NEWTON'S FIRST LAW OF MOTION

A body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force.

A freely moving body will remain in motion.

Objects moving at constant velocity are in Inertial Reference Frames.

A reference frame accelerating relative to an inertial frame is not inertial.

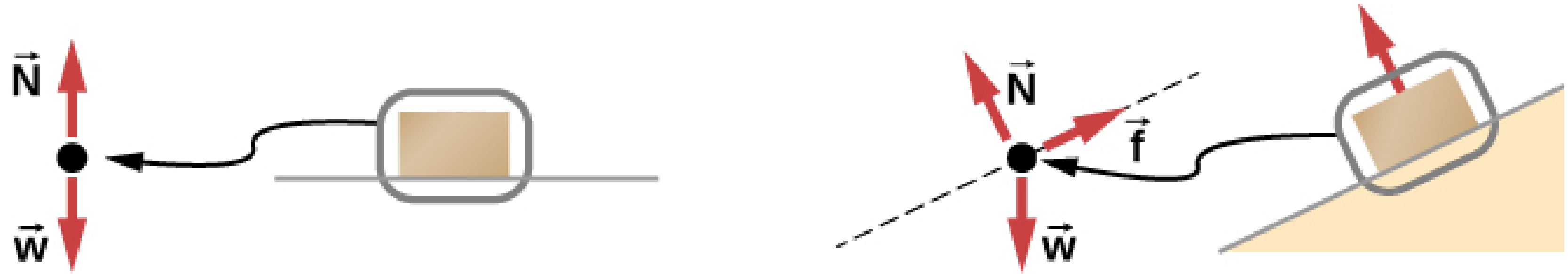
A body is in equilibrium when there is zero net force (or resultant = sum total of all forces) acting on it.

The object moves at constant velocity (including velocity zero: static)

It defines an inertial frame.

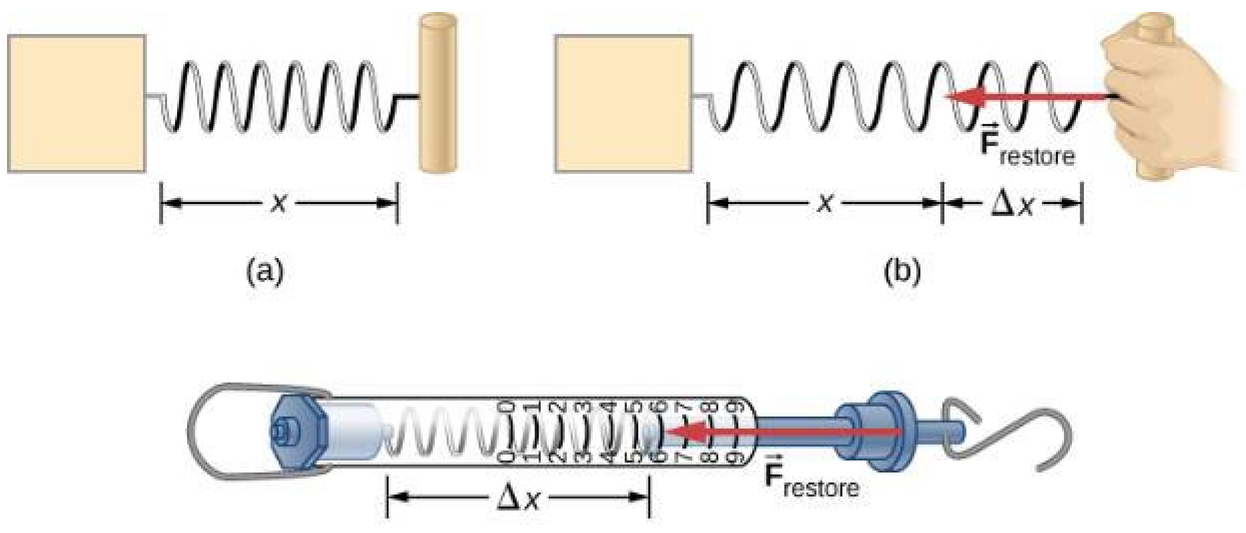
FIGURE 5.4

In these free-body diagrams, $\vec{\mathbf{N}}$ is the normal force, $\vec{\mathbf{w}}$ is the weight of the object, and $\vec{\mathbf{f}}$ is the friction.



(a) Box at rest on a horizontal surface

(b) Box on an inclined plane



(c)

FIGURE 5.5

The force exerted by a stretched spring can be used as a standard unit of force.

(a) This spring has a length *x* when undistorted.

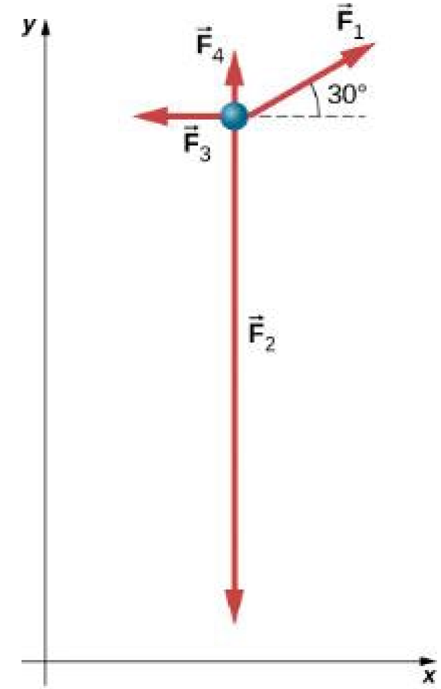
(b) When stretched a distance Δx, the spring exerts a restoring force $\vec{\mathbf{F}}_{\text{restore}}$, which is reproducible.

(c) A spring scale is one device that uses a spring to measure force. The force $\vec{\mathbf{F}}_{\text{restore}}$ is exerted on whatever is attached to the hook. Here, this force has a magnitude of six units of the force standard being employed.

NEWTON'S SECOND LAW: FORCE & ACCELERATION

$$\vec{\mathbf{F}}_{\text{net}} = \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}},$$

$$\sum \vec{\mathbf{F}}_x = m\vec{\mathbf{a}}_x, \ \sum \vec{\mathbf{F}}_y = m\vec{\mathbf{a}}_y, \text{ and } \sum \vec{\mathbf{F}}_z = m\vec{\mathbf{a}}_z.$$



$$\begin{aligned}
&\sum F_x = ma_x \\
&F_{1x} - F_{3x} = ma_x \\
&F_1 \cos 30° - F_{3x} = ma_x \\
&(10.0\,\text{N})(\cos 30°) - 5.0\,\text{N} = (4.0\,\text{kg})\,a_x \\
&a_x = 0.92\,\text{m/s}^2.
\end{aligned}$$

$$\begin{aligned}
&\sum F_y = ma_y \\
&F_{1y} + F_{4y} - F_{2y} = ma_y \\
&F_1 \sin 30° + F_{4y} - F_{2y} = ma_y \\
&(10.0\,\text{N})(\sin 30°) + 2.0\,\text{N} - 40.0\,\text{N} = (4.0\,\text{kg})\,a_y \\
&a_y = -8.3\,\text{m/s}^2.
\end{aligned}$$

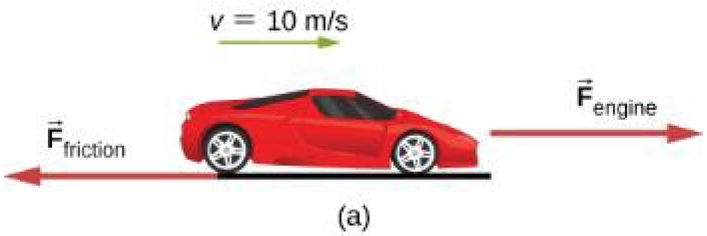
the net acceleration is

$$\vec{\mathbf{a}} = \left(0.92\hat{\mathbf{i}} - 8.3\hat{\mathbf{j}}\right)\ \text{m/s}^2,$$

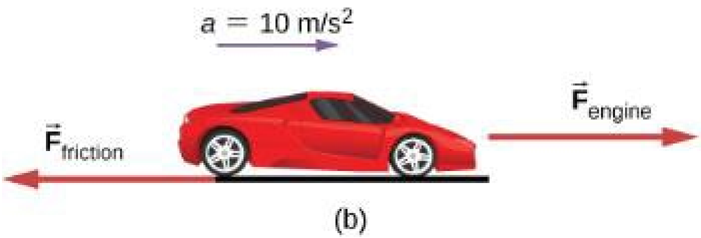
FIGURE 5.13

A car is shown (a) moving at constant speed and (b) accelerating. How do the forces acting on the car compare in each case?

(a) What does the knowledge that the car is moving at constant velocity tell us about the net horizontal force on the car compared to the friction force? Answer Net Force = 0



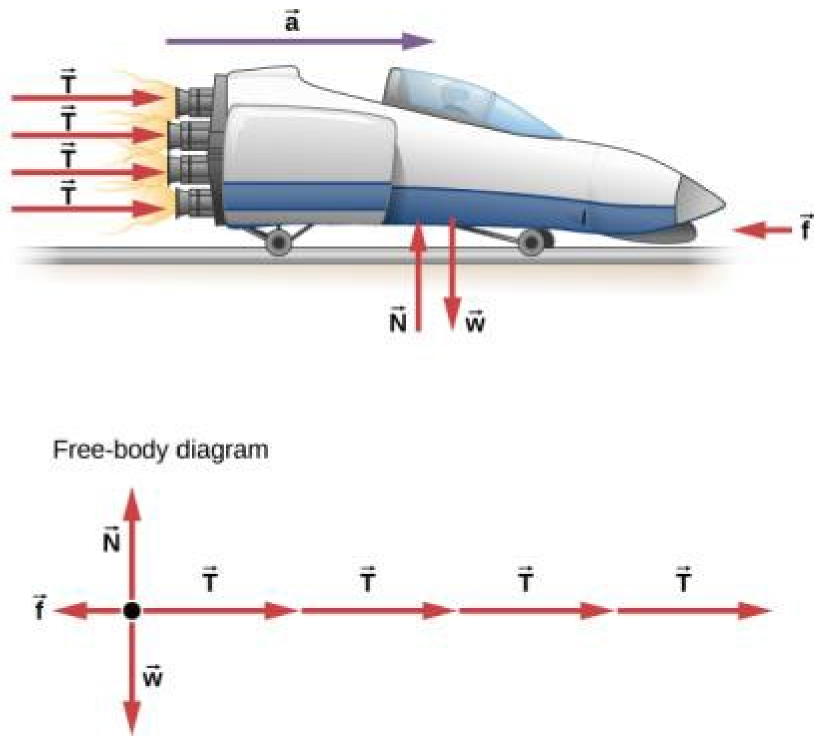
(b) What does the knowledge that the car is accelerating tell us about the horizontal force on the car compared to the friction force? Answer: Net force forward >0



Force of engine is greater than friction drag

Note: This illustration is the more correct way to explain the difference between a) inertial motion and b) acceleration as compared to what's shown in Fig 5.13 of the book (friction vs drag)

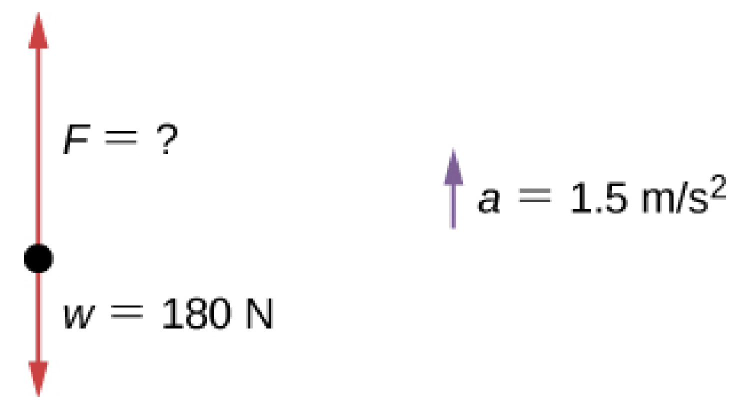
FIGURE 5.14



A sled experiences a rocket thrust that accelerates it to the right. Each rocket creates an identical thrust *T*. The system here is the sled, its rockets, and its rider, so none of the forces between these objects are considered. The arrow representing friction ($\vec{\mathbf{f}}$) is drawn larger than scale.

EXAMPLE 5.8 WEIGHT: $\vec{\mathbf{w}} = m\vec{\mathbf{g}}.$

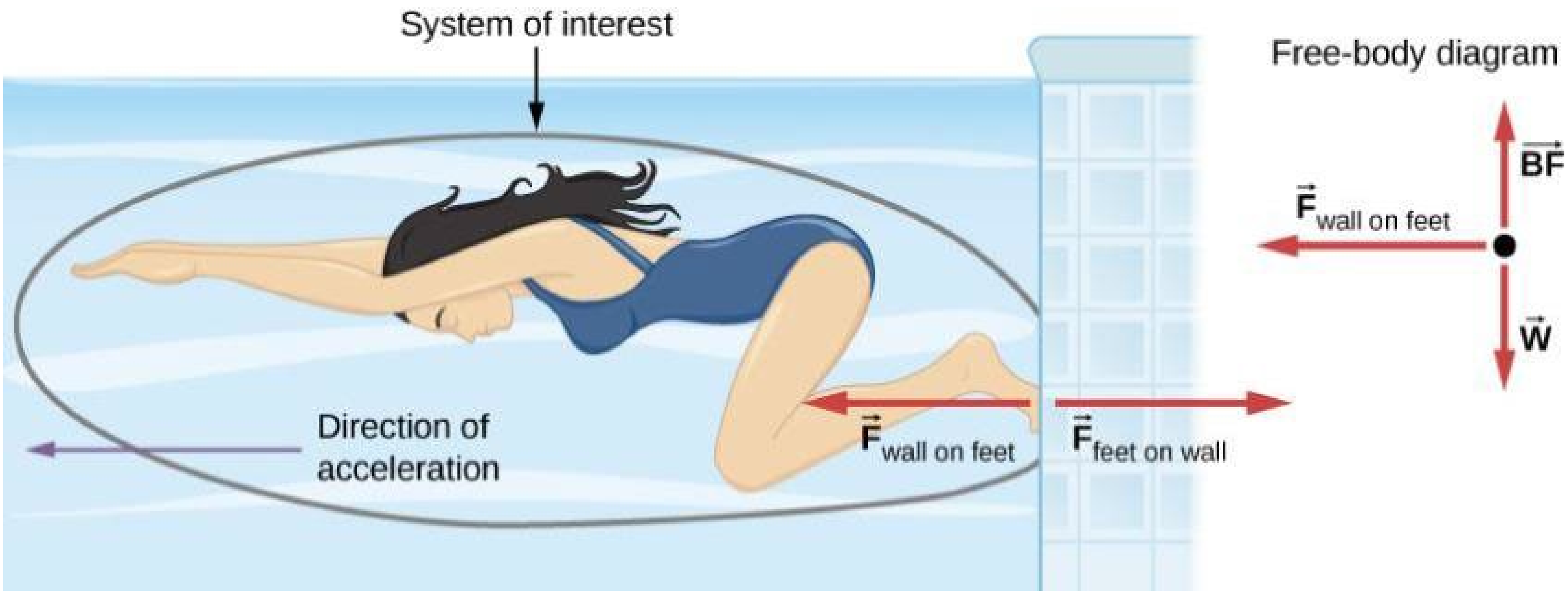
A farmer is lifting some moderately heavy rocks from a field to plant crops. He lifts a stone that weighs 40.0 lb. (about 180 N). What force does he apply if the stone accelerates at a rate of 1.5 m/s^2



$$\begin{aligned} \sum F &= ma \\ F - w &= ma \\ F - 180\,\text{N} &= (18\,\text{kg})(1.5\,\text{m/s}^2) \end{aligned}$$

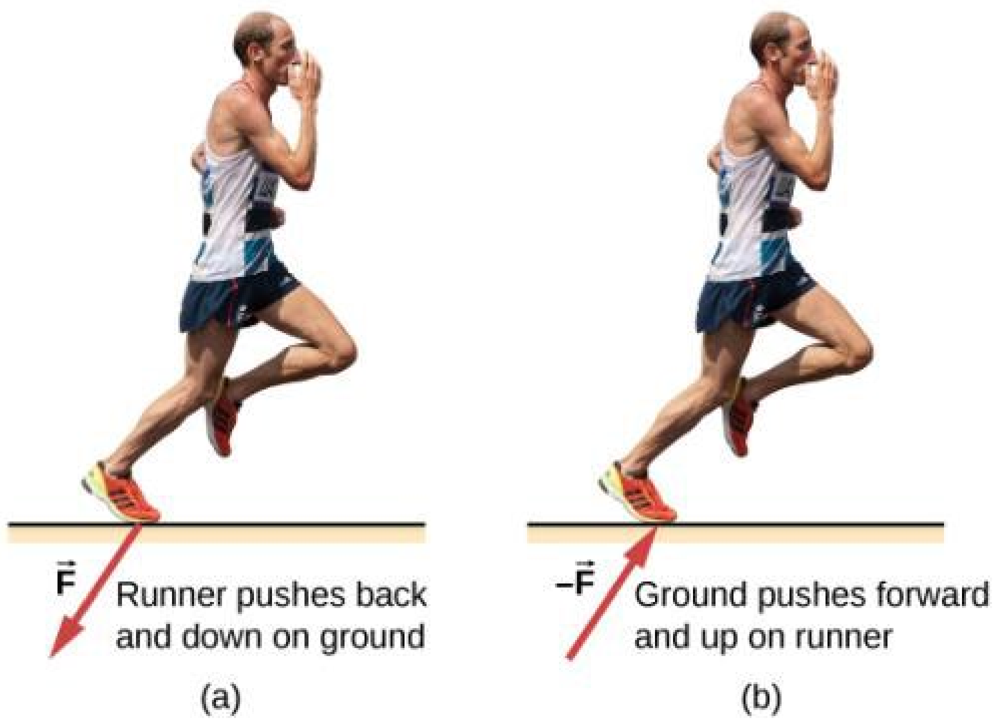
F = 207 N

NEWTON’S THIRD LAW: ACTION = REACTION



When the swimmer exerts a force on the wall, she accelerates in the opposite direction; in other words, the net external force on her is in the direction opposite of $\boldsymbol{F}_{\text{feet on wall}}$. This opposition occurs because, in accordance with Newton’s third law, the wall exerts a force $\boldsymbol{F}_{\text{wall on feet}}$ on the swimmer that is equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Thus, the free-body diagram shows only $\boldsymbol{F}_{\text{wall on feet}}$, *w* (the gravitational force), and *BF*, which is the buoyant force of the water supporting the swimmer’s weight. The vertical forces *w* and *BF* cancel because there is no vertical acceleration.

FIGURE 5.18

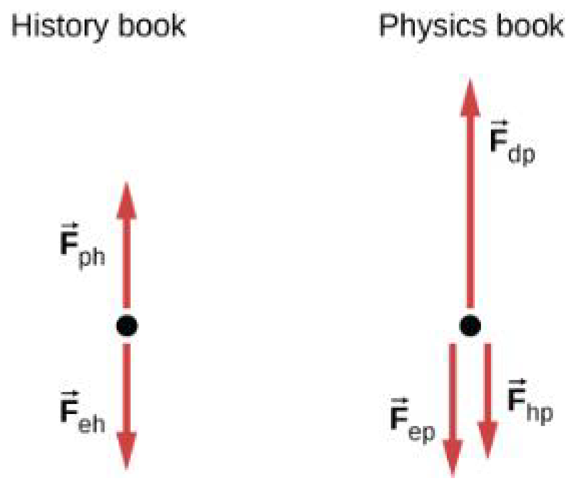


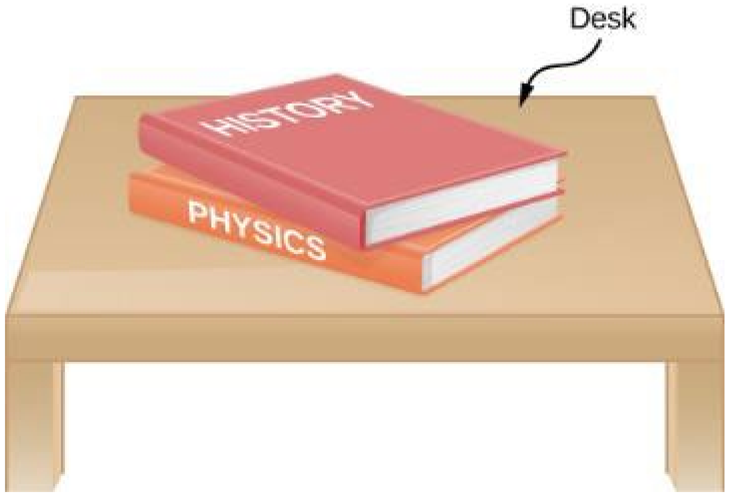
The runner experiences Newton’s third law.

(a) A force is exerted by the runner on the ground.

(b) The reaction force of the ground on the runner pushes him forward.

EXERCISE 53.1

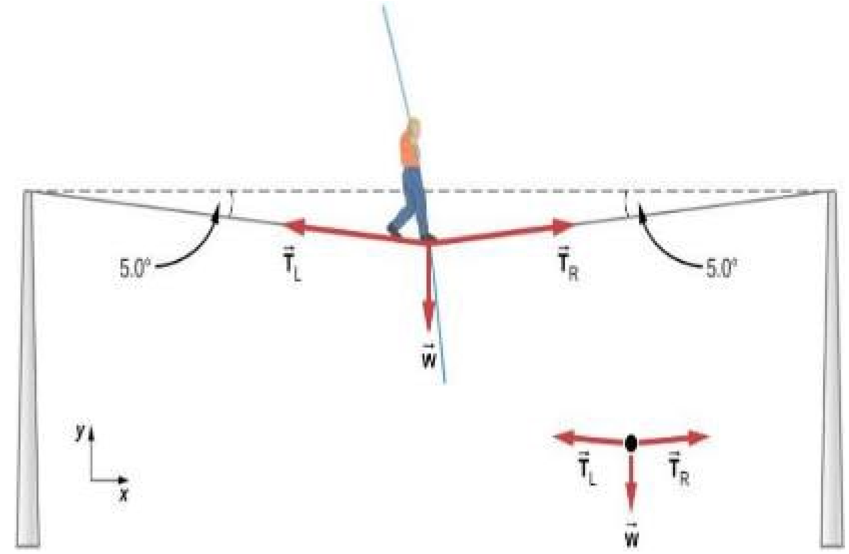




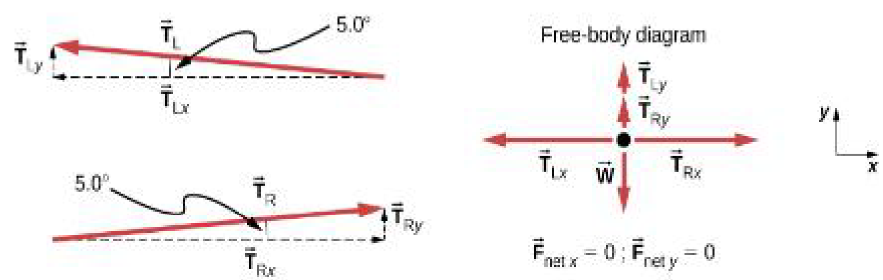
Because the weight of the history book is the force exerted by Earth on the history book, we represent it as $\vec{\mathbf{F}}_{EH} = -14\hat{\mathbf{j}}$ N. Aside from this, the history book interacts only with the physics book. Because the acceleration of the history book is zero, the net force on it is zero by Newton's second law: $\vec{\mathbf{F}}_{PH} + \vec{\mathbf{F}}_{EH} = \vec{\mathbf{0}}$, where $\vec{\mathbf{F}}_{PH}$ is the force exerted by the physics book on the history book. Thus, $\vec{\mathbf{F}}_{PH} = -\vec{\mathbf{F}}_{EH} = -\left(-14\hat{\mathbf{j}}\right)$ N $= 14\hat{\mathbf{j}}$ N. We find that the physics book exerts an upward force of magnitude 14 N on the history book. The physics book has three forces exerted on it: $\vec{\mathbf{F}}_{EP}$ due to Earth, $\vec{\mathbf{F}}_{HP}$ due to the history book, and $\vec{\mathbf{F}}_{DP}$ due to the desktop. Since the physics book weighs 18 N, $\vec{\mathbf{F}}_{EP} = -18\hat{\mathbf{j}}$ N. From Newton's third law, $\vec{\mathbf{F}}_{HP} = -\vec{\mathbf{F}}_{PH}$, so $\vec{\mathbf{F}}_{HP} = -14\hat{\mathbf{j}}$ N. Newton's second law applied to the physics book gives $\sum \vec{\mathbf{F}} = \vec{\mathbf{0}}$, or $\vec{\mathbf{F}}_{DP} + \vec{\mathbf{F}}_{EP} + \vec{\mathbf{F}}_{HP} = \vec{\mathbf{0}}$, so $\vec{\mathbf{F}}_{DP} = -\left(-18\hat{\mathbf{j}}\right) - \left(-14\hat{\mathbf{j}}\right) = 32\hat{\mathbf{j}}$ N. The desk exerts an upward force of 32 N on the physics book. To arrive at this solution, we apply Newton's second law twice and Newton's third law once.

FIGURE 5.26

The weight of a tightrope walker causes a wire to sag by 5.0°. The system of interest is the point in the wire at which the tightrope walker is standing. Since he is in balance, we see immediately that the x component of the tension from the right is equal to that from the left. The y component from the left and right add up to balance his weight:



$$
\begin{aligned}
F_{\text{net } y} &= T_{\text{L}y} + T_{\text{R}y} - w = 0 \\
F_{\text{net } y} &= T \sin 5.0^\circ + T \sin 5.0^\circ - w = 0 \\
2T \sin 5.0^\circ - w &= 0 \\
2T \sin 5.0^\circ &= w
\end{aligned}
$$



$$T = \frac{w}{2 \sin 5.0^\circ} = \frac{mg}{2 \sin 5.0^\circ},$$

$$T = \frac{(70.0\,\text{kg})\left(9.80\,\text{m/s}^2\right)}{2\,(0.0872)},$$

$$T = 3930\,\text{N}.$$

When the vectors are projected onto vertical and horizontal axes, their components along these axes must add to zero, since the tightrope walker is stationary. The small angle results in *T* being much greater than *w*.

TENSION

Prisoner escape

Fish weight

(Blackboard)

SIMPLE HARMONIC MOTION FIGURE 5.29

$$\vec{\mathbf{F}} = -k\vec{\mathbf{x}}.$$

k is the spring constant: stiffness

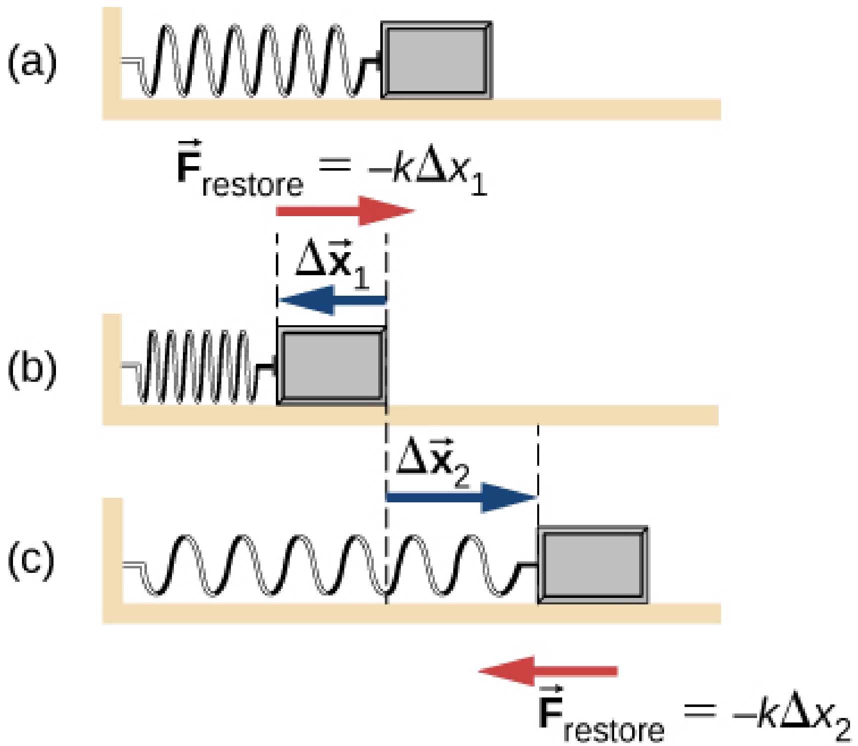
Minus sign indicates that it is a restoring Force.

A spring exerts its force proportional to a displacement, whether it is compressed or stretched.

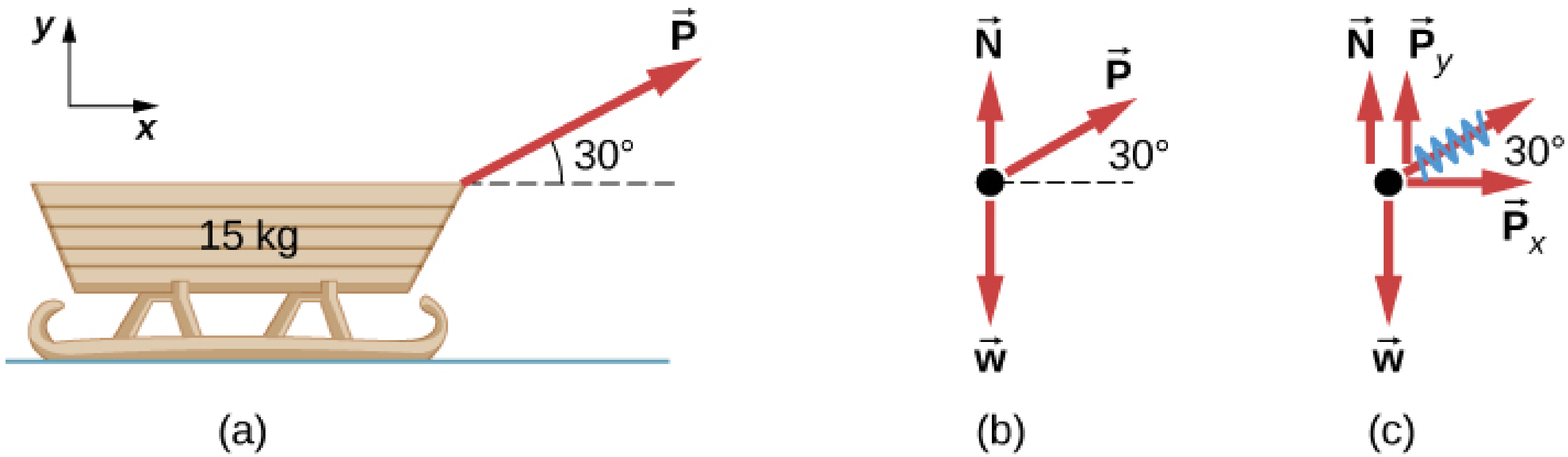
(a) The spring is in a relaxed position and exerts no force on the block.

(b) The spring is compressed by displacement $\Delta\vec{\mathbf{x}}_1$ of the object and exerts restoring force $-k\Delta\vec{\mathbf{x}}_1$.

(c) The spring is stretched by displacement $\Delta\vec{\mathbf{x}}_2$ of the object and exerts restoring force $-k\Delta\vec{\mathbf{x}}_2$.

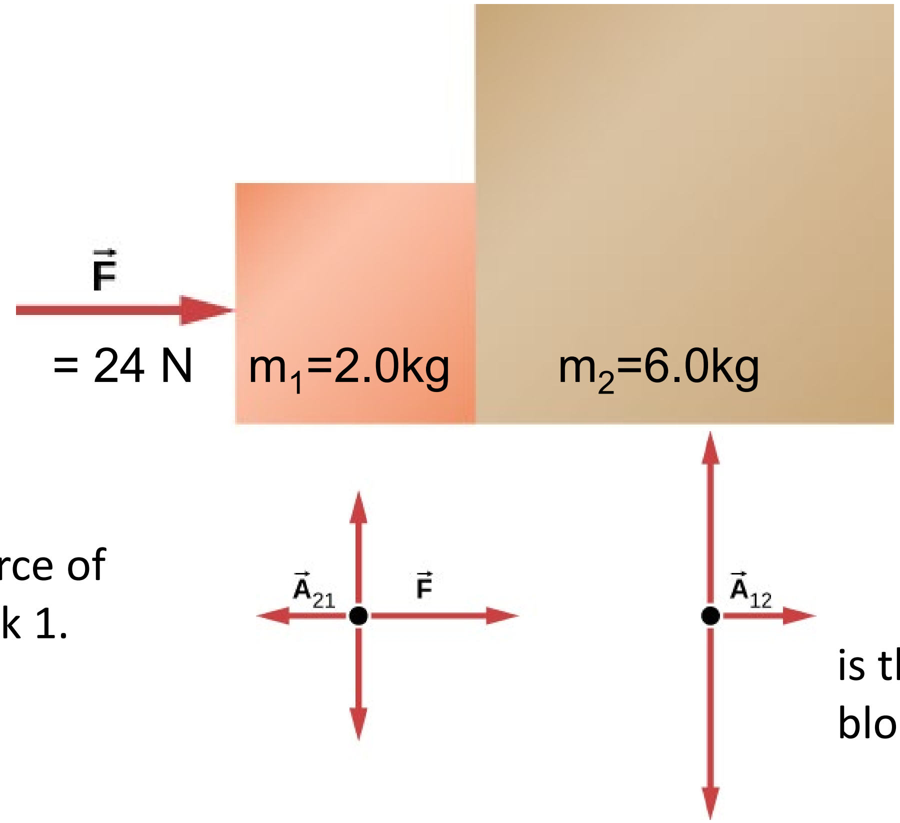


DRAWING THE CORRECT FREE BODY DIAGRAM IS THE ESSENTIAL FIRST STEP



(a) A moving sled is shown as (b) a free-body diagram and (c) a free-body diagram with force components.

EXAMPLE 5.11 (P.223) 5.15.1 → CHAPTER 6

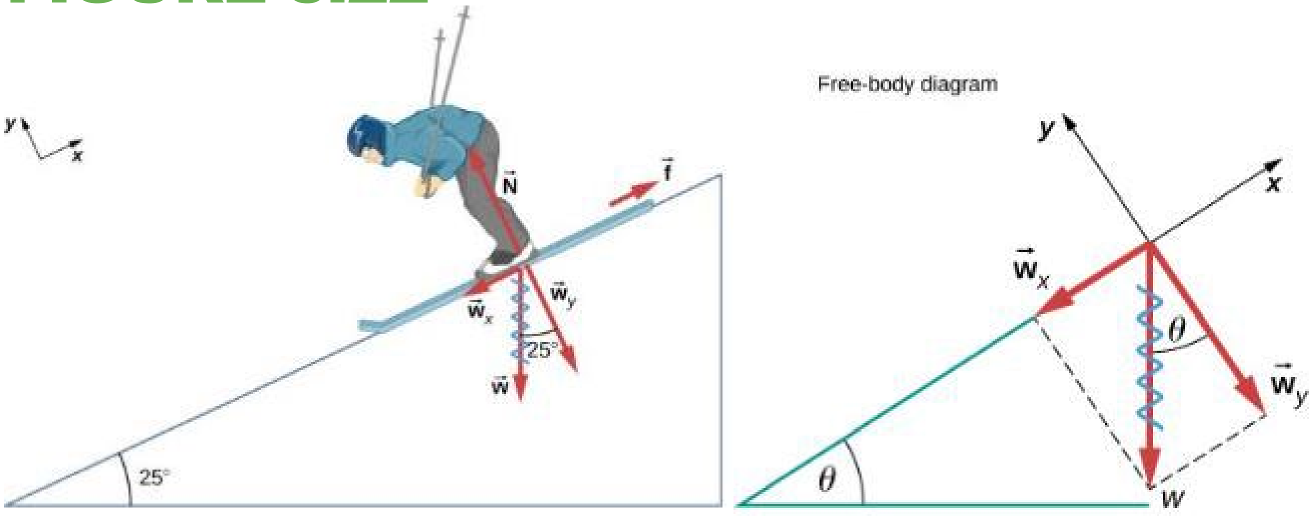


is the action force of block 2 on block 1.

is the reaction force of block 1 on block 2.

(a) Find the acceleration of the system of blocks. (b) Suppose that the blocks are later separated. What force will give the second block, with the mass of 6.0 kg, the same acceleration as the system of blocks?

FIGURE 5.22



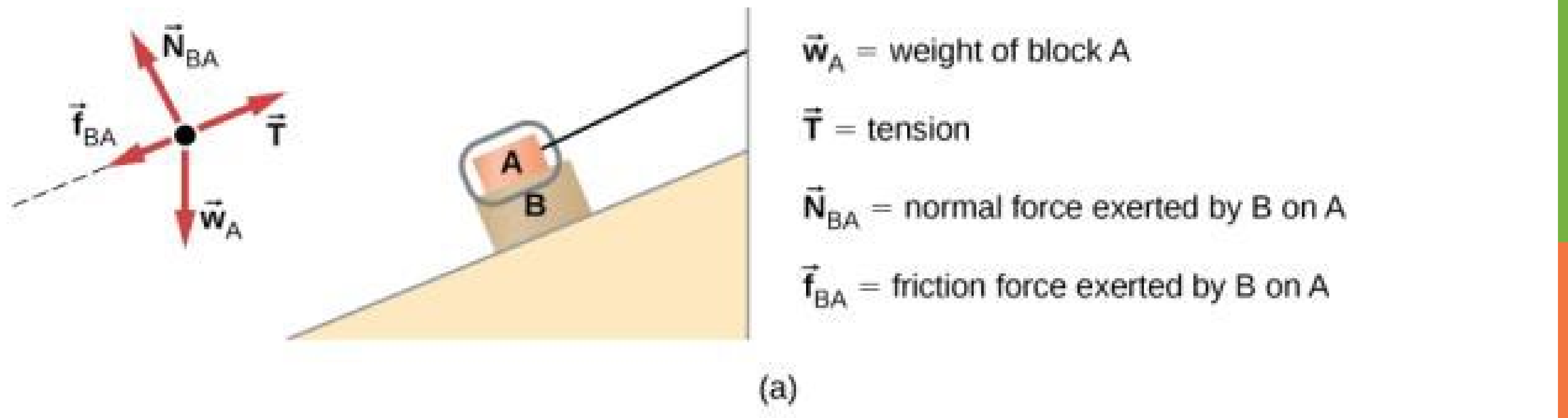
$$w_x = w\sin(\theta) = mg\sin(\theta)$$
$$w_y = w\cos(\theta) = mg\cos(\theta)$$

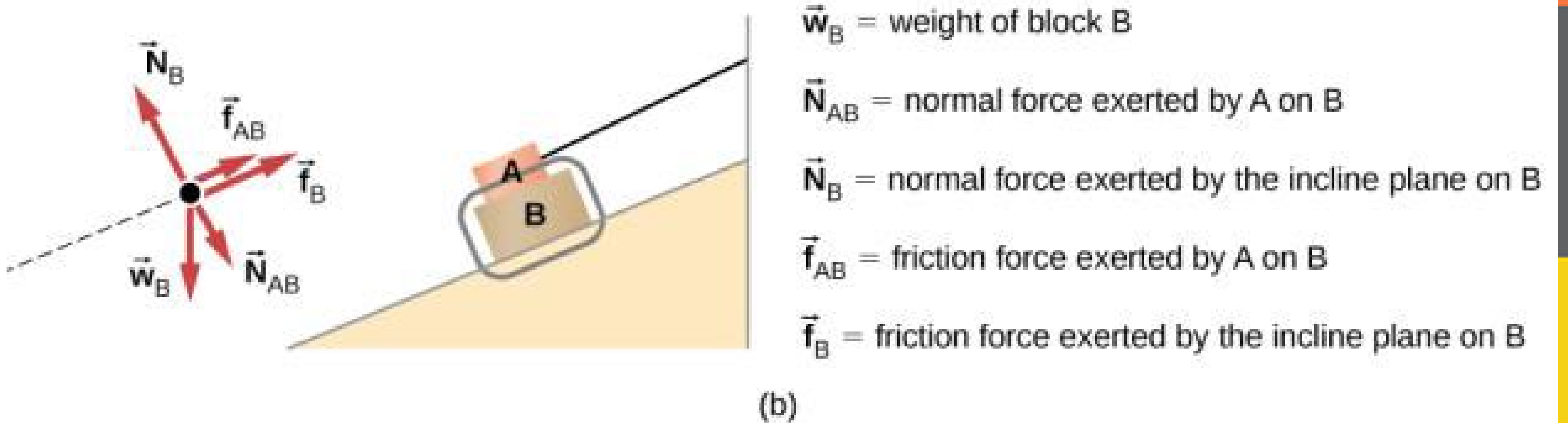
Since the acceleration is parallel to the slope and acting down the slope, it is most convenient to project all forces onto a coordinate system where one axis is parallel to the slope and the other is perpendicular to it (axes shown to the left of the skier).

$\vec{\mathbf{N}}$ is perpendicular to the slope and $\vec{\mathbf{f}}$ is parallel to the slope, but $\vec{\mathbf{w}}$ has components along both axes, namely, w_y and w_x. (Here, $\vec{\mathbf{w}}$ has a squiggly line to show that it has been replaced by these components.)

The force $\vec{\mathbf{N}}$ is equal in magnitude to w_y, so there is no acceleration perpendicular to the slope, but f is less than w_x, so there is a downslope acceleration (along the axis parallel to the slope).

Two examples of inclined plane worked out on board

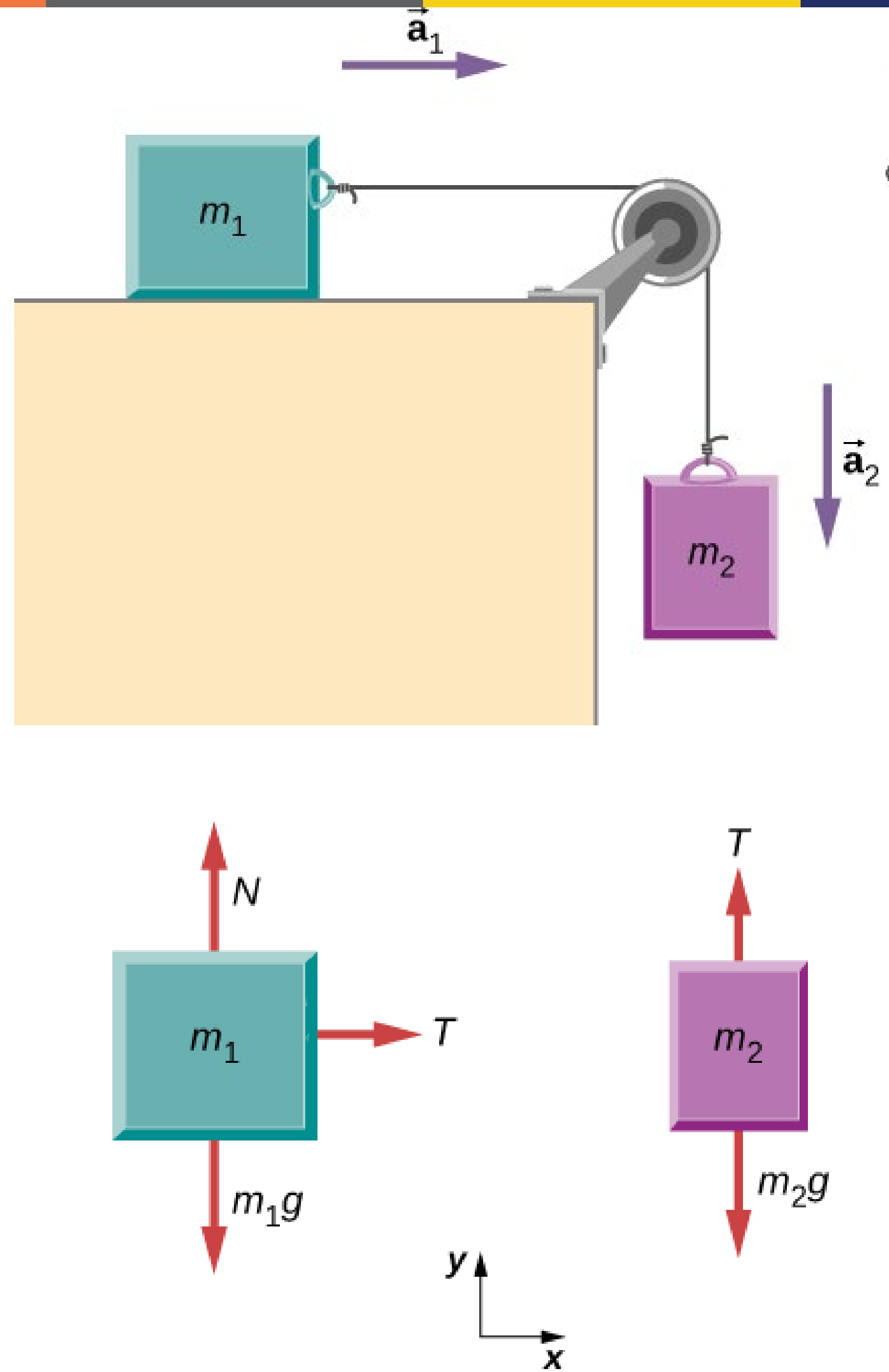




(a)The free-body diagram for isolated object A.

(b)The free-body diagram for isolated object B. Comparing the two drawings, we see that friction acts in the opposite direction in the two figures. Because object A experiences a force that tends to pull it to the right, friction must act to the left. Because object B experiences a component of its weight that pulls it to the left, down the incline, the friction force must oppose it and act up the ramp. Friction always acts opposite the intended direction of motion.

EXAMPLE 5.16.1



Counterweight in Elevator

(Blackboard)