^2 \\ \vec{a} &= 0.49\ \text{m/s}^2\ [\text{S}] \end{aligned}$$

Since the sled coasts to a stop, calculate the coasting distance of the sled.

$$\begin{aligned} (v_f)^2 &= (v_i)^2 + 2ad \\ 0 &= (v_i)^2 + 2ad \\ 2ad &= -(v_i)^2 \\ d &= \frac{-(v_i)^2}{2a} \\ &= \frac{-(4.0\ \text{m/s})^2}{2(-0.49\ \text{m/s}^2)} \\ &= 16\ \text{m} \end{aligned}$$

Paraphrase

The sled will coast for 16 m before it stops.

Extensions

11. ***Given***

$\vec{F}_{app} = 120$ N [12.0°]

$m = 35$ kg

$\mu_k = 0.30$

$\vec{g} = 9.81\ \text{m/s}^2$ [down]

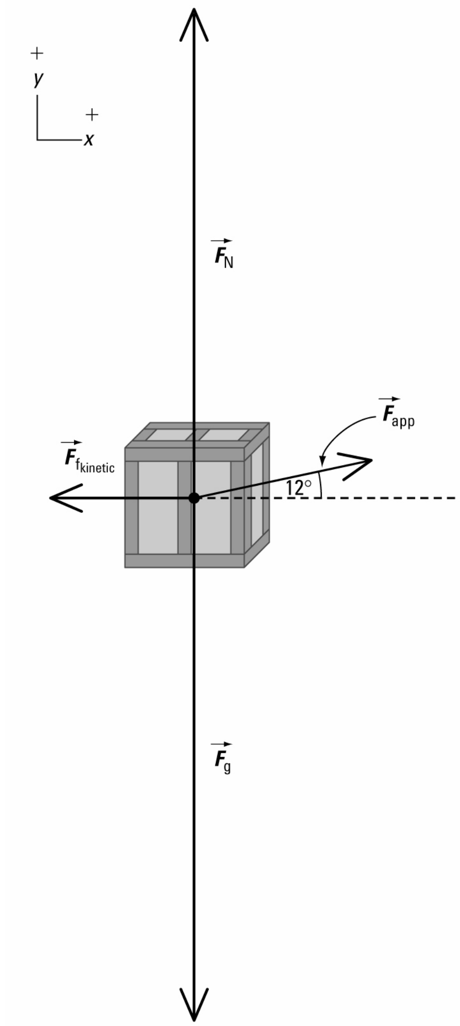
$\vec{v}_f = 1.2$ m/s [0°]

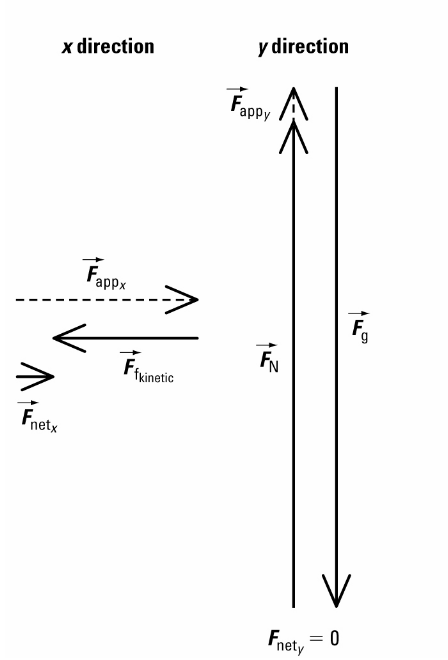
Required

elapsed time (Δt)

Analysis and Solution

Draw a free-body diagram for the crate.





Resolve $\vec{F}_{app}$ into x and y components.

Vector	x component	y component
$\vec{F}_{app}$	(120 N)(cos 12.0°)	(120 N)(sin 12.0°)

Since the crate is accelerating in the x direction, $F_{net_x} \neq 0$ N but $F_{net_y} = 0$ N.

Write equations to find the net force on the crate in the x and y directions.

x direction

$$\vec{F}_{net_x} = \vec{F}_{app_x} + \vec{F}_{f_{kinetic}}$$

$$F_{net_x} = F_{app_x} + F_{f_{kinetic}}$$

$$\begin{aligned} ma &= (120\text{ N})(\cos 12.0°) + (-\mu_k F_N) \\ &= (120\text{ N})(\cos 12.0°) - \mu_k F_N \end{aligned}$$

y direction

$$\vec{F}_{net_y} = \vec{F}_N + \vec{F}_{app_y} + \vec{F}_g$$

$$F_{net_y} = F_N + F_{app_y} + F_g$$

$$\begin{aligned} 0 &= F_N + (120\text{ N})(\sin 12.0°) + (-mg) \\ F_N &= mg - (120\text{ N})(\sin 12.0°) \\ &= (35\text{ kg})(9.81\text{ m/s}^2) \\ &\quad - (120\text{ N})(\sin 12.0°) \\ &= 318\text{ N} \end{aligned}$$

Substitute F_N = 318 N into the last equation for the x direction.

$$ma = (120 \text{ N})(\cos 12.0°) - (0.30)(318 \text{ N})$$
$$= 21.9 \text{ N}$$
$$a = \frac{21.9 \text{ N}}{35 \text{ kg}}$$
$$= 0.625 \text{ m/s}^2$$

The crate is accelerating along the 0° direction.

$$\vec{a} = 0.625 \text{ m/s}^2 \text{ [0°]}$$

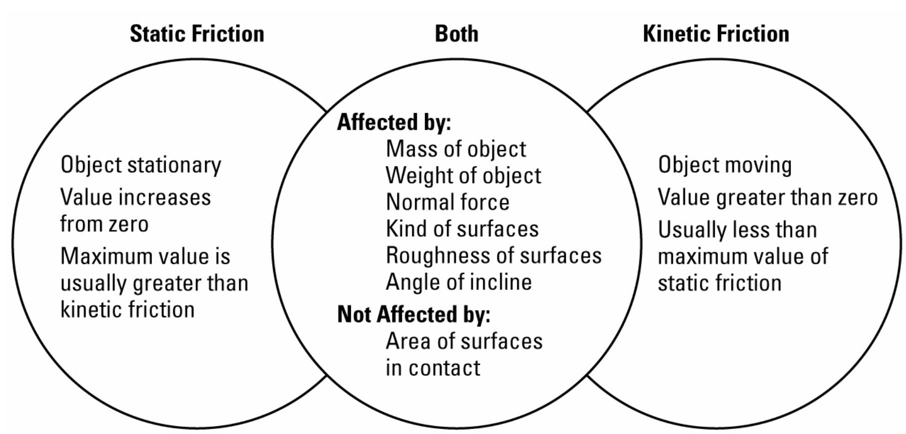
Calculate the elapsed time.

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$0.625 \text{ m/s}^2 = \frac{1.2 \text{ m/s} - 0}{\Delta t}$$
$$\Delta t = \frac{1.2 \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}}{0.625 \dfrac{\cancel{\text{m}}}{\text{s}^{\cancel{2}}}}$$
$$= 1.9 \text{ s}$$

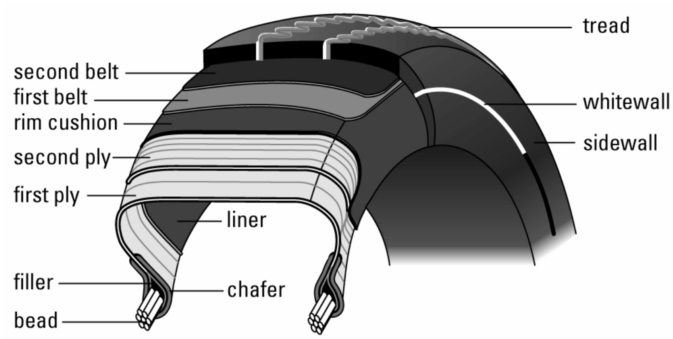
Paraphrase

The elapsed time will be 1.9 s.

12.

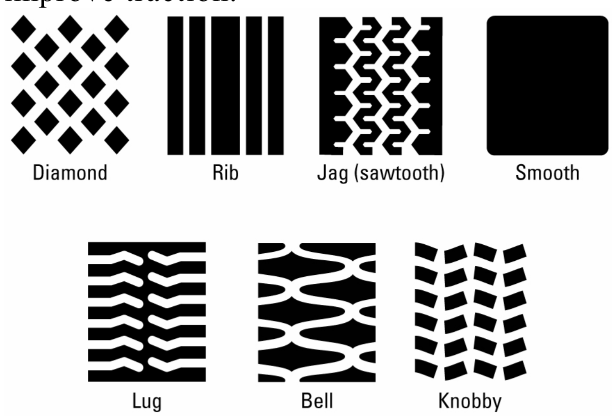


13. A tire is made up of natural and synthetic rubber, synthetic fabrics and chemicals, and possibly metal, and is designed to provide traction, cushion road shock, and carry a load under any condition.



Traction is the force of friction, exerted by the tire tread on a road surface, that provides grip. Traction is determined by measuring the force needed to start dragging a tire over a road surface. This force depends on the temperature of the road surface and the tire, and the nature of the road surface, e.g., dry concrete, dry asphalt, packed snow, black ice, or a surface covered with a layer of water. Coefficients of static and kinetic friction are measured for different tire tread patterns and surfaces using the equation $\mu = \frac{F_{\mathrm{f}}}{F_{\mathrm{N}}}$.

The tread is the groove design on the operating surface of the tire and is made from a mixture of many different types of natural and synthetic rubbers. The tread pattern is designed to dissipate heat, maintain contact with the road, and improve traction.



Some common tire types are slicks, snow tires, ice tires, all-season tires, and rain tires. Slicks are racing tires and have no treads in order to get the maximum amount of rubber in contact with the road. This enables the tires to dissipate heat during drag racing. Snow tires are designed to “bite” into the snow to provide better traction. Ice tires now have a winter-rubber compound, siping technologies, and an aggressive V-shaped tread design. Siping is the process of cutting small slits perpendicular to the face of the tire, which in turn creates thousands of tiny edges that improve traction and braking effectiveness. The National Safety Council performed tests on siped tires and found that there was a 22% increase in traction on snow and ice. All-season tires are tires on passenger cars that are designed for use on wet and dry surfaces, and provide traction on snow and ice. The tire must have a row of fairly

large grooves that start at the edge of the tire and extend toward the centre. At least 25% of the surface must be grooved so that the tire can "bite" through snow and provide traction.
Rain tires are used during wet conditions. They have grooves at the centre and sides that carry water away from the centre of the tire, enabling a good contact area, called the patch, with the road and minimizing hydroplaning.
Hydroplaning is the skimming effect caused by tires losing contact with a surface covered with water. If the water cannot squirt out from under the tire fast enough, the tire will float on the water surface and the driver may lose control of the vehicle.
All tires have rolling friction, the resistance of a tire as it rolls rather than slides over a road surface. The coefficient of rolling friction (μ_{rf}) can be used to calculate the amount of rolling resistance caused by the tire. The table below lists typical coefficients of rolling friction for different tires.

Tire Type	**Coefficient of Rolling Friction (μ_{rf})**
Low-rolling resistance tire	0.006–0.01
Car tire	0.015
Truck tire	0.006–0.01
Train wheel	0.001

The force required to roll a car on tires is calculated using the equation

$F_{f_{rolling}} = \mu_{rf} F_N$.

Below is a sample calculation to determine the force of rolling friction and the power used to move a car on a level road having a mass of 1814 kg and a coefficient of rolling friction of 0.015.
The weight of the car is given by $\vec{F}_g = m\vec{g}$.

$$\begin{aligned}\vec{F}_g &= (1814\ \text{kg})(9.81\ \text{m/s}^2)\\ &= 1.780 \times 10^4\ \text{N [down]}\end{aligned}$$

Since the car is not accelerating in the vertical direction, $\vec{F}_g + \vec{F}_N = 0$.
So $\vec{F}_N = mg$ [up].
The force of rolling friction acts parallel to the surface and is directed backward.

$$\begin{aligned}F_{f_{rolling}} &= \mu_{rf} F_N\\ &= (0.015)(1.780 \times 10^4\ \text{N})\\ &= 267\ \text{N}\end{aligned}$$

The power required to move the car on level ground at a particular speed is given by the equation $P = F_{f_{rolling}} v$ where v is the average speed. If the car has a speed of 100 km/h (27.8 m/s), the power to overcome rolling friction is 7.41 kW or about 10 hp.
For interesting Web sites on the topic of tires, follow the links at www.pearsoned.ca/school/physicssource.

14. A possible Inquiry Lab to determine the coefficients of static and kinetic friction for a curling stone is shown below. Students will find that μ_s is slightly greater than μ_k, and that temperature has an effect on the coefficients. They will also find that not all curling stones have exactly the same coefficients on the same surface. That is why professional curlers always check their set of eight stones before a competition.

Question

What are the coefficients of static and kinetic friction on a curling stone on ice? How does the ice temperature affect these coefficients?

Hypothesis

State a hypothesis relating the value of μ_s to μ_k. State another hypothesis relating the ice temperature to the coefficients of friction.

Variables

Read the procedure and identify the controlled, manipulated, and responding variable(s).

Materials

balance
thermometer
string
spring scale of appropriate range

Procedure

1. Determine the mass of the curling stone and calculate its weight in newtons.
2. Place the curling stone on the icy surface and allow its temperature to equilibrate to the ice. Measure the temperature of the ice surface.
3. Attach a durable string around the rim of the curling stone and make a loop at the end. Attach the string to the spring scale.
4. Pull gently, slowly increasing the force until the curling stone just begins to move. Measure the maximum value of the force of static friction in newtons just as the curling stone begins to move. Repeat the procedure several times and average the results.
5. Repeat step 4 for a curling stone being pulled at a slow constant velocity along the ice surface.
6. Have the icemaker change the temperature of the ice. Allow sufficient time for the ice to stabilize and repeat steps 2 to 5. Do this for several temperatures.
7. Average the forces of static and kinetic friction for each temperature. Determine the coefficients of static and kinetic friction.

Analysis

1. Compare the coefficients of static and kinetic friction.
2. How did the ice temperature affect the coefficients of friction?
3. What would be the ideal ice temperature to make a curling stone slide the fastest?
4. Design and conduct an experiment to determine if all curling stones in a set of eight have the same coefficient of kinetic friction. Analyze your data and form a conclusion.

Chapter 3 Review

Knowledge

1. ***Given***

$\vec{F}_A = 300$ N [E]　　$\vec{F}_B = 350$ N [E]

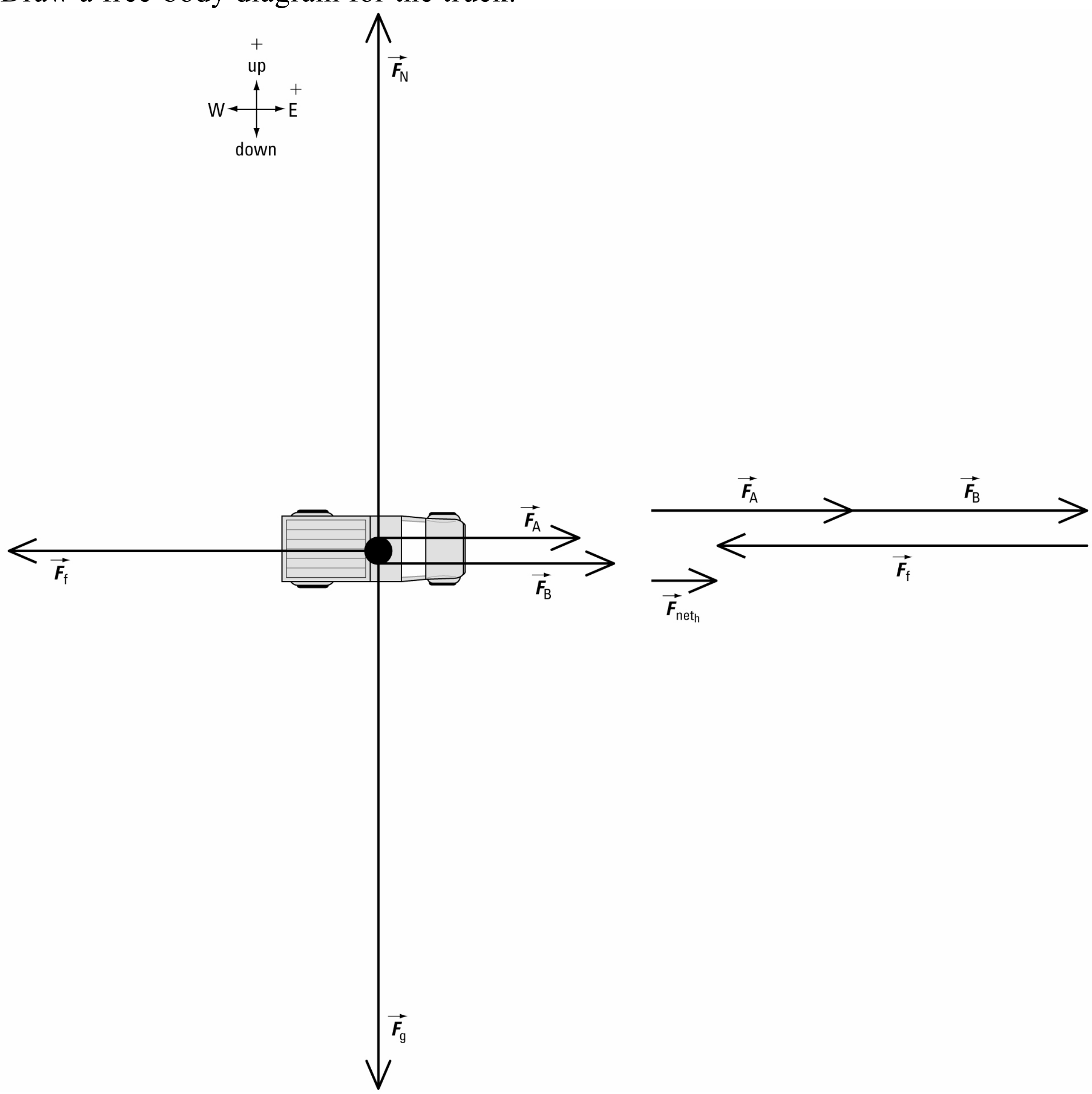
$m = 2000$ kg　　$\vec{F}_f = 550$ N [W]

Required

acceleration of truck ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the truck.



The truck is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the truck in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{\text{net}_h} = \vec{F}_A + \vec{F}_B + \vec{F}_f$$

$$\begin{aligned} F_{\text{net}_h} &= F_A + F_B + F_f \\ &= 300\text{ N} + 350\text{ N} + (-550\text{ N}) \\ &= 300\text{ N} + 350\text{ N} - 550\text{ N} \\ &= 100\text{ N} \end{aligned}$$

vertical direction

$$\vec{F}_{\text{net}_v} = \vec{F}_N + \vec{F}_g$$

$$F_{\text{net}_v} = 0$$

Calculations in the vertical direction are not required in this problem.

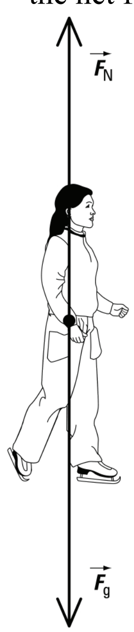
Apply Newton's second law to the horizontal direction.

$$\begin{aligned} F_{\text{net}_h} &= m\,a \\ a &= \frac{F_{\text{net}_h}}{m} \\ &= \frac{100\text{ N}}{2000\text{ kg}} \\ &= \frac{100\ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{2000\ \cancel{\text{kg}}} \\ &= 5.00 \times 10^{-2}\text{ m/s}^2 \\ \vec{a} &= 5.00 \times 10^{-2}\text{ m/s}^2\text{ [E]} \end{aligned}$$

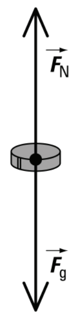
Paraphrase

The truck will have an acceleration of 5.00×10^{-2} m/s^2 [E].

2. (a) A figure skater during a glide travels at constant velocity. Newton's first law states that an object will continue being at rest or moving at constant velocity unless acted upon by an external non-zero net force. Since the ice can be considered frictionless, the net force on the figure skater is zero and the skater's velocity remains constant.



(b) A hockey puck during a cross-ice pass travels at constant velocity. Since the ice can be considered frictionless, the net force on the hockey puck is zero and the velocity of the puck remains constant.



3. If a transport truck pulls a trailer with a force of 1850 N [E], according to Newton's third law, the trailer exerts a force of 1850 N [W] on the truck.

4. If the driver presses the accelerator too hard, the tires will spin, causing the snow beneath the tires to melt. This watery layer will make it even more difficult for the tires to exert any frictional force on the snow. Also, when the tires spin, kinetic friction is present, not static friction. Since μ_k is usually less than μ_s, the traction that the tires will have with the snow will be reduced. In general, it is better to use lower gears and to gently press the accelerator so that the tires can exert the maximum force of friction on the snow.

Applications

5. (a) ***Given***

$\vec{F}_{T_1}$ $\quad\quad$ $\vec{F}_{T_2}$

$\theta_1 = 45.0°$ $\quad\quad$ $\theta_2 = 45.0°$

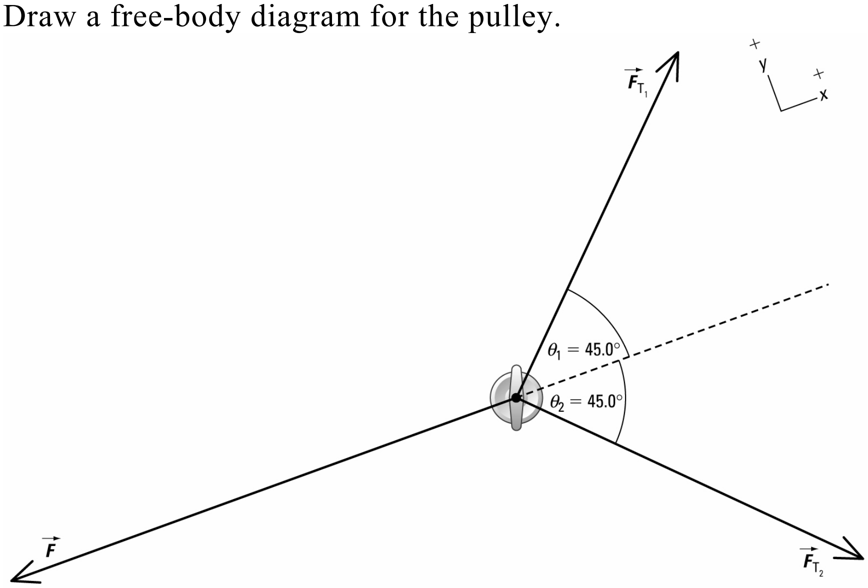
$m = 3.0$ kg $\quad\quad$ $\vec{g} = 9.81 \text{ m/s}^2$ [down]

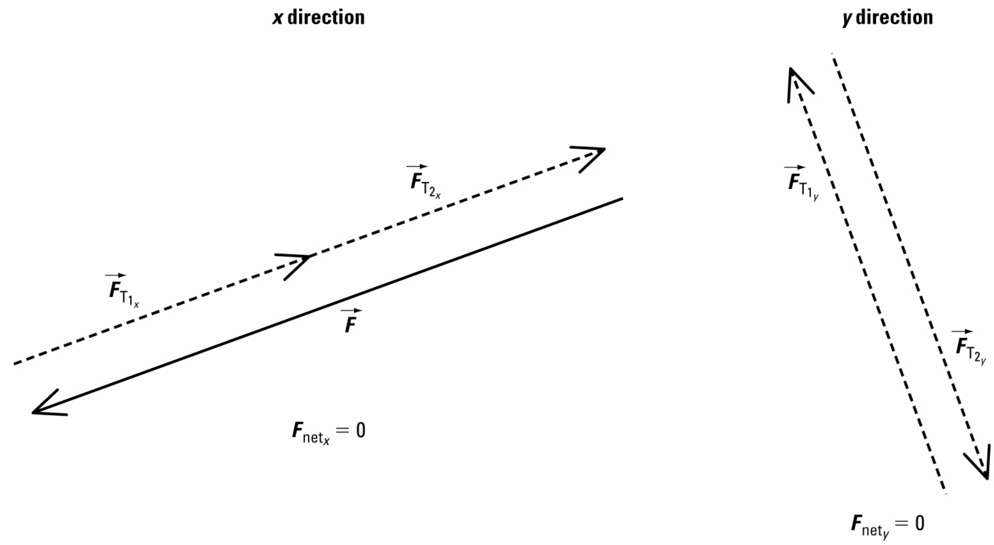
Required

force exerted by foot ($\vec{F}$)

Analysis and Solution

Draw a free-body diagram for the pulley.





Resolve all given forces into x and y components.

Vector	***x* component**	***y* component**
$\vec{F}_{T_1}$	$F_{T_1}(\cos 45.0°)$	$F_{T_1}(\sin 45.0°)$
$\vec{F}_{T_2}$	$F_{T_2}(\cos 45.0°)$	$-F_{T_2}(\sin 45.0°)$

The rope has a negligible mass. So the tension in the rope is the same on both sides of the pulley.

$$F_{T_1} = F_{T_2}$$

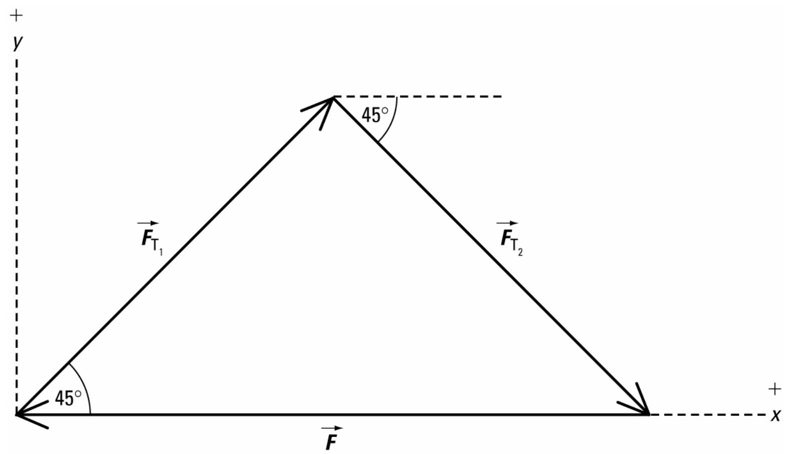
The hanging object will provide the tension in the rope.

$$\begin{aligned} F_{T_1} &= mg \\ &= (3.0\text{ kg})(9.81\text{ m/s}^2) \\ &= 29.4\ \frac{\text{kg•m}}{\text{s}^2} \\ &= 29.4\text{ N} \end{aligned}$$

Since the hanging object is not accelerating, the net force in both the x and y directions is zero.

$$F_{net_x} = F_{net_y} = 0\text{ N}$$

Add the x and y components of all force vectors in the vector addition diagram.



x direction

$$\vec{F}_{\text{net}_x} = \vec{F}_{T_{1x}} + \vec{F}_{T_{2x}} + \vec{F}$$

$$F_{\text{net}_x} = F_{T_{1x}} + F_{T_{2x}} + F$$

$$0 = 2(29.4\text{ N})(\cos 45.0°) + F$$

$$F = -42\text{ N}$$

y direction

$$\vec{F}_{\text{net}_y} = \vec{F}_{T_{1y}} + \vec{F}_{T_{2y}}$$

$$F_{\text{net}_y} = 0$$

Calculations in the vertical direction are not required in this problem.

From the vector addition diagram,
$\vec{F}$ is directed along the rope connecting the foot to the pulley, which is also along the negative *x*-axis.

$\vec{F}$ = 42 N [along rope connecting foot to pulley]

Paraphrase

The foot exerts a force of 42 N [along rope connecting foot to pulley].

(b) If θ_1 and θ_2 decrease, the magnitude of $\vec{F}$ will increase because the *x* components of $\vec{F}_{T_1}$ and $\vec{F}_{T_2}$ will increase.

6. ***Given***

m_s = 255 kg m_p = 98 kg m_b = 97 kg

$\vec{F}_A$ = 1200 N [forward] $\vec{F}_f$ = 400 N [backward]

$\vec{a}$ = 4.4 m/s^2 [forward]

Required

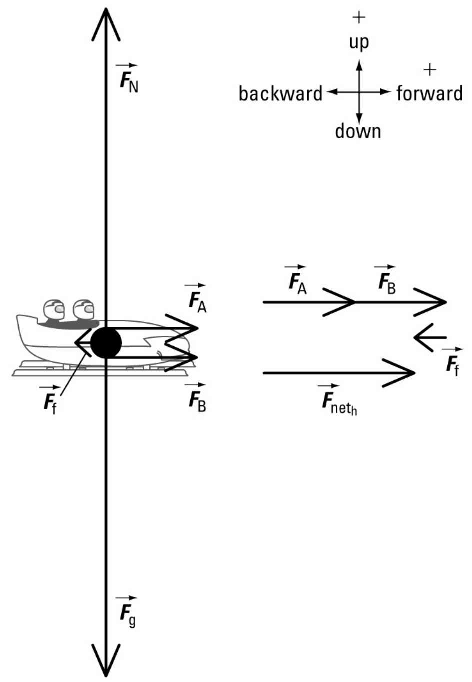
average force exerted by rider B ($\vec{F}_B$)

Analysis and Solution

The bobsled, pilot, and brakeman are a system because they move together as a unit. Find the total mass of the system.

$$\begin{aligned} m_T &= m_s + m_p + m_b \\ &= 255\text{ kg} + 98\text{ kg} + 97\text{ kg} \\ &= 450\text{ kg} \end{aligned}$$

Draw a free-body diagram for the system.



The system is not accelerating up or down. So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the system in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_A + \vec{F}_B + \vec{F}_f$$
$$F_{net_h} = F_A + F_B + F_f$$

Apply Newton's second law to the horizontal direction.

$$\begin{aligned} m_T a &= F_A + F_B + F_f \\ F_B &= m_T a - F_A - F_f \\ &= (450 \text{ kg})(4.4 \text{ m/s}^2) - 1200 \text{ N} - (-400 \text{ N}) \\ &= (450 \text{ kg})(4.4 \text{ m/s}^2) - 1200 \text{ N} + 400 \text{ N} \\ &= 1.2 \times 10^3 \text{ N [forward]} \\ \vec{F}_B &= 1.2 \times 10^3 \text{ N [forward]} \end{aligned}$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = 0$$

Calculations in the vertical direction are not required in this problem.

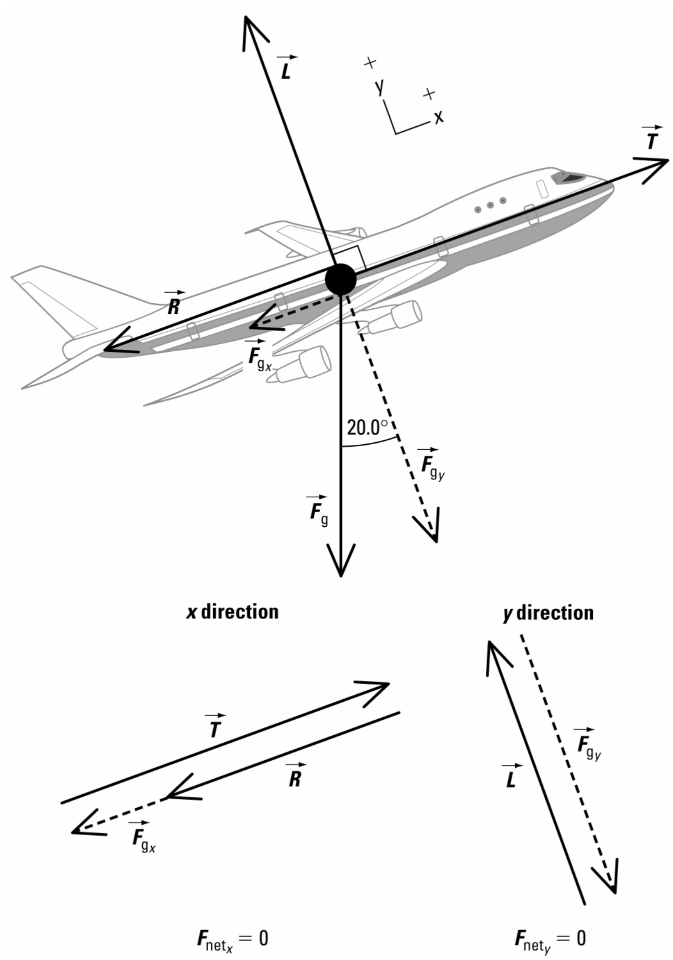
Paraphrase

Rider B exerts an average force of 1.2×10^3 N [forward].

7. *Given*

$m = 4.0 \times 10^5$ kg
$\theta = 20.0°$
$\vec{T} = 4.60 \times 10^6$ N [forward]
$\vec{a} = 0$ m/s^2
$\vec{g} = 9.81$ m/s^2 [down]

Required
magnitudes of $\vec{L}$ and $\vec{R}$
Analysis and Solution
Draw a free-body diagram for the jet.



Resolve all given forces into x and y components.

Vector	x component	y component
$\vec{T}$	4.60×10^6 N	0
$\vec{F}_g$	$-mg(\sin 20.0°)$	$-mg(\cos 20.0°)$

Since the jet is not accelerating, the net force in both the x and y directions is zero.

$$F_{net_x} = F_{net_y} = 0 \text{ N}$$

Add the x and y components of all force vectors in the vector addition diagram.

x direction

$$\vec{F}_{net_x} = \vec{T} + \vec{R} + \vec{F}_{g_x}$$

$$F_{net_x} = T + R + F_{g_x}$$

y direction

$$\vec{F}_{net_y} = \vec{L} + \vec{F}_{g_y}$$

$$F_{net_y} = L + F_{g_y}$$

$0 = 4.60 \times 10^6$ N $+ R + \{-mg(\sin 20.0°)\}$
$= 4.60 \times 10^6$ N $+ R - mg(\sin 20.0°)$
$R = mg(\sin 20.0°) - 4.60 \times 10^6$ N
$= (4.0 \times 10^5 \text{ kg})(9.81 \text{ m/s}^2)(\sin 20.0°) - 4.60 \times 10^6$ N
$= -3.3 \times 10^6$ N

$0 = L + \{-mg(\cos 20.0°)\}$
$= L - mg(\cos 20.0°)$
$L = mg(\cos 20.0°)$
$= (4.0 \times 10^5 \text{ kg})(9.81 \text{ m/s}^2)(\cos 20.0°)$
$= 3.7 \times 10^6$ N

Paraphrase

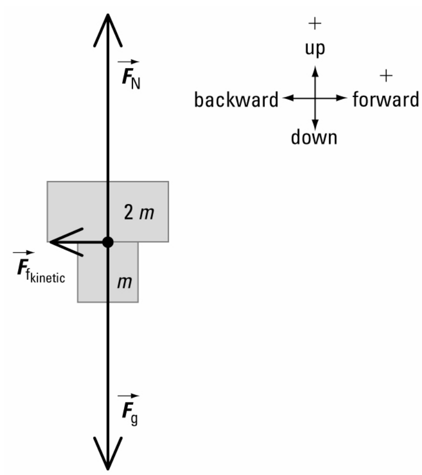
The magnitudes of $\vec{L}$ and $\vec{R}$ are 3.7×10^6 N and 3.3×10^6 N respectively.

8. ***Analysis and Solution***

From the equation $\vec{F}_{\text{f}_{\text{kinetic}}} = \mu_k F_N$, $F_{\text{f}_{\text{kinetic}}} \propto F_N$ and $F_N = mg$.

So, $F_{\text{f}_{\text{kinetic}}} \propto mg$

The free-body diagram below represents the situation of the problem.



$F_{\text{f}_{\text{kinetic}}} \propto (m + 2m)g$

$F_{\text{f}_{\text{kinetic}}} \propto 3mg$

Calculate $F_{\text{f}_{\text{kinetic}}}$.

$3F_{\text{f}_{\text{kinetic}}} = 3 \times (2.5 \text{ N})$
$= 7.5$ N

The new force of kinetic friction will be 7.5 N [backward].

9. (a) ***Given***

$m_1 = 1385$ kg $\qquad m_2 = 453$ kg

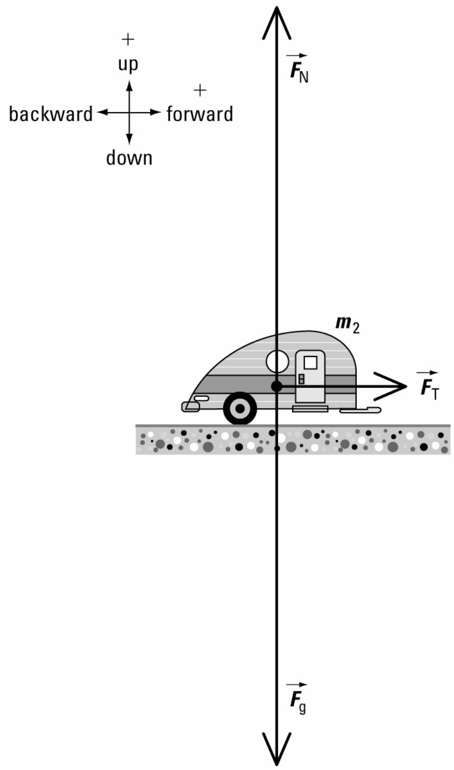
$\vec{a} = 0.75 \text{ m/s}^2$ [forward]

Required

tension in the hitch ($\vec{F}_T$)

Analysis and Solution

Draw a free-body diagram for the trailer.



The trailer is not accelerating up or down.
So in the vertical direction, F_{net_v} = 0 N.

Write equations to find the net force on the trailer in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_T$$
$$F_{net_h} = F_T$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = 0$$

Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$$m_2 a = F_T$$
$$\begin{aligned} F_T &= m_2 a \\ &= (453 \text{ kg})(0.75 \text{ m/s}^2) \\ &= 3.4 \times 10^2 \text{ N} \end{aligned}$$

Paraphrase

The tension in the hitch is 3.4×10^2 N.

(b) ***Given***

m_1 = 1385 kg $\qquad m_2$ = 453 kg

$\vec{a}$ = 0.75 m/s^2 [forward]

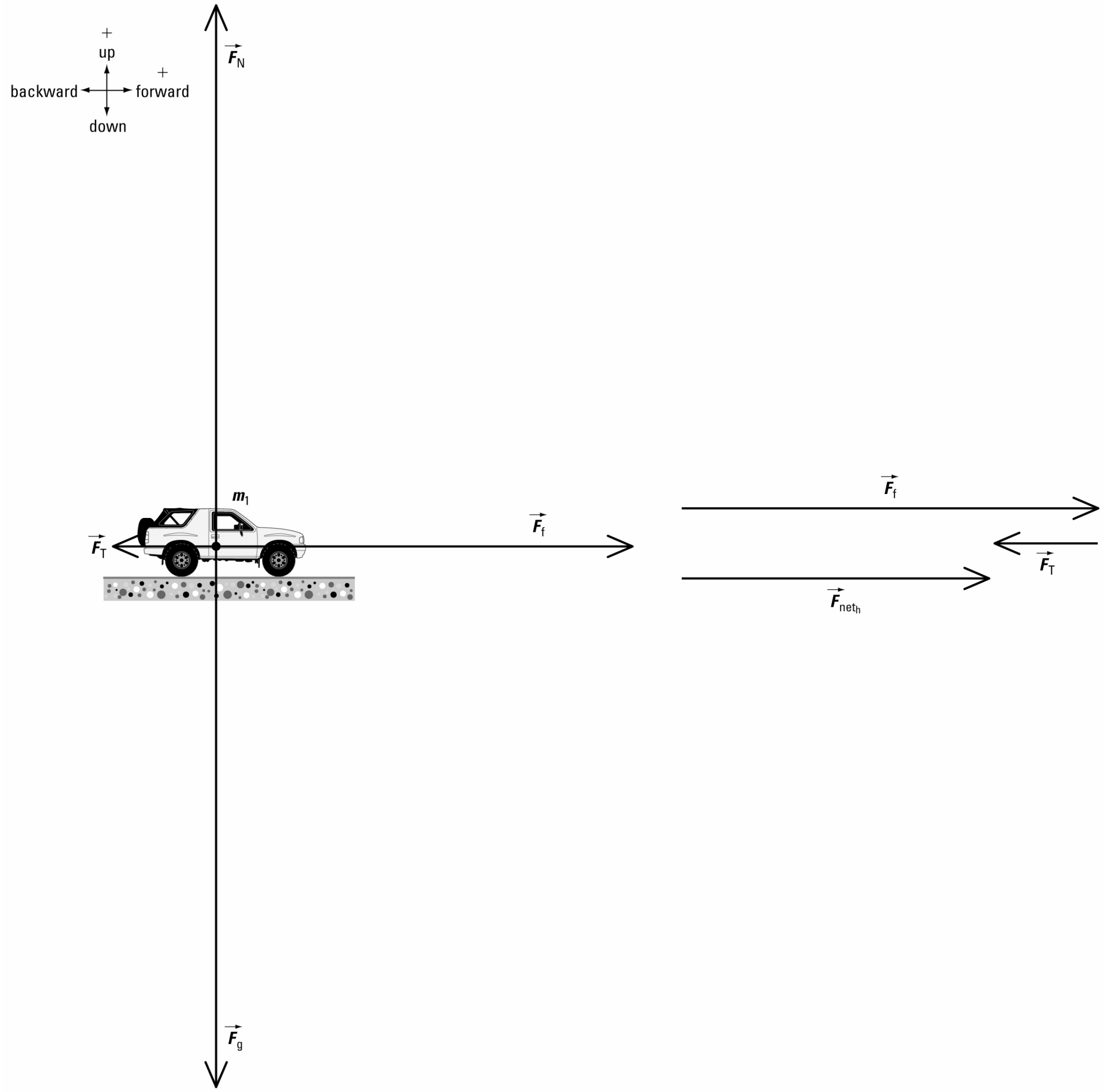
$F_T = 3.40 \times 10^2$ N from part (a)

Required

force of friction on truck ($\vec{F}_f$)

Analysis and Solution

Draw a free-body diagram for the truck.



The truck is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the truck in both the horizontal and vertical directions.

horizontal direction

$$\vec{F}_{net_h} = \vec{F}_f + \vec{F}_T$$
$$F_{net_h} = F_f + F_T$$

vertical direction

$$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$$
$$F_{net_v} = 0$$

Calculations in the vertical direction are not required in this problem.

Apply Newton's second law to the horizontal direction.

$$\begin{aligned} m_1 a &= F_f + F_T \\ F_f &= m_1 a - F_T \\ &= (1385 \text{ kg})(0.75 \text{ m/s}^2) - (-3.40 \times 10^2 \text{ N}) \\ &= (1385 \text{ kg})(0.75 \text{ m/s}^2) + 3.40 \times 10^2 \text{ N} \\ &= 1.4 \times 10^3 \text{ N} \\ \vec{F}_f &= 1.4 \times 10^3 \text{ N [forward]} \end{aligned}$$

Paraphrase

The road exerts a force of friction of 1.4×10^3 N [forward] on the truck.

(c) ***Analysis and Solution***

From the free-body diagram in part (a), $\vec{F}_T = \vec{F}_{1 \text{ on } 2}$.

Apply Newton's third law.

$$\begin{aligned} \vec{F}_{2 \text{ on } 1} &= -\vec{F}_{1 \text{ on } 2} \\ &= 3.4 \times 10^2 \text{ N [backward]} \end{aligned}$$

The trailer exerts a force of 3.4×10^2 N [backward] on the truck.

10. (a) ***Given***

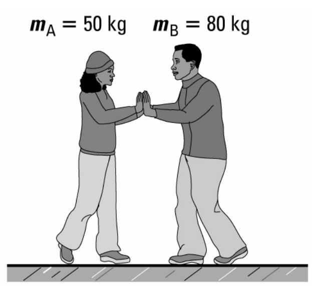
$m_A = 50$ kg

$m_B = 80$ kg

$\vec{F}_{f \text{ on A}} = 24.5$ N [E]

$\vec{F}_{f \text{ on B}} = 39.2$ N [W]

$\vec{F}_{A \text{ on B}} = 60$ N [E]

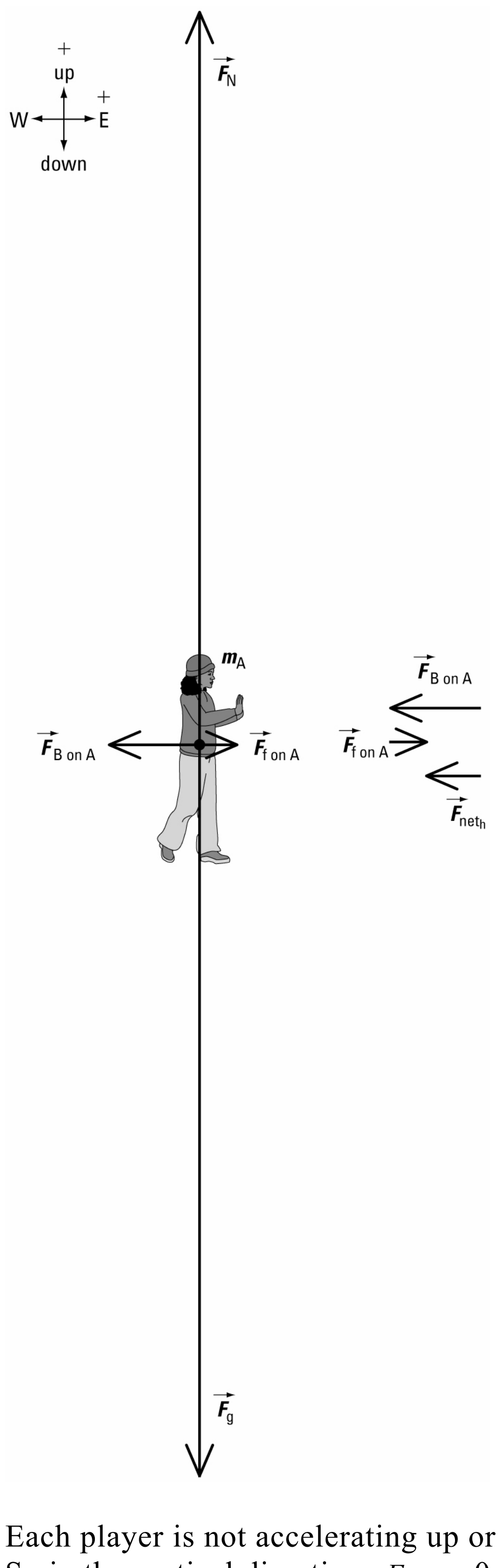


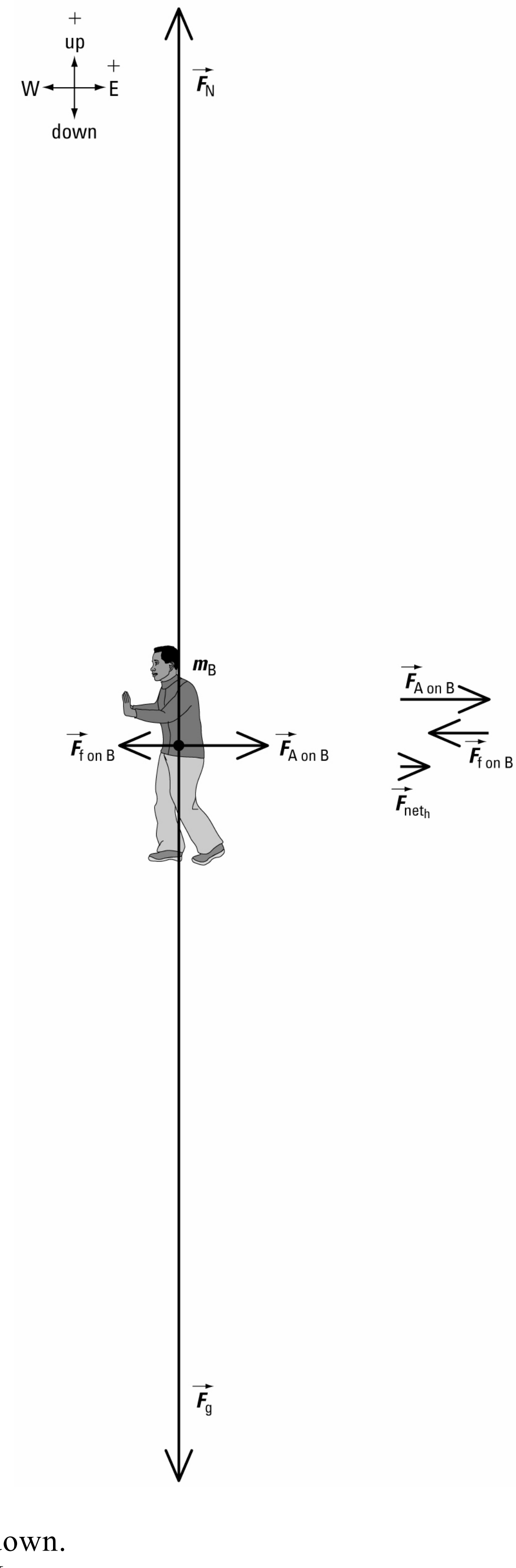
Required

net force on each player ($\vec{F}_{\text{net}_A}$ and $\vec{F}_{\text{net}_B}$)

Analysis and Solution

Draw a free-body diagram for each player.





Each player is not accelerating up or down.
So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on player A in both the horizontal and vertical directions.

horizontal direction

$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{f on A}} + \vec{F}_{\text{B on A}}$

$F_{\text{net}_\text{h}} = F_{\text{f on A}} + F_{\text{B on A}}$

vertical direction

$\vec{F}_{\text{net}_\text{v}} = \vec{F}_\text{N} + \vec{F}_\text{g}$

$F_{\text{net}_\text{v}} = 0$

Calculations in the vertical direction are not required in this problem.

Apply Newton's third law.

$\vec{F}_{\text{B on A}} = -\vec{F}_{\text{A on B}}$

Substitute $\vec{F}_{\text{B on A}}$ into the equation for F_{net_h}.

$$
\begin{aligned}
F_{\text{net}_\text{h}} &= 24.5\ \text{N} + (-60\ \text{N}) \\
&= -36\ \text{N} \\
\vec{F}_{\text{net}_\text{A}} &= 36\ \text{N [W]}
\end{aligned}
$$

Write equations to find the net force on player B in both the horizontal and vertical directions.

horizontal direction

$$
\begin{aligned}
\vec{F}_{\text{net}_\text{h}} &= \vec{F}_{\text{f on B}} + \vec{F}_{\text{A on B}} \\
F_{\text{net}_\text{h}} &= F_{\text{f on B}} + F_{\text{A on B}} \\
&= -39.2\ \text{N} + 60\ \text{N} \\
&= 21\ \text{N} \\
\vec{F}_{\text{net}_\text{B}} &= 21\ \text{N [E]}
\end{aligned}
$$

vertical direction

$\vec{F}_{\text{net}_\text{v}} = \vec{F}_\text{N} + \vec{F}_\text{g}$

$F_{\text{net}_\text{v}} = 0$

Calculations in the vertical direction are not required in this problem.

Paraphrase

The net force on player A is 36 N [W] and on player B is 21 N [E].

(b) ***Given***

$m_\text{A} = 50\ \text{kg}$ | $m_\text{B} = 80\ \text{kg}$

$\vec{F}_{\text{f on A}} = 24.5\ \text{N [E]}$ | $\vec{F}_{\text{f on B}} = 39.2\ \text{N [W]}$

$\vec{F}_{\text{A on B}} = 60\ \text{N [E]}$

$\vec{F}_{\text{net}_\text{A}} = 35.5\ \text{N [W]}$ | $\vec{F}_{\text{net}_\text{B}} = 20.8\ \text{N [E]}$ from part (a)

Required

acceleration of each player ($\vec{a}_\text{A}$ and $\vec{a}_\text{B}$)

Analysis and Solution

Apply Newton's second law to the horizontal direction for player A.

$$
\begin{aligned}
F_{\text{net}_\text{A}} &= m_\text{A} a_\text{A} \\
a_\text{A} &= \frac{F_{\text{net}_\text{A}}}{m_\text{A}} \\
&= \frac{35.5\ \text{N}}{50\ \text{kg}} \\
&= \frac{35.5\ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{50\ \cancel{\text{kg}}} \\
&= 0.71\ \text{m/s}^2 \\
\vec{a}_\text{A} &= 0.71\ \text{m/s}^2\ \text{[W]}
\end{aligned}
$$

Apply Newton's second law to the horizontal direction for player B.

$$F_{\text{net}_B} = m_B a_B$$

$$a_B = \frac{F_{\text{net}_B}}{m_B}$$

$$= \frac{20.8\ \text{N}}{80\ \text{kg}}$$

$$= \frac{20.8\ \frac{\cancel{\text{kg}}\bullet\text{m}}{\text{s}^2}}{80\ \cancel{\text{kg}}}$$

$$= 0.26\ \text{m/s}^2$$

$$\vec{a}_B = 0.26\ \text{m/s}^2\ [\text{E}]$$

Paraphrase

The acceleration of player A is 0.71 m/s^2 [W] and of player B is 0.26 m/s^2 [E].

11. ***Given***

$\vec{F}_{\text{app}} = 15$ N [S]

$\vec{F}_{\text{g}} = 40$ N [down]

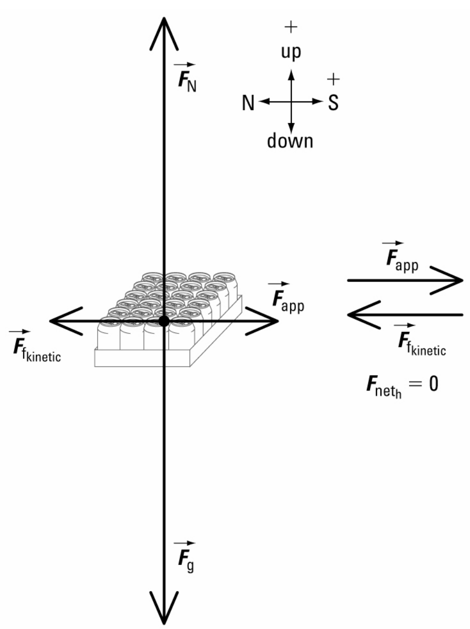
$\vec{a} = 0$ m/s^2

Required

coefficient of kinetic friction (μ_k)

Analysis and Solution

Draw a free-body diagram for the case.



Since the case is moving at constant speed, $\vec{F}_{\text{net}} = 0$ N in both the horizontal and vertical directions.

Write equations to find the net force on the case in both directions.

horizontal direction

$\vec{F}_{\text{net}_h} = \vec{F}_{\text{app}} + \vec{F}_{\text{f}_{\text{kinetic}}}$

$F_{\text{net}_h} = F_{\text{app}} + F_{\text{f}_{\text{kinetic}}}$

$0 = 15\text{ N} + (-\mu_k F_N)$

$= 15\text{ N} - \mu_k F_N$

$\mu_k F_N = 15\text{ N}$

vertical direction

$\vec{F}_{\text{net}_v} = \vec{F}_N + \vec{F}_g$

$F_{\text{net}_v} = F_N + F_g$

$0 = F_N + (-40\text{ N})$

$= F_N - 40\text{ N}$

$F_N = 40\text{ N}$

Substitute F_N = 40 N into the last equation for the horizontal direction.

$\mu_k(40\text{ N}) = 15\text{ N}$

$\mu_k = \dfrac{15\cancel{\text{ N}}}{40\cancel{\text{ N}}}$

$= 0.38$

Paraphrase

The coefficient of kinetic friction for the case on the counter is 0.38.

12. ***Given***

m_c = 1450 kg

m_t = 454 kg

$\vec{F}_{\text{air}}$ = 7471 N [backward]

$\vec{a}$ = 0.225 m/s^2 [forward]

Required

coefficient of static friction (μ_s)

Analysis and Solution

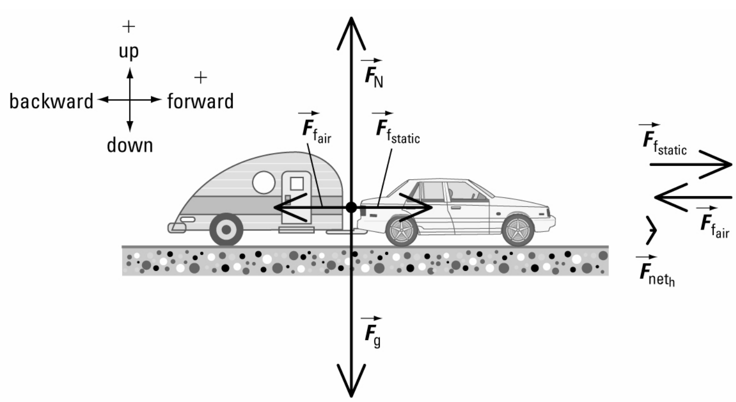
The car and trailer are a system because they move together as a unit. Find the total mass of the system.

$m_T = m_c + m_t$

$= 1450\text{ kg} + 454\text{ kg}$

$= 1904\text{ kg}$

Draw a free-body diagram for the system.



The system is not accelerating up or down.

So in the vertical direction, F_{net_v} = 0 N.

Write equations to find the net force on the system in both directions.

horizontal direction

$$\vec{F}_{\text{net}_\text{h}} = \vec{F}_{\text{f}_\text{static}} + \vec{F}_{\text{air}}$$
$$F_{\text{net}_\text{h}} = F_{\text{f}_\text{static}} + F_{\text{air}}$$
$$m_\text{T}a = \mu_\text{s}F_\text{N} + (-7471\text{ N})$$
$$= \mu_\text{s}F_\text{N} - 7471\text{ N}$$
$$\mu_\text{s}F_\text{N} = m_\text{T}a + 7471\text{ N}$$

vertical direction

$$\vec{F}_{\text{net}_\text{v}} = \vec{F}_\text{N} + \vec{F}_\text{g}$$
$$F_{\text{net}_\text{v}} = F_\text{N} + F_\text{g}$$
$$0 = F_\text{N} + (-m_\text{T}g)$$
$$= F_\text{N} - m_\text{T}g$$
$$F_\text{N} = m_\text{T}g$$

Substitute $F_\text{N} = m_\text{T}g$ into the last equation for the horizontal direction.

$$\mu_\text{s}m_\text{T}g = m_\text{T}a + 7471\text{ N}$$
$$\mu_\text{s} = \frac{a}{g} + \frac{7471\text{ N}}{m_\text{T}g}$$
$$= \frac{0.225\ \cancel{\frac{\text{m}}{\text{s}^2}}}{9.81\ \cancel{\frac{\text{m}}{\text{s}^2}}} + \frac{7471\ \cancel{\text{kg}}\bullet\cancel{\frac{\text{m}}{\text{s}^2}}}{(1904\ \cancel{\text{kg}})\left(9.81\ \cancel{\frac{\text{m}}{\text{s}^2}}\right)}$$
$$= 0.423$$

Paraphrase

The coefficient of static friction for the car and trailer on the ground is 0.423.

13. (a) ***Analysis and Solution***

If the pulley is prevented from turning, the reading on the spring scale will be equal to the sum of the gravitational force acting on each bag.

$$\vec{F}_\text{s} = \vec{F}_{\text{g}_1} + \vec{F}_{\text{g}_2}$$
$$F_\text{s} = F_{\text{g}_1} + F_{\text{g}_2}$$
$$= m_1g + m_2g$$
$$= g(m_1 + m_2)$$
$$= (9.81\text{ m/s}^2)(60\text{ kg} + 40\text{ kg})$$
$$= 9.8 \times 10^2\text{ N}$$

(b) ***Given***

$m_1 = 60$ kg

$m_2 = 40$ kg

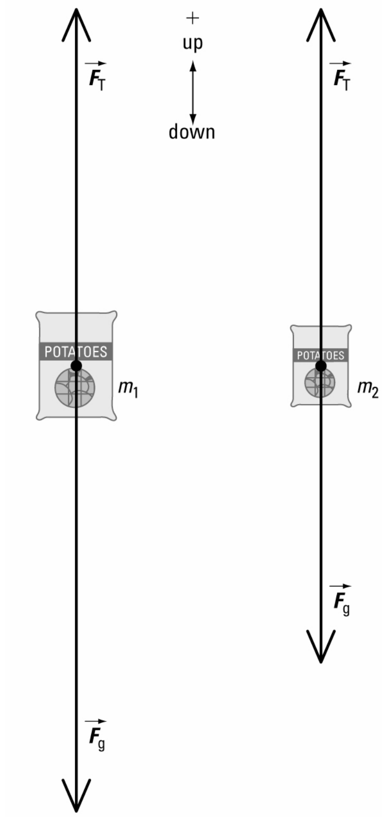
$\vec{g} = 9.81$ m/s^2 [down]

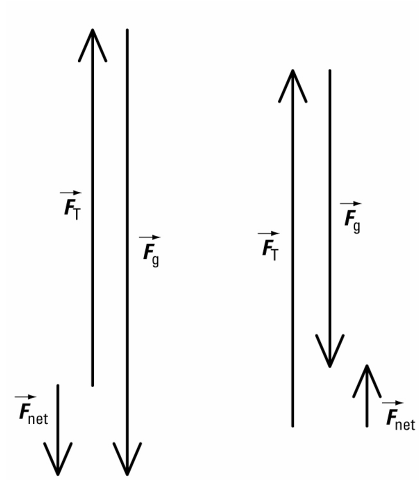
(i) ***Required***

acceleration of the system ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for each bag.





Each bag is not accelerating left or right.
So in the horizontal direction, F_{net_h} = 0 N.

For the vertical direction, write an equation to find the net force on each bag.

60-kg bag

$$\vec{F}_{net_1} = \vec{F}_T + \vec{F}_{g_1}$$
$$F_{net_1} = F_T + F_{g_1}$$

40-kg bag

$$\vec{F}_{net_2} = \vec{F}_T + \vec{F}_{g_2}$$
$$F_{net_2} = F_T + F_{g_2}$$

Apply Newton's second law.

$$\begin{aligned} -m_1a &= F_T + F_{g_1} \\ -m_1a &= F_T + (-m_1g) \\ -m_1a &= F_T - m_1g \\ F_T &= m_1g - m_1a \end{aligned}$$

$$\begin{aligned} m_2a &= F_T + F_{g_2} \\ m_2a &= F_T + (-m_2g) \\ m_2a &= F_T - m_2g \\ F_T &= m_2g + m_2a \end{aligned}$$

Set both equations for F_T equal to each other.

$$\begin{aligned} m_1g - m_1a &= m_2g + m_2a \\ a(m_1 + m_2) &= g(m_1 - m_2) \\ a &= \left(\frac{m_1 - m_2}{m_1 + m_2}\right)g \\ &= \left(\frac{60\text{ kg} - 40\text{ kg}}{60\text{ kg} + 40\text{ kg}}\right)(9.81\text{ m/s}^2) \\ &= \left(\frac{20\ \cancel{\text{kg}}}{100\ \cancel{\text{kg}}}\right)(9.81\text{ m/s}^2) \\ &= 2.0\text{ m/s}^2 \end{aligned}$$

Paraphrase
The acceleration of the 60-kg bag will be 2.0 m/s^2 [down] and of the 40-kg bag will be 2.0 m/s^2 [up].
(ii) ***Required***
tension in rope
Analysis and Solution
Substitute the value of a into the equation for F_T for the 40-kg bag.

$$\begin{aligned} F_T &= m_2(g + a) \\ &= (40 \text{ kg})(9.81 \text{ m/s}^2 + 1.96 \text{ m/s}^2) \\ &= 4.7 \times 10^2 \text{ N} \end{aligned}$$

The tension in the rope will be 4.7×10^2 N.

(c) ***Analysis and Solution***
The rope exerts a force on each side of the pulley (the magnitude of this force is the tension). So when the bags are accelerating, the reading on the spring scale will be twice the tension.

$$\begin{aligned} F_s &= 2F_T \\ &= 2(4.71 \times 10^2 \text{ N}) \\ &= 9.4 \times 10^2 \text{ N} \end{aligned}$$

(d) When the bags are at rest, the spring scale reads the total weight of the bags. When the bags are accelerating, the scale reads twice the tension in the rope. When the bags are released, the 20-kg difference in mass between the two bags will provide the net force to accelerate the system. That force is 39 N, which is the difference between the two readings on the spring scale.

14. ***Given***
$v_i = 0$ m/s $\qquad v_f = 320$ km/h
$\Delta t = 6.50$ s $\qquad \vec{F}_{\text{w on g}} = 1.52 \times 10^4$ N [backward]
$\vec{F}_{\text{air}} = 5.2 \times 10^3$ N [backward]

Required
mass of car (m)
Analysis and Solution
Convert the final speed of the car to metres per second.

$$\begin{aligned} v_f &= \frac{320 \cancel{\text{ km}}}{1 \cancel{\text{ h}}} \times \frac{1000 \text{ m}}{1 \cancel{\text{ km}}} \times \frac{1 \cancel{\text{ h}}}{3600 \text{ s}} \\ &= 88.9 \text{ m/s} \end{aligned}$$

Calculate the magnitude of the acceleration of the car.

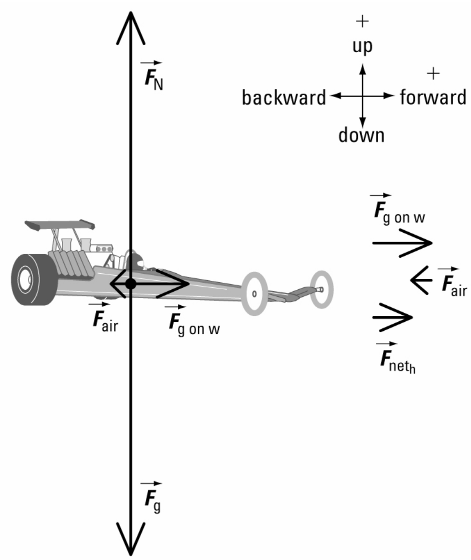
$$\begin{aligned} a &= \frac{\Delta v}{\Delta t} \\ &= \frac{v_f - v_i}{\Delta t} \\ &= \frac{88.9 \text{ m/s} - 0 \text{ m/s}}{6.50 \text{ s}} \\ &= 13.7 \text{ m/s}^2 \end{aligned}$$

Apply Newton's third law.

$$\vec{F}_{\text{g on w}} = -\vec{F}_{\text{w on g}}$$
$$= 1.52 \times 10^4 \text{ N [forward]}$$

It is the reaction force $\vec{F}_{\text{g on w}}$ that causes the car to accelerate.

Draw a free-body diagram for the car.



The car is not accelerating up or down.
So in the vertical direction, $F_{\text{net}_v} = 0$ N.

Write equations to find the net force on the car in both directions.

horizontal direction

$$\vec{F}_{\text{net}_h} = \vec{F}_{\text{g on w}} + \vec{F}_{\text{air}}$$
$$F_{\text{net}_h} = F_{\text{g on w}} + F_{\text{air}}$$

Apply Newton's second law to the horizontal direction.

$$ma = F_{\text{g on w}} + F_{\text{air}}$$
$$m = \frac{F_{\text{g on w}} + F_{\text{air}}}{a}$$
$$= \frac{1.52 \times 10^4 \text{ N} + (-5.2 \times 10^3 \text{ N})}{13.7 \text{ m/s}^2}$$
$$= \frac{1.52 \times 10^4 \text{ N} - 5.2 \times 10^3 \text{ N}}{13.7 \text{ m/s}^2}$$
$$= \frac{1.00 \times 10^4 \text{ kg} \bullet \cancel{\frac{\text{m}}{\text{s}^2}}}{13.7 \cancel{\frac{\text{m}}{\text{s}^2}}}$$
$$= 7.3 \times 10^2 \text{ kg}$$

vertical direction

$$\vec{F}_{\text{net}_v} = \vec{F}_N + \vec{F}_g$$
$$F_{\text{net}_v} = 0$$

Calculations in the vertical direction are not required in this problem.

Paraphrase

The car has a mass of 7.3×10^2 kg.

15. ***Given***

$\vec{a} = 0\ \text{m/s}^2$

$\vec{F}_{\text{app}} = 1.0 \times 10^4$ N [forward]

$\vec{g} = 9.81\ \text{m/s}^2$ [down]

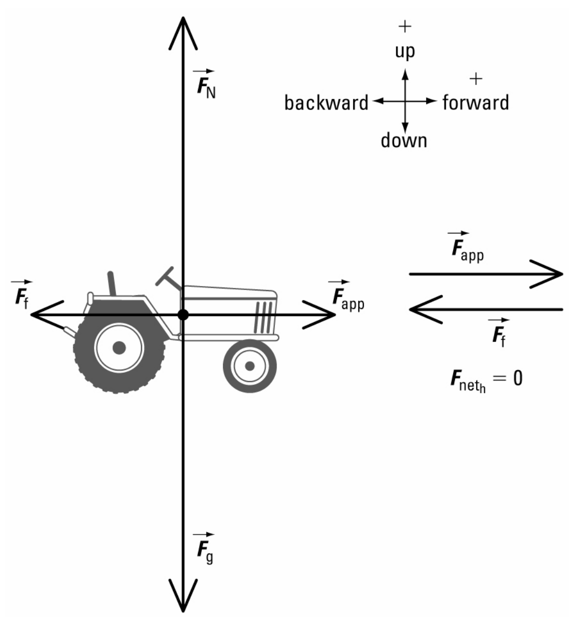
$\mu_k = 0.5$ from Table 3.4 (rubber tires on wet concrete)

Required

mass of tractor (m)

Analysis and Solution

Draw a free-body diagram for the tractor.



Since the tractor is not accelerating in the vertical direction, $F_{\text{net}_h} = 0$ N.

Write equations to find the net force on the tractor in both directions.

horizontal direction

$$\begin{aligned}
\vec{F}_{\text{net}_h} &= \vec{F}_{\text{app}} + \vec{F}_{\text{f}_{\text{kinetic}}} \\
F_{\text{net}_h} &= F_{\text{app}} + F_{\text{f}_{\text{kinetic}}} \\
0 &= F_{\text{app}} + F_{\text{f}_{\text{kinetic}}} \\
&= F_{\text{app}} + (-\mu_k F_N) \\
&= F_{\text{app}} - \mu_k F_N \\
\mu_k F_N &= F_{\text{app}}
\end{aligned}$$

vertical direction

$$\begin{aligned}
\vec{F}_{\text{net}_v} &= \vec{F}_N + \vec{F}_g \\
F_{\text{net}_v} &= F_N + F_g \\
0 &= F_N + (-mg) \\
&= F_N - mg \\
F_N &= mg
\end{aligned}$$

Substitute $F_N = mg$ into equation for F_{app}.

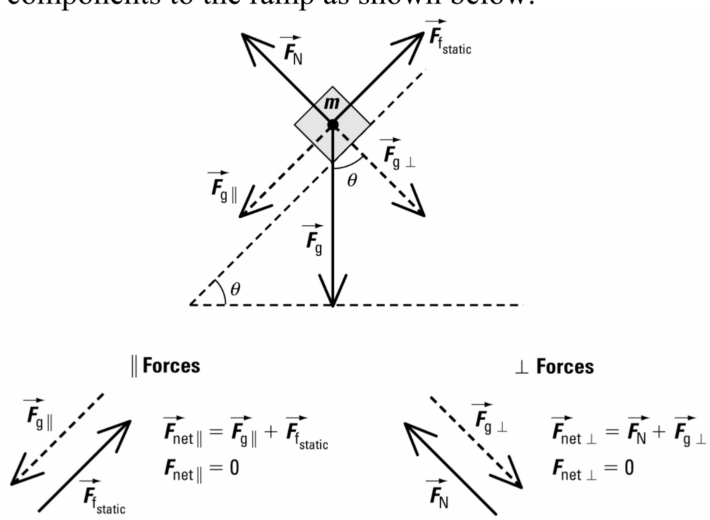
$$\mu_k mg = F_{\text{app}}$$

$$
\begin{aligned}
m &= \frac{F_{\text{app}}}{\mu_k g} \\
&= \frac{1.0 \times 10^4 \text{ N}}{\mu_k g} \\
&= \frac{1.0 \times 10^4 \text{ kg}\bullet\frac{\cancel{\text{m}}}{\cancel{\text{s}}^2}}{(0.5)\left(9.81 \frac{\cancel{\text{m}}}{\cancel{\text{s}}^2}\right)} \\
&= 2 \times 10^3 \text{ kg}
\end{aligned}
$$

Paraphrase

The tractor has a mass of 2×10^3 kg.

16. Students may use a familiar object such as a crate moving down the ramp of a delivery truck. They need to first measure the mass of the object and the angle the ramp makes with the ground. Then they should demonstrate how to calculate the gravitational force on the object. Students should include a free-body diagram of the object that clearly shows the weight vector resolved into parallel and perpendicular components to the ramp as shown below.



Students must explain why they used the sine and cosine of the angle to determine the parallel and perpendicular components respectively.

17. (a) Since μ_s for dry concrete is less than that for dry asphalt, dry asphalt exerts more static friction on a rubber tire than dry concrete.

(b) Since μ_k is the same for wet concrete and wet asphalt, the car will slide with equal ease on both.

(c) The moving car will begin to slide more easily on the surface with the smaller coefficient of static friction. Since μ_s for dry concrete is less than dry asphalt, the car will begin to slide more easily on dry concrete.

(d) When the brakes are locked, the car is sliding. So kinetic friction is present. For the car to slide a minimum distance, μ_k for that road surface must be greater than the other surface. Since μ_k is greater for dry concrete than dry asphalt, the car will slide a shorter distance.

Extensions

18. (a) ***Given***

$m = 80$ kg $\qquad \mu_k = 0.70$

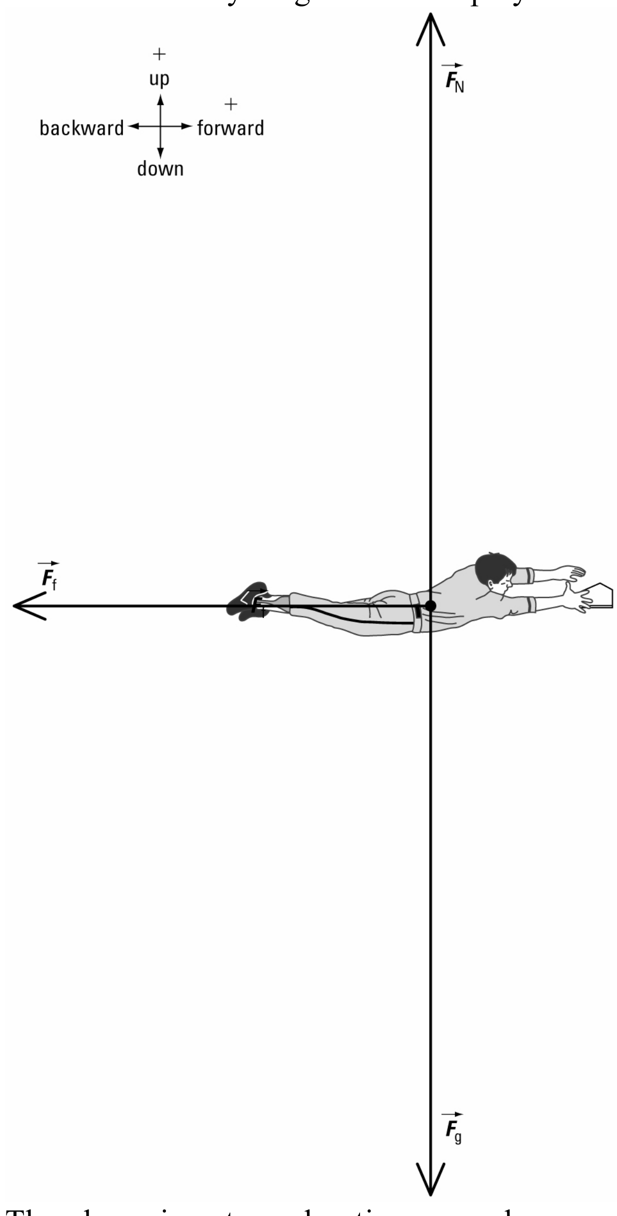
$v_i = 8.23$ m/s [forward] $\qquad \vec{g} = 9.81$ m/s^2 [down]

Required

acceleration of player ($\vec{a}$)

Analysis and Solution

Draw a free-body diagram for the player.



The player is not accelerating up or down.

So in the vertical direction, $F_{net_v} = 0$ N.

Write equations to find the net force on the player in both directions.

horizontal direction

$\vec{F}_{net_h} = \vec{F}_f$

vertical direction

$\vec{F}_{net_v} = \vec{F}_N + \vec{F}_g$

$$F_{\text{net}_\text{h}} = F_\text{f}$$
$$ma = -\mu_\text{k}F_\text{N}$$

$$\begin{aligned} F_{\text{net}_\text{v}} &= F_\text{N} + F_\text{g} \\ 0 &= F_\text{N} + (-mg) \\ &= F_\text{N} - mg \\ F_\text{N} &= mg \end{aligned}$$

Substitute $F_\text{N} = mg$ into the last equation for the horizontal direction.

$$\begin{aligned} \cancel{m}\, a &= -\mu_\text{k}\, \cancel{m}\, g \\ a &= -\mu_\text{k} g \\ &= -(0.70)(9.81\ \text{m/s}^2) \\ &= -6.9\ \text{m/s}^2 \\ \vec{a} &= 6.9\ \text{m/s}^2\ [\text{backward}] \end{aligned}$$

Paraphrase

The baseball player will have an acceleration of 6.9 m/s^2 [backward] during the slide.

(b) ***Given***

$m = 80$ kg
$v_\text{i} = 8.23$ m/s [forward]
$\vec{a} = 6.87$ m/s^2 [backward] from part (a)
$\mu_\text{k} = 0.70$
$\vec{g} = 9.81$ m/s^2 [down]

Required

time interval of slide (Δt)

Analysis and Solution

Calculate the time interval of the slide.

$$\begin{aligned} a &= \frac{\Delta v}{\Delta t} \\ \Delta t &= \frac{\Delta v}{a} \\ &= \frac{v_\text{f} - v_\text{i}}{a} \\ &= \frac{0\ \text{m/s} - 8.23\ \text{m/s}}{-6.87\ \text{m/s}^2} \\ &= 1.2\ \text{s} \end{aligned}$$

Paraphrase

The baseball player will slide for 1.2 s.

(c) ***Analysis and Solution***

Substitute $a = -\mu_\text{k} g$ from part (a) into the equation for Δt.

$$\begin{aligned} \Delta t &= \frac{\Delta v}{a} \\ &= \frac{v_\text{f} - v_\text{i}}{a} \\ &= \frac{0 - v_\text{i}}{-\mu_\text{k} g} \\ &= \frac{v_\text{i}}{\mu_\text{k} g} \end{aligned}$$

