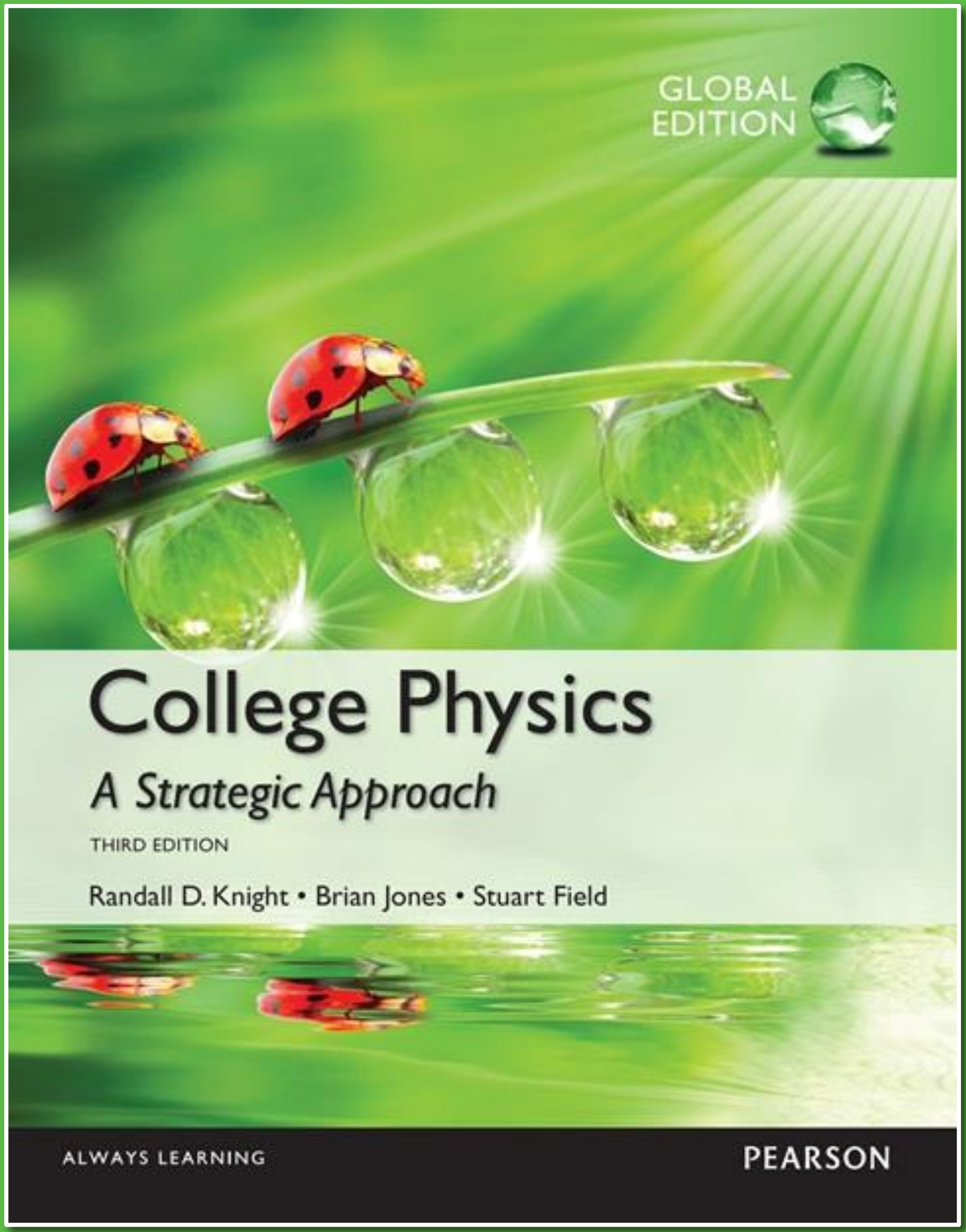


Lecture Presentation

Chapter 4

Forces and Newton's Laws of Motion

Chapter 4 Forces and Newton's Laws of Motion

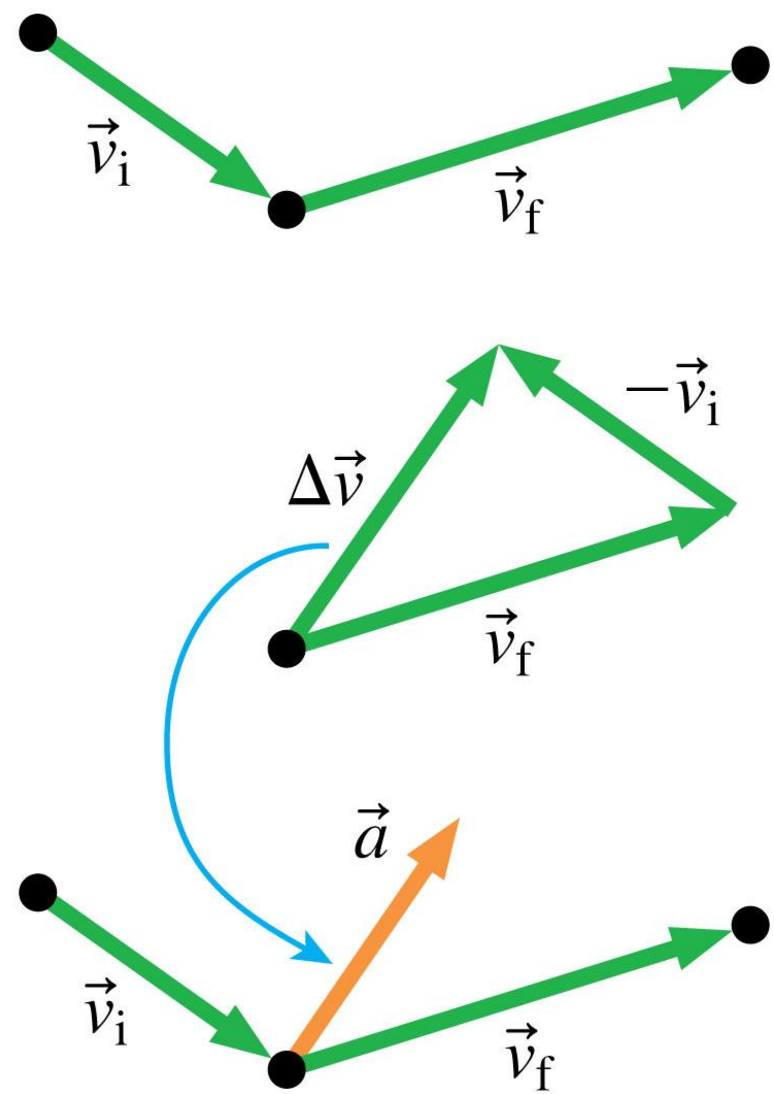
Chapter Goal: To establish a connection between force and motion.

Chapter 4 Forces and Newton's Laws of Motion

Chapter 4 Preview
Looking Back: Acceleration

- You learned in Chapters 2 and 3 that acceleration is a vector pointing in the direction of the change in velocity.

- If the velocity is changing, there is an acceleration. And so, as you'll learn in this chapter, there must be a net force.



Section 4.1 Motion and Forces

What Is a Force?

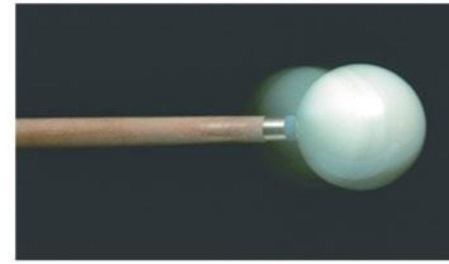
- A **force** is a *push* or a *pull*.

- **A force acts on an object.**

- Every force has an **agent**, something that acts or pushes or pulls.

What Is a Force?

- A **force** is a *vector*. The general symbol for a force is the vector symbol $\vec{F}$. The size or strength of such a force is its magnitude F.



- **Contact forces** are forces that act on an object by touching it at a point of contact.

- **Long-range forces** are forces that act on an object without physical contact.

Reading Question 4.1

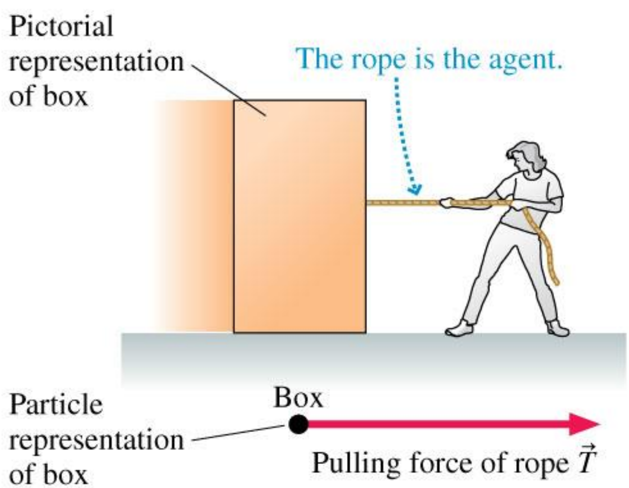
If you are not wearing a seat belt and the car you are driving hits a fixed barrier, you will hit the steering wheel with some force. This is because

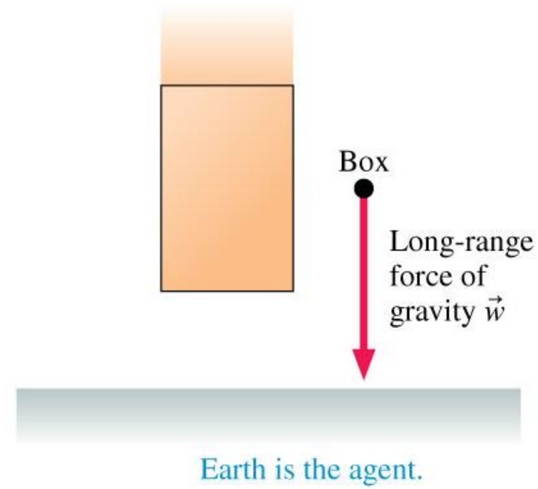
A. The force of the collision has thrown you forward.
B. The steering wheel has been pushed back toward you.
C. You continue moving even after the car has stopped.

What Causes Motion?

Newton's first law An object has no forces acting on it. If it is at rest, it will remain at rest. If it is moving, it will continue to move in a straight line at a constant speed.

Force Vectors



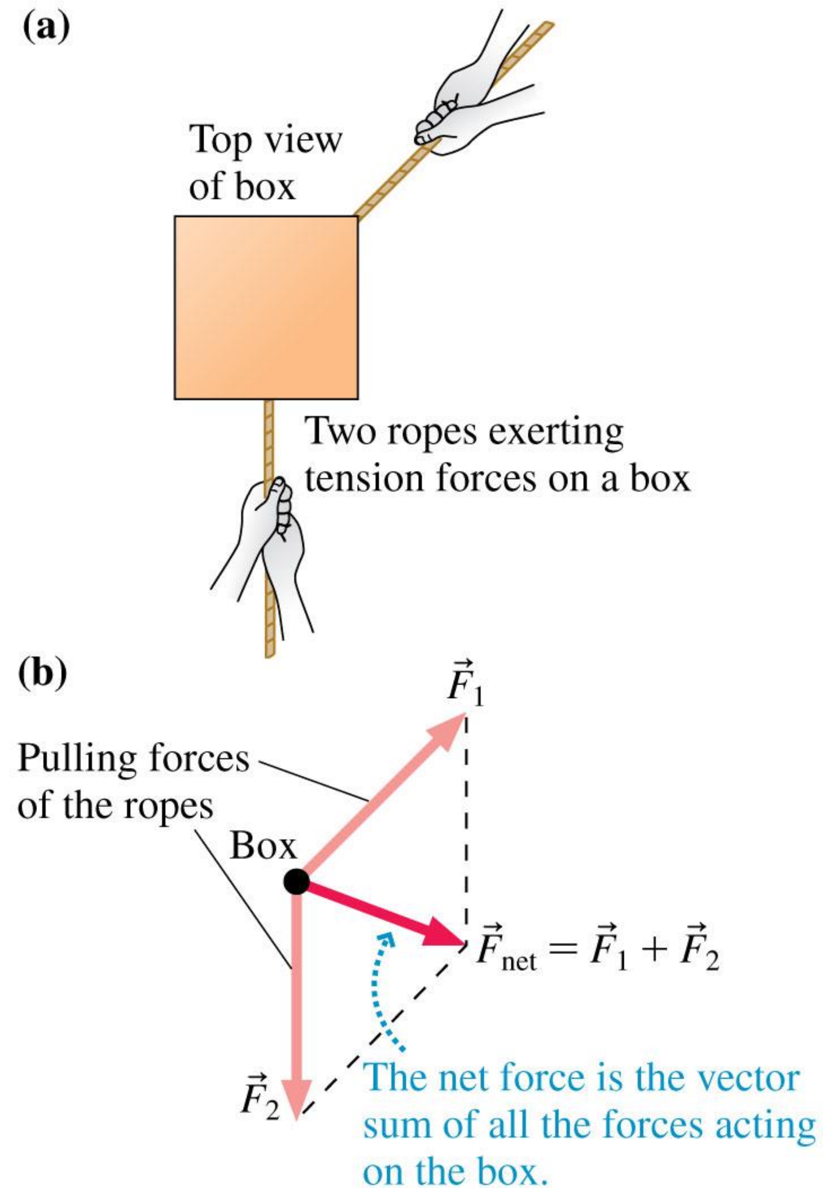


Combining Forces

- Experiments show that when several forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots$ are exerted on an object, the combine to form a **net force** that is the *vector sum* of all the forces:

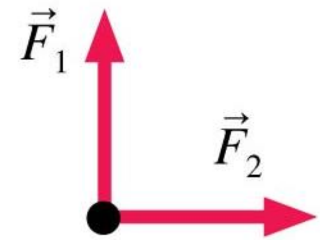
$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$

- The net force is sometimes called the resultant force. It is not a new force. Instead, we should think of the original forces being *replaced* by $\vec{F}_{net}$.

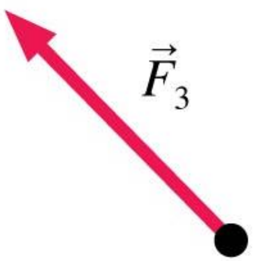


QuickCheck 4.1

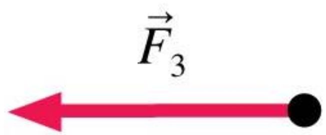
- The net force on an object points to the left. Two of three forces are shown. Which is the missing third force?



Two of the three forces exerted on an object



A.



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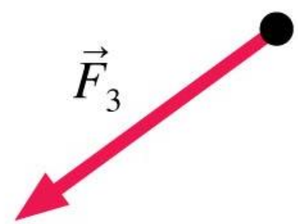

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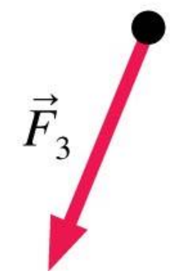
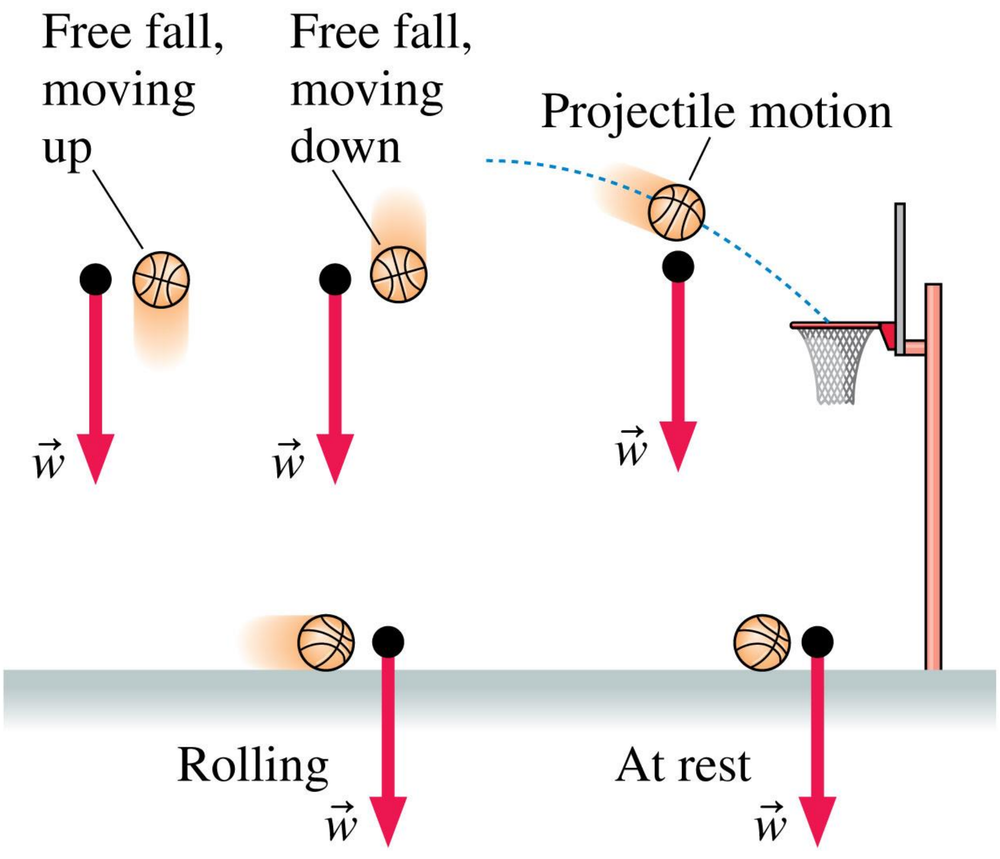


D.

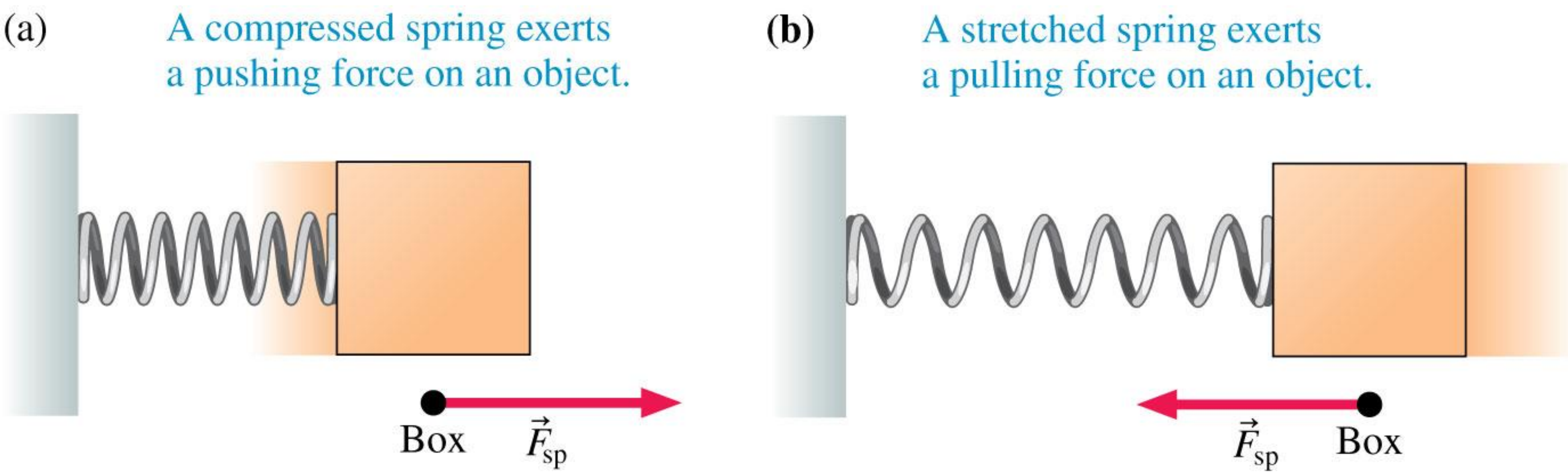
Section 4.2 A Short Catalog of Forces

Weight

- The gravitational pull of the earth on an object on or near the surface of the earth is called **weight**.
- The agent for the weight forces is the *entire earth* pulling on an object.
- **An object's weight vector always points vertically downward,** no matter how the object is moving**.**

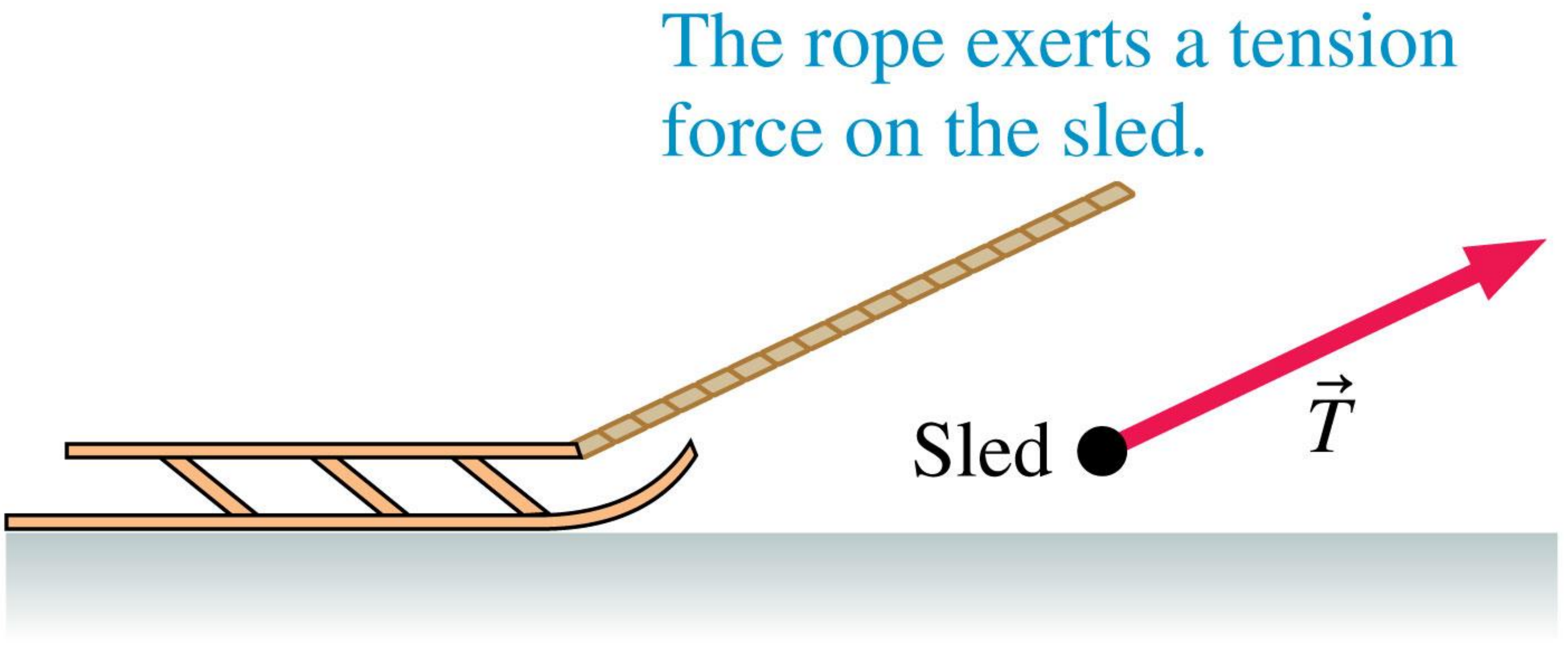


Spring Force



- Springs come in in many forms. When deflected, they push or pull with a spring force.

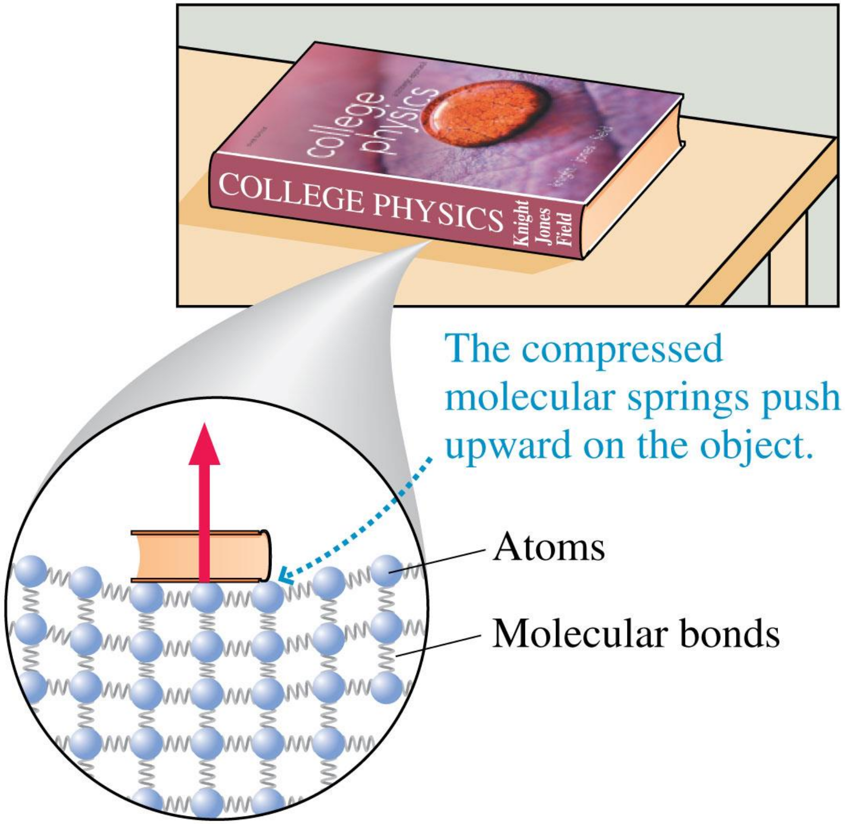
Tension Force



- When a string or rope or wire pulls on an object, it exerts a contact force that we call the **tension force**.
- **The direction of the tension force is always in the direction of the string or rope**.

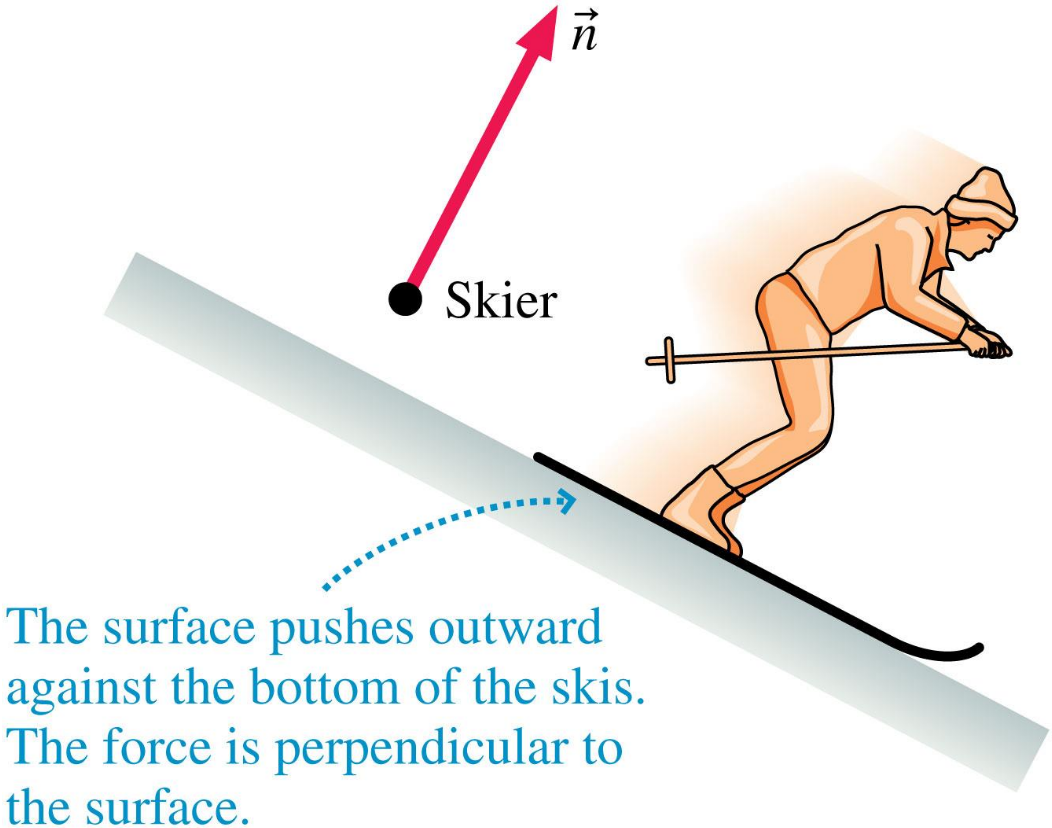
Normal Force

- The force exerted on an object that is pressing against a surface is in a direction *perpendicular* to the surface.
- The **normal force** is the force exerted by a surface (the agent) against an object that is pressing against the surface.



Normal Force

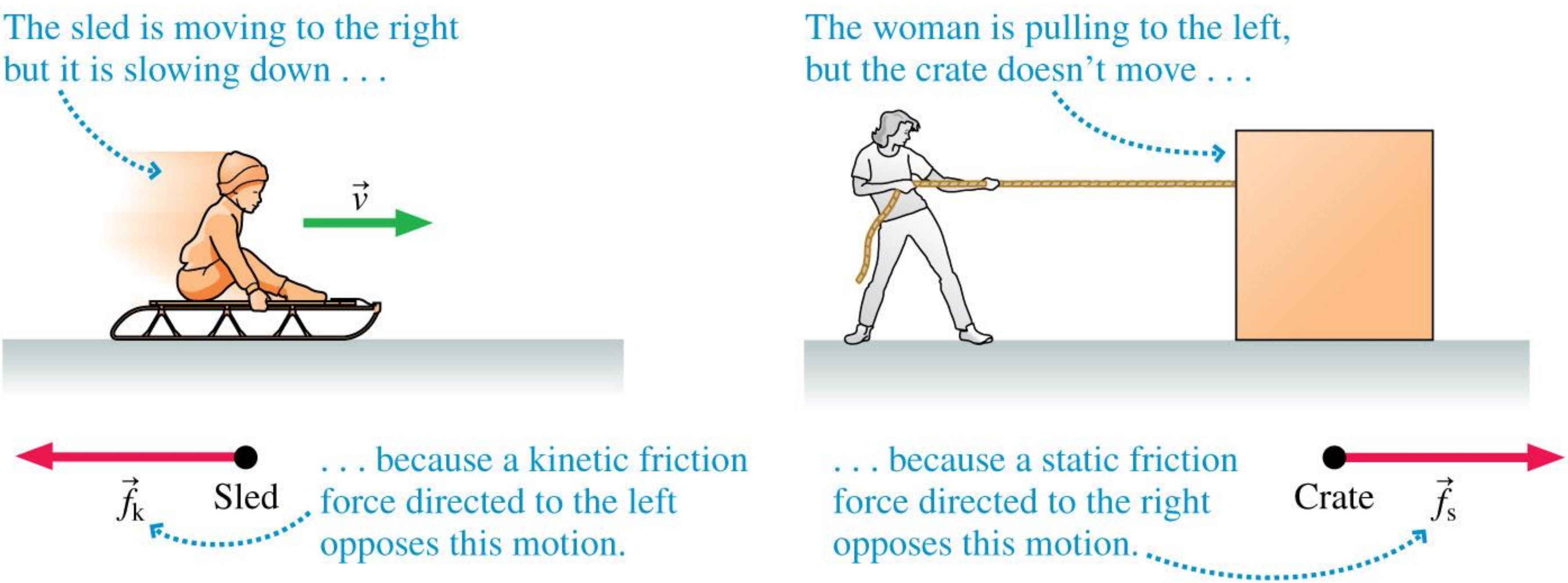
- The normal force is responsible for the “solidness” of solids.
- The symbol for the normal force is $\vec{n}$.



Friction

- Friction, like the normal force, is exerted by a surface.
- The frictional force is always parallel to the surface.
- *Kinetic friction*, denoted by $\vec{f}_{\mathrm{k}}$, acts as an object slides across a surface. Kinetic friction is a force that always "opposes the motion."
- *Static friction*, denoted by $\vec{f}_{\mathrm{s}}$, is the force that keeps an object "stuck" on a surface and prevents its motion relative to the surface. Static friction points in the direction necessary to *prevent* motion.

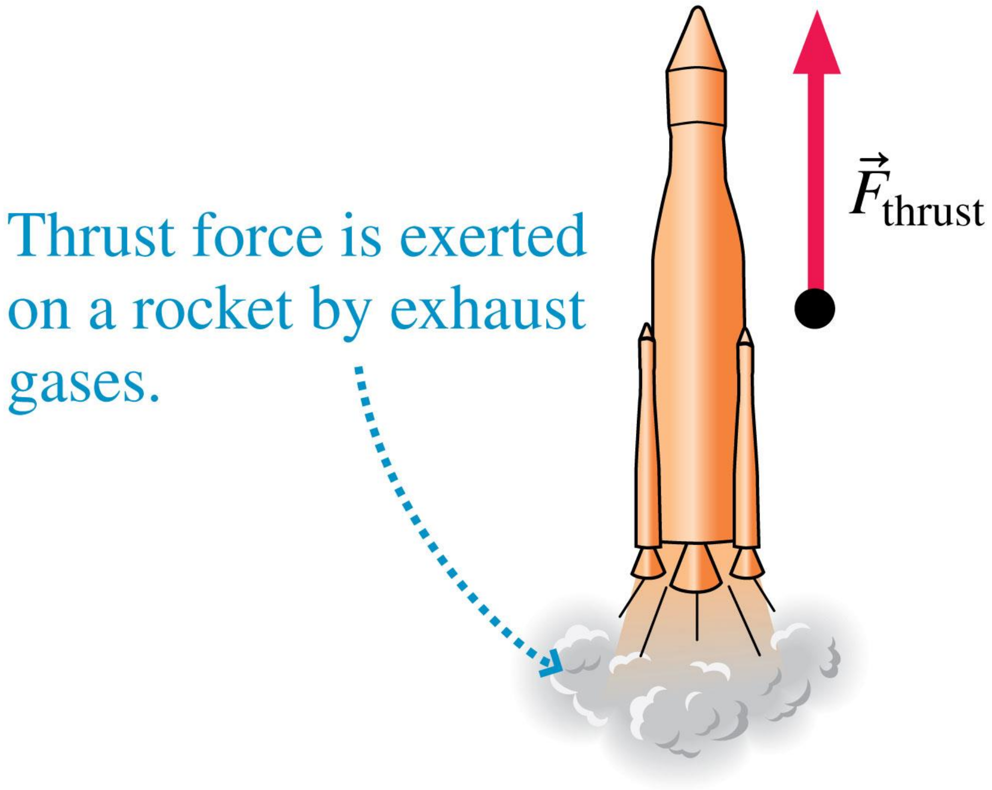
Friction



The sled is moving to the right
but it is slowing down . . .
$\vec{v}$
$\vec{f}_k$
Sled
. . . because a kinetic friction
force directed to the left
opposes this motion.
The woman is pulling to the left,
but the crate doesn't move . . .
. . . because a static friction
force directed to the right
opposes this motion.
Crate
$\vec{f}_s$

Thrust

- **Thrust** is a force that occurs when a jet or rocket engine expels gas molecules at high speed.
- **Thrust is a force opposite the direction in which the exhaust gas is expelled.**



Electric and Magnetic Forces

- Electricity and magnetism, like gravity, exert long-range forces.
- The forces of electricity and magnetism act on charged particles.
- These forces—and the forces inside the nucleus—won’t be important for the dynamics problems we consider in the next several chapters.

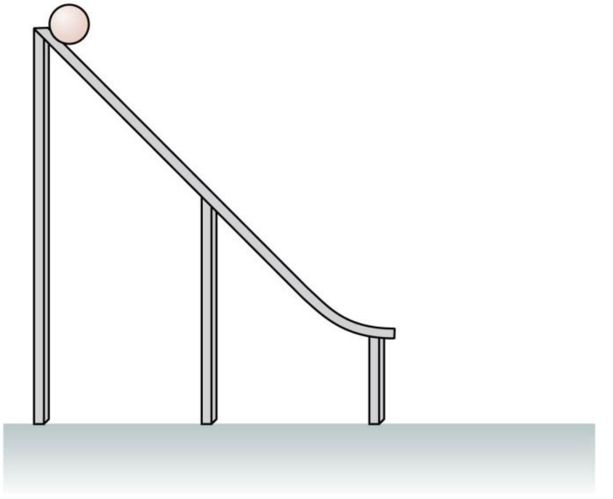
Reading Question 4.4

If you are standing on the floor, motionless, what are the forces that act on you?

A. Weight force
B. Weight force and normal force
C. Normal force and friction force
D. Weight force and tension force

QuickCheck 4.2

- A ball rolls down an incline and off a horizontal ramp. Ignoring air resistance, what force or forces act on the ball as it moves through the air just after leaving the horizontal ramp?



  - The weight of the ball acting vertically down.
  - A horizontal force that maintains the motion.
  - A force whose direction changes as the direction of motion changes.
  - The weight of the ball and a horizontal force.
  - The weight of the ball and a force in the direction of motion.

QuickCheck 4.3

- A steel beam hangs from a cable as a crane lifts the beam. What forces act on the beam?

A. Gravity
B. Gravity and tension in the cable
C. Gravity and a force of motion
D. Gravity and tension and a force of motion

Section 4.3 Identifying Forces

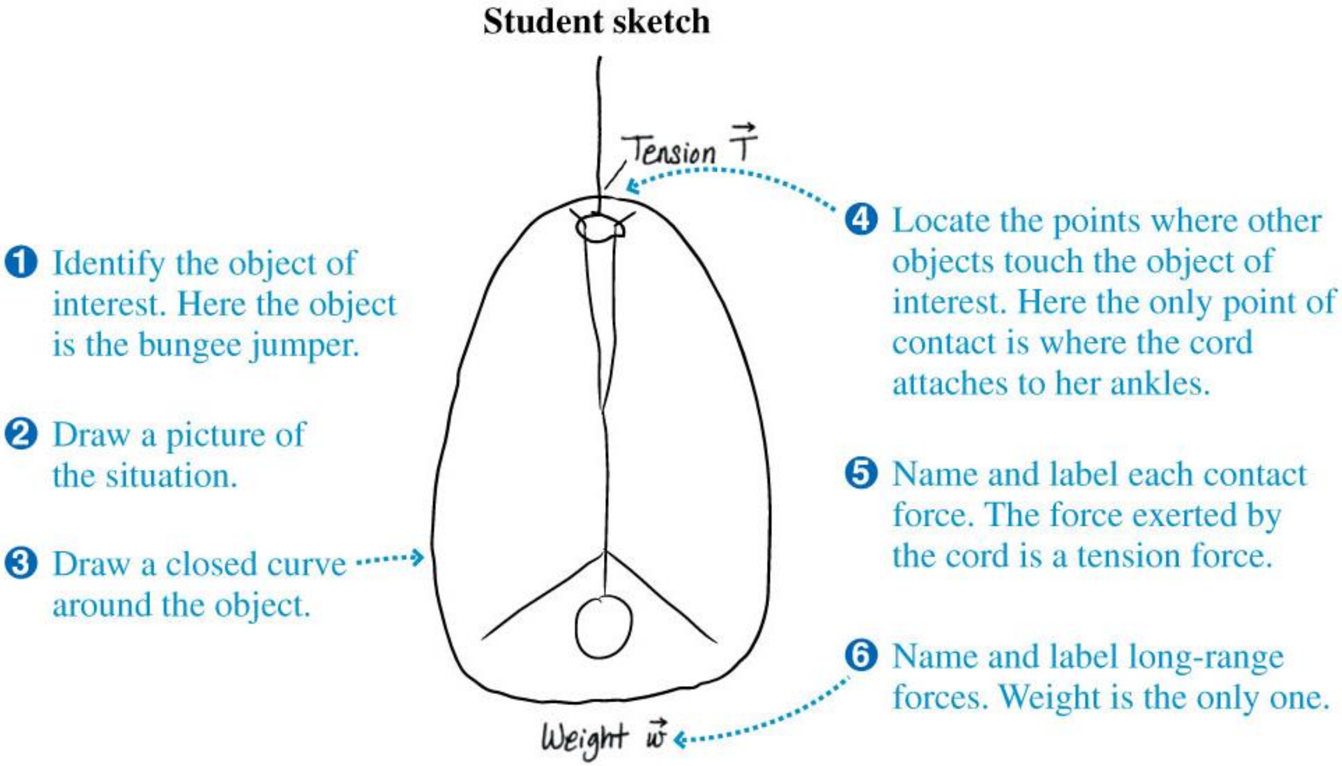
Identifying Forces

TABLE 4.1 Common forces and their notation

Force	Notation
General force	$\vec{F}$
Weight	$\vec{w}$
Spring force	$\vec{F}_{sp}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_s$
Kinetic friction	$\vec{f}_k$

Conceptual Example 4.1: Identifying forces on a bungee jumper

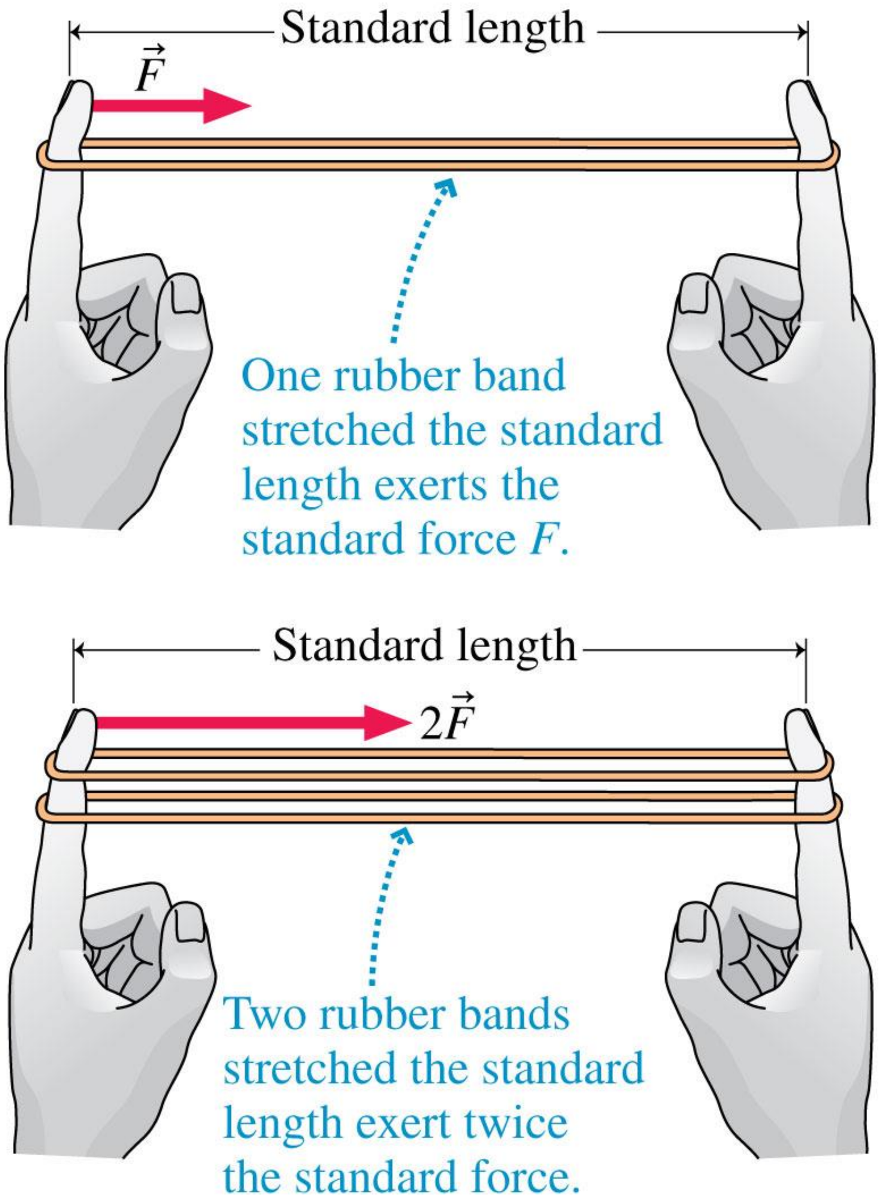
A bungee jumper has leapt off a bridge and is nearing the bottom of her fall. What forces are being exerted on the bungee jumper?



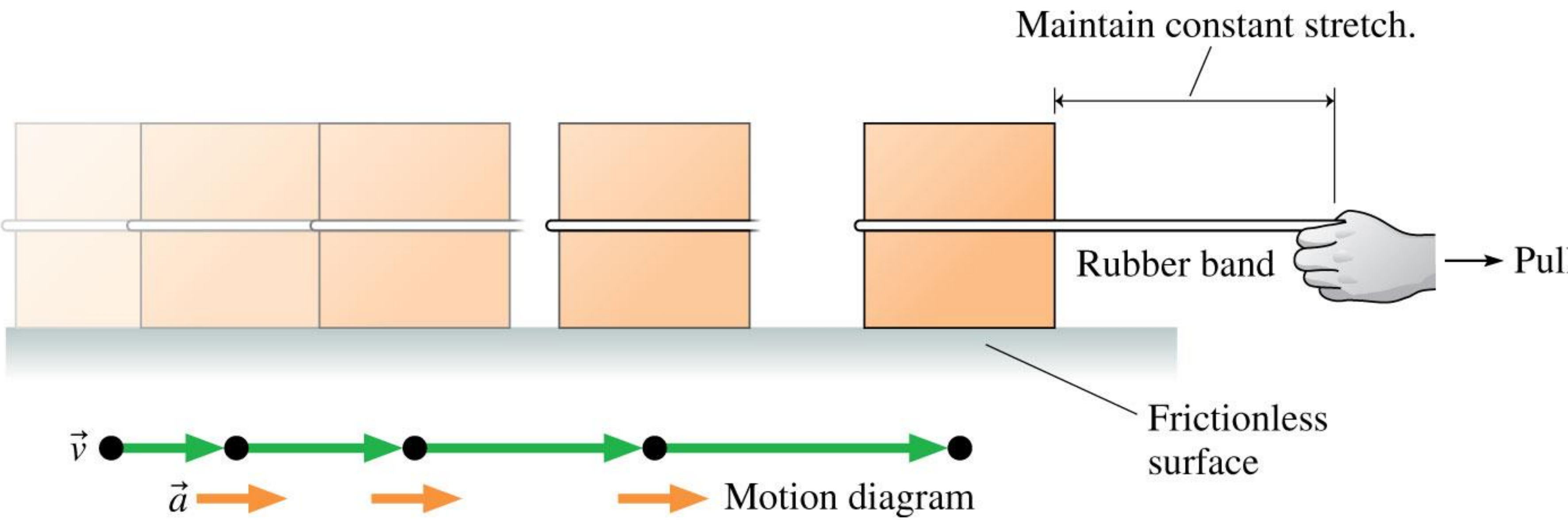
Section 4.4 What Do Forces Do?

What Do Forces Do?

- How does an object move when a force is exerted on it?



What Do Forces Do?



- As the block starts to move, in order to keep the pulling force constant you must *move your hand* in just the right way to keep the length of the rubber band—and thus the force—*constant*.

What Do Forces Do?

The experimental findings of the motion of objects acted on by constant forces are:

- **An object pulled with a constant force moves with a constant acceleration.**
- **Acceleration is directly proportional to force.**
- **Acceleration is *inversely proportional* to an object's mass.**

Section 4.5 Newton’s Second Law

Newton’s Second Law

- **A force causes an object to accelerate.**
- **The acceleration *a* is directly proportional to the force *F* and inversely proportional to the mass *m*:**

$$a = \frac{F}{m}$$

- The direction of the acceleration is the same as the direction of the force:

$$\vec{a} = \frac{\vec{F}}{m}$$

Newton's Second Law

Newton's second law An object of mass m subjected to forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \ldots$ will undergo an acceleration $\vec{a}$ given by

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

where the net force $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all forces acting on the object. **The acceleration vector $\vec{a}$ points in the same direction as the net force vector $\vec{F}_{\text{net}}$.**

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

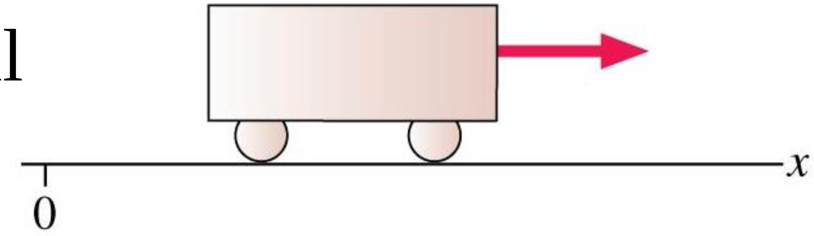
Units of Force

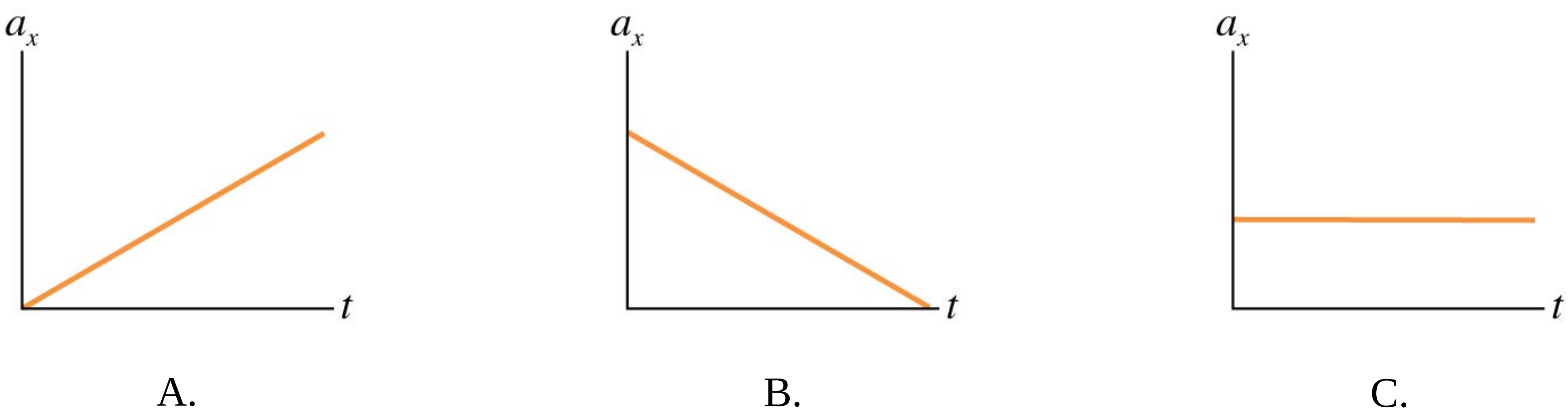
$$1 \text{ basic unit of force} = (1 \text{ kg}) \times (1 \text{ m/s}^2) = 1 \frac{\text{kg} \cdot \text{m}}{\text{s}^2}$$

The basic unit of force is called a *newton*. One **newton** is the force that causes a 1 kg mass to accelerate at 1 m/s^2.

QuickCheck 4.5

- A cart is pulled to the right with a constant, steady force. How will its acceleration graph look?





Example 4.4 Finding the mass of an unknown block

When a rubber band is stretched to pull on a 1.0 kg block with a constant force, the acceleration of the block is measured to be 3.0 m/s^2. When a block with an unknown mass is pulled with the same rubber band, using the same force, its acceleration is 5.0 m/s^2. What is the mass of the unknown block?

PREPARE Each block's acceleration is inversely proportional to its mass.

Example 4.4 Finding the mass of an unknown block (cont.)

SOLVE We can use the result of the Inversely Proportional Relationships box to write

$$\frac{3.0\ \text{m/s}^2}{5.0\ \text{m/s}^2} = \frac{m}{1.0\ \text{kg}}$$

or

$$m = \frac{3.0\ \text{m/s}^2}{5.0\ \text{m/s}^2} \times (1.0\ \text{kg}) = 0.60\ \text{kg}$$

ASSESS With the same force applied, the unknown block had a *larger* acceleration than the 1.0 kg block. It makes sense, then, that its mass—its resistance to acceleration—is *less* than 1.0 kg.

QuickCheck 4.6

- A constant force causes an object to accelerate at $4\ m/s^2$. What is the acceleration of an object with twice the mass that experiences the same force?

A. $1\ m/s^2$
B. $2\ m/s^2$
C. $4\ m/s^2$
D. $8\ m/s^2$
E. $16\ m/s^2$

QuickCheck 4.7

- An object, when pushed with a net force *F*, has an acceleration of 2 m/s^2. Now twice the force is applied to an object that has four times the mass. Its acceleration will be

A. ½ m/s^2
B. 1 m/s^2
C. 2 m/s^2
D. 4 m/s^2

QuickCheck 4.8

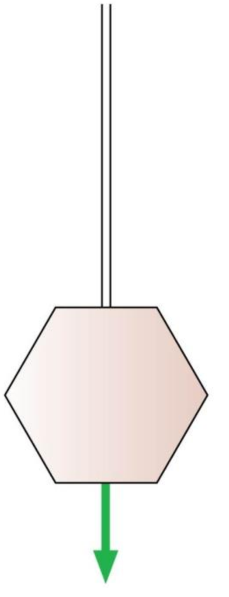
- A 40-car train travels along a straight track at 60 km/h.

A skier speeds up as she skis downhill. On which is the net force greater?

A. The train
B. The skier
C. The net force is the same on both.
D. There's not enough information to tell.

QuickCheck 4.9

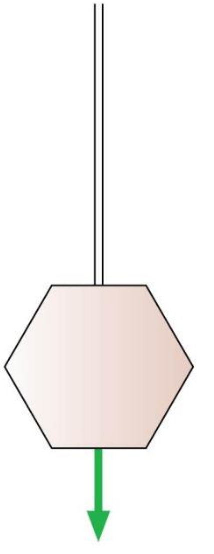
- An object on a rope is lowered at constant speed Which is true?



A. The rope tension is greater than the object’s weight.
B. The rope tension equals the object’s weight.
C. The rope tension is less than the object’s weight.
D. The rope tension can’t be compared to the object’s weight.

QuickCheck 4.10

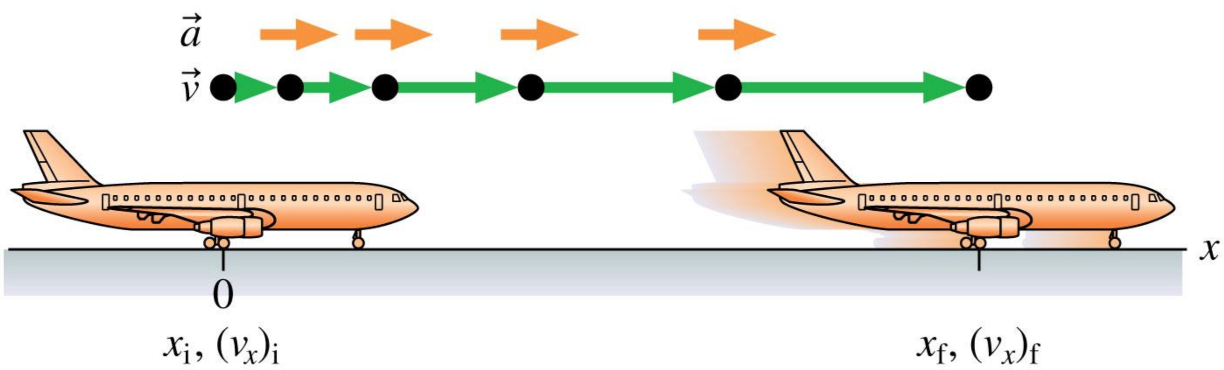
- An object on a rope is lowered at a steadily decreasing speed. Which is true?



A. The rope tension is greater than the object's weight.
B. The rope tension equals the object's weight.
C. The rope tension is less than the object's weight.
D. The rope tension can't be compared to the object's weight.

Example 4.6 Racing down the runway

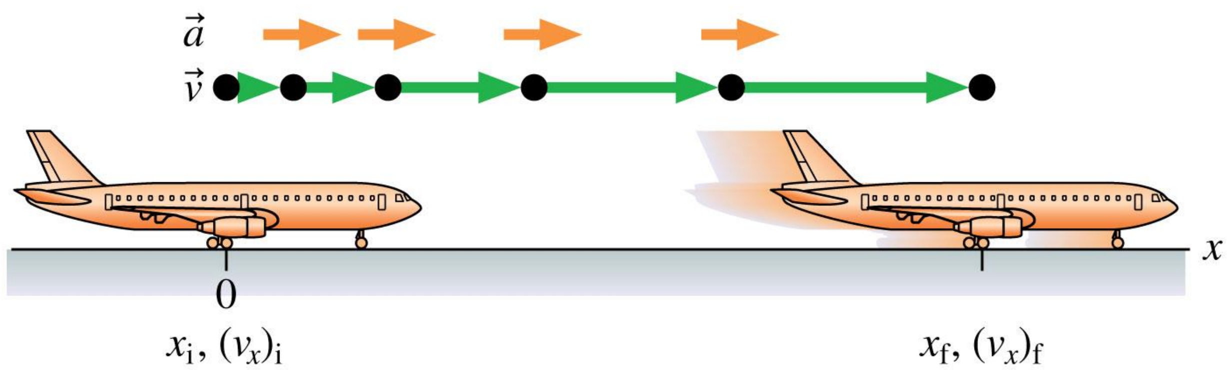
A Boeing 737—a small, short-range jet with a mass of 51,000 kg—sits at rest. The pilot turns the pair of jet engines to full throttle, and the thrust accelerates the plane down the runway. After traveling 940 m, the plane reaches its takeoff speed of 70 m/s and leaves the ground. What is the thrust of **each engine**?



Known	Find
$x_i = 0$ m, $(v_x)_i = 0$ m/s	a_x and F_{net}
$x_f = 940$ m, $(v_x)_f = 70$ m/s	

Example 4.6 Racing down the runway (cont.)

PREPARE If we assume that the plane undergoes a constant acceleration (a reasonable assumption), we can use kinematics to find the magnitude of that acceleration. Then we can use Newton’s second law to find the force—the thrust—that produced this acceleration.



Known

$x_i = 0$ m, $(v_x)_i = 0$ m/s

$x_f = 940$ m, $(v_x)_f = 70$ m/s

Find

a_x and F_{net}

Example 4.6 Racing down the runway (cont.)

SOLVE We don't know how much time it took the plane to reach its takeoff speed, but we do know that it traveled a distance of 940 m. We can solve for the acceleration by using the third constant-acceleration equation:

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\,\Delta x$$

The displacement is $\Delta x = x_f - x_i = 940$ m, and the initial velocity is 0. We can rearrange the equation to solve for the acceleration:

$$a_x = \frac{(v_x)_f^2}{2\,\Delta x} = \frac{(70\text{ m/s})^2}{2(940\text{ m})} = 2.61\text{ m/s}^2$$

Example 4.6 Racing down the runway (cont.)

We've kept an extra significant figure because this isn't our final result—we are asked to solve for the thrust. We complete the solution by using Newton's second law:

$$F = ma_x = (51{,}000 \text{ kg})(2.61 \text{ m/s}^2) = 133{,}000 \text{ N}$$

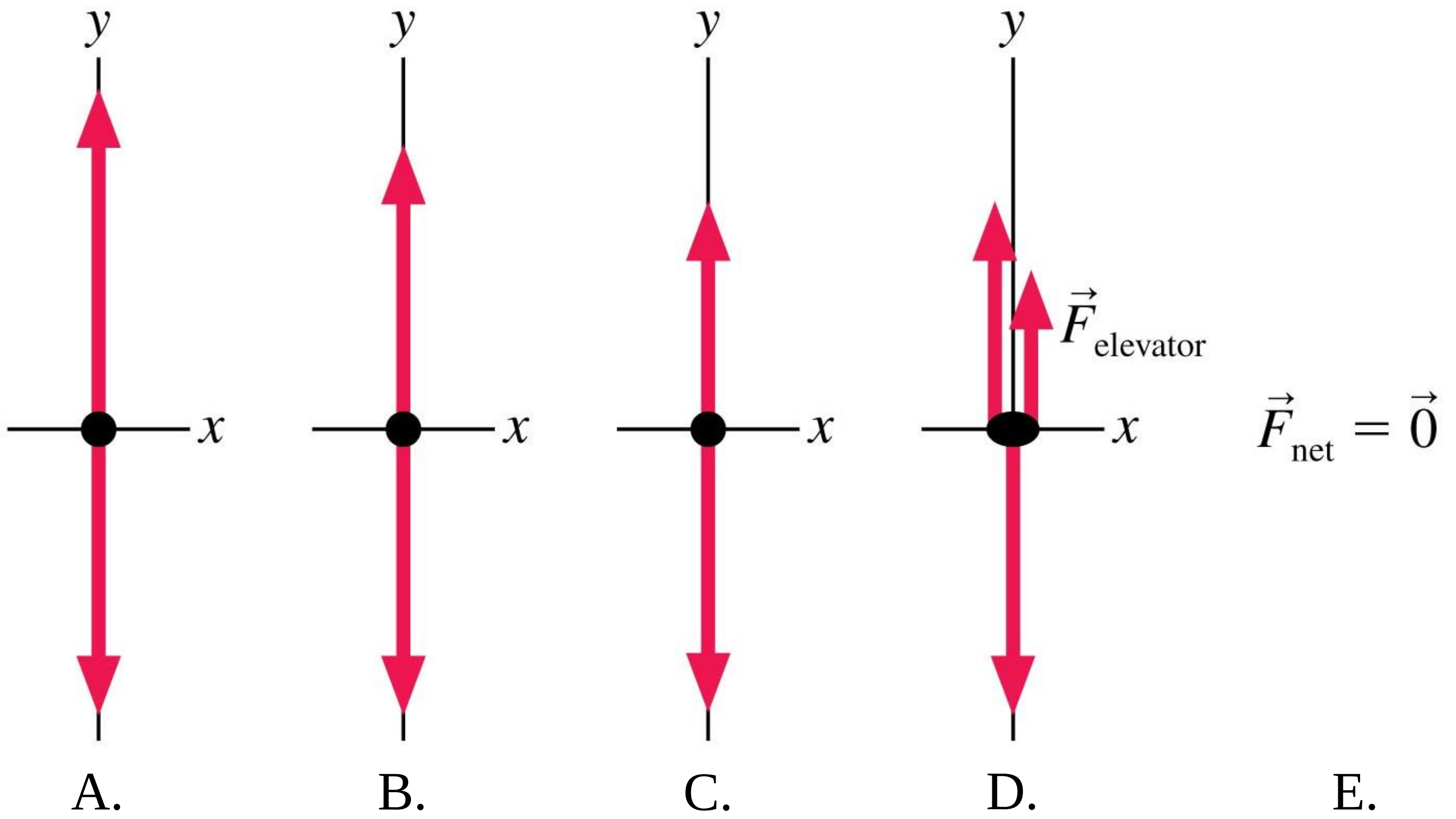
The thrust of each engine is half of this total force:

$$\text{Thrust of one engine} = 67{,}000 \text{ N} = 67 \text{ kN}$$

Section 4.6 Free-Body Diagrams

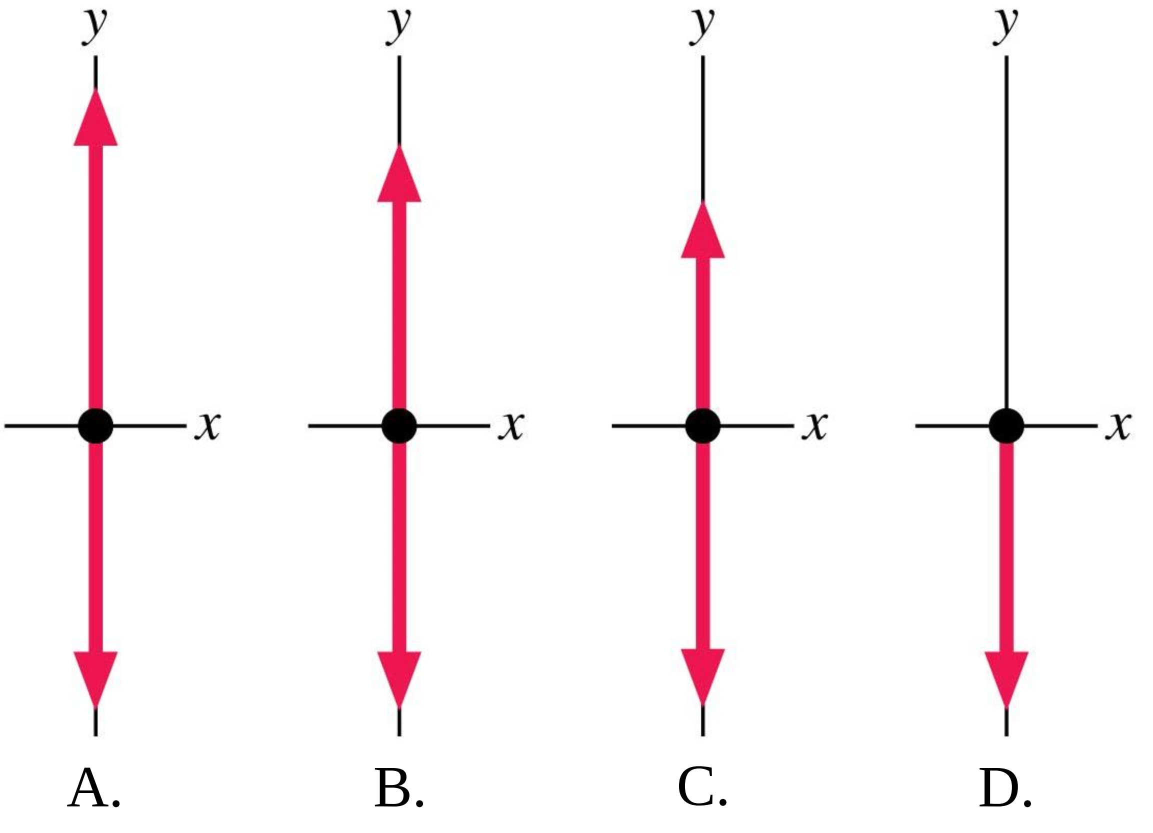
QuickCheck 4.11

- An elevator, lifted by a cable, is moving upward and slowing. Which is the correct free-body diagram?



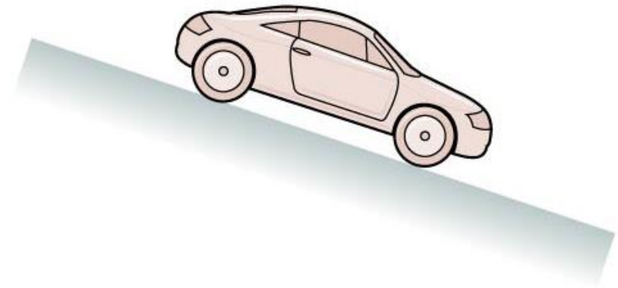
QuickCheck 4.12

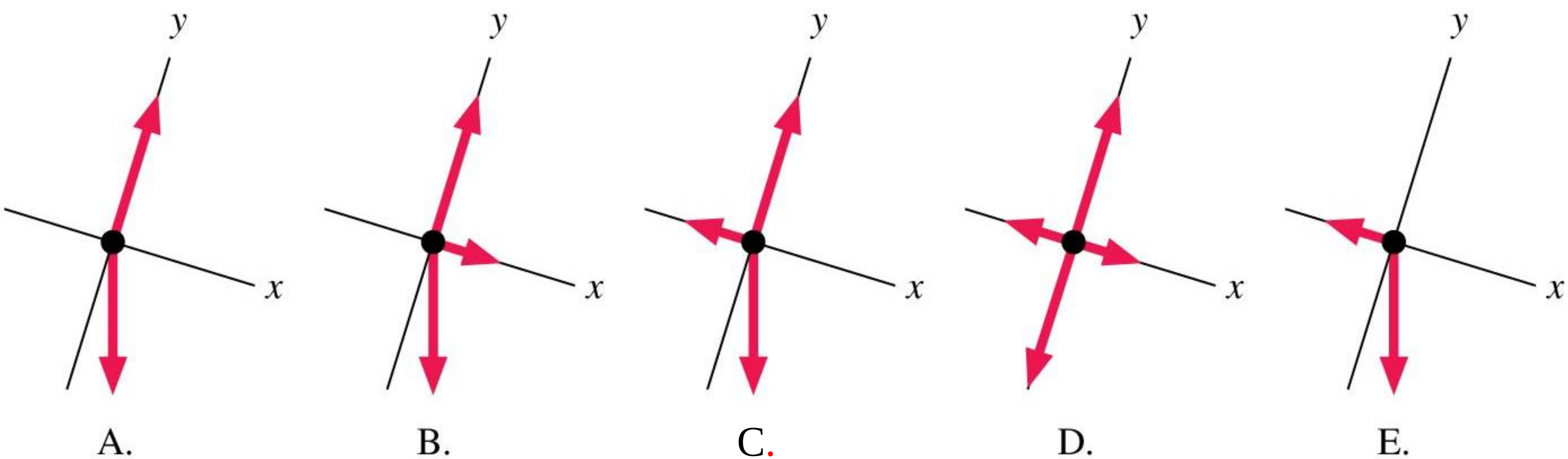
- A ball has been tossed straight up. Which is the correct free-body diagram just after the ball has left the hand? Ignore air resistance.



QuickCheck 4.14

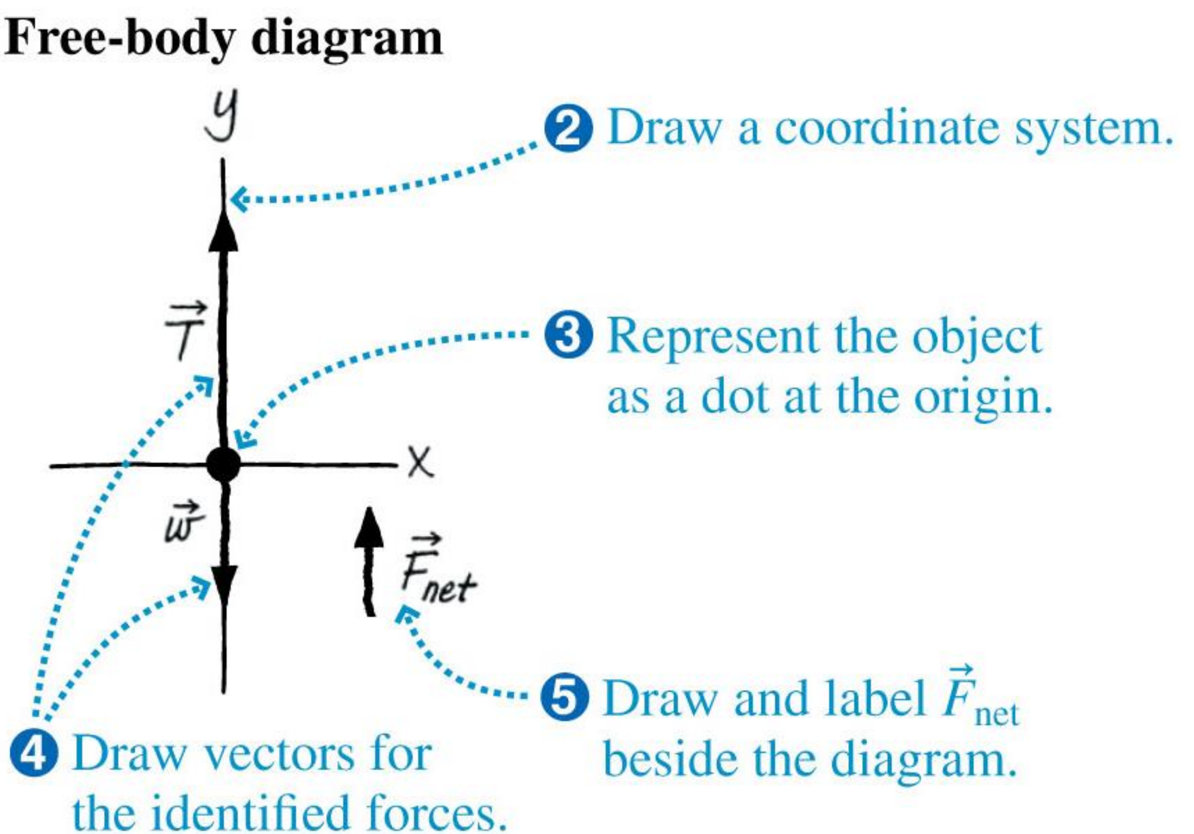
- A car is parked on a hill. Which is the correct free-body diagram?





Example 4.7 Forces on an elevator

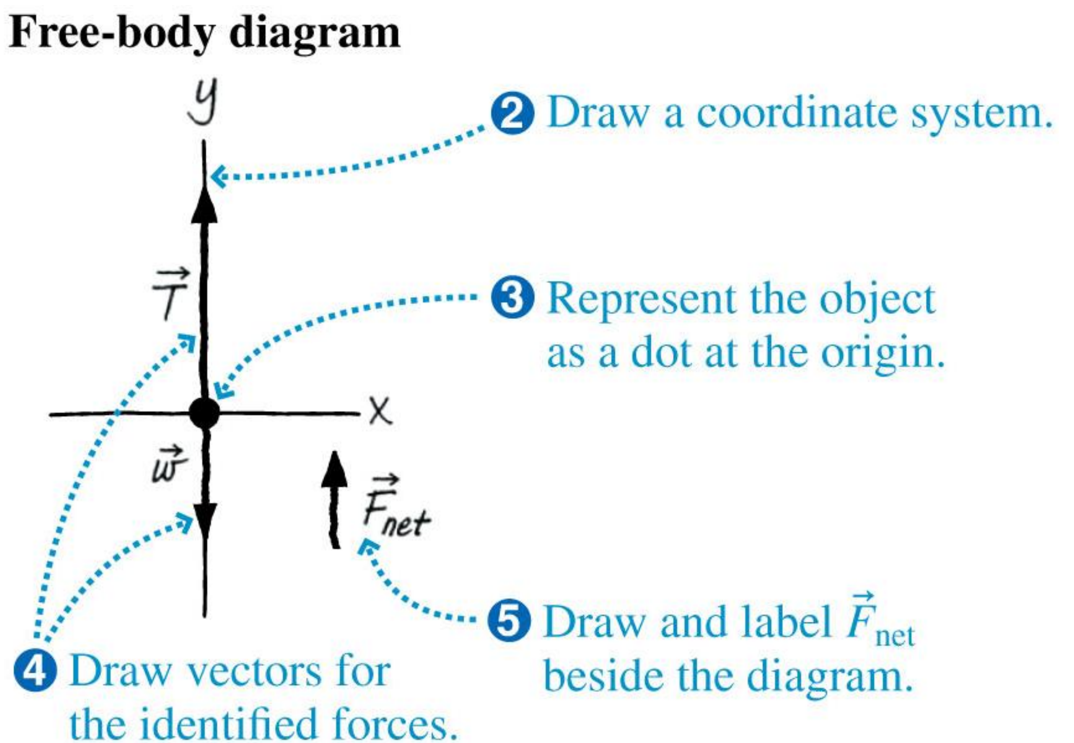
An elevator, suspended by a cable, speeds up as it moves upward from the ground floor. Draw a free-body diagram of the elevator.



Example 4.7 Forces on an elevator (cont.)

PREPARE The elevator is moving upward, and its speed is increasing. This means that the acceleration is directed upward—that's enough to say about acceleration for the purposes of this problem. Next, we continue with the forces.

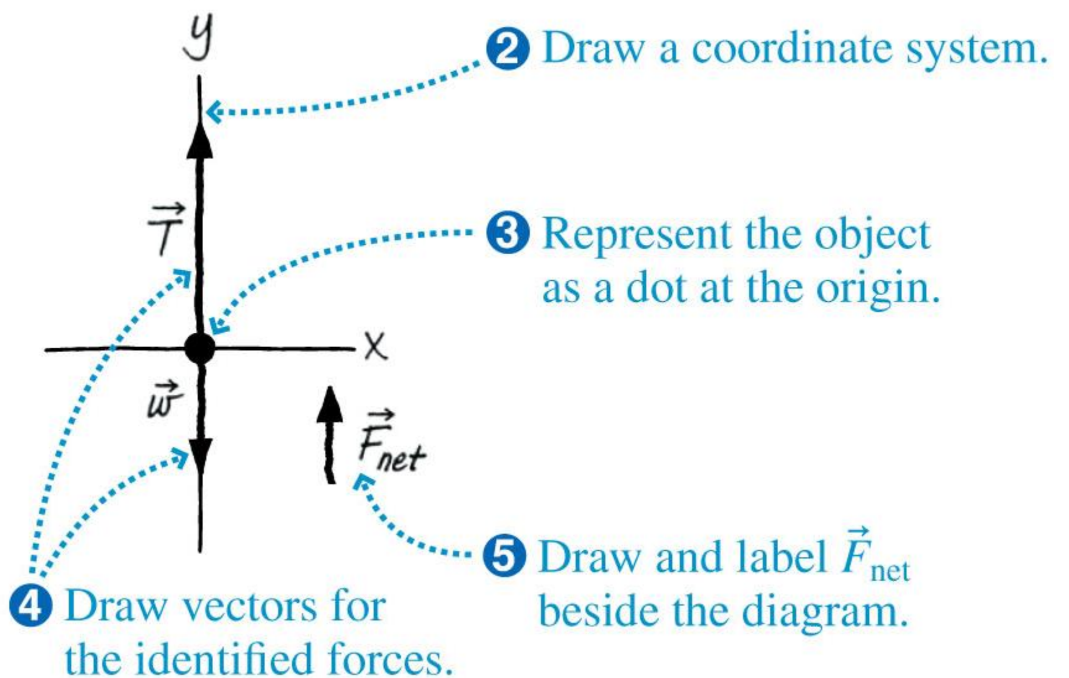
We know that the acceleration is directed upward, so $\vec{F}_{\text{net}}$ must be directed upward as well.



Example 4.7 Forces on an elevator (cont.)

ASSESS Let's take a look at our picture and see if it makes sense. The coordinate axes, with a vertical *y*-axis, are the ones we would use in a pictorial representation of the motion, so we've chosen the correct axes. $\vec{F}_{\text{net}}$ is directed upward. For this to be true, the magnitude of $\vec{T}$ must be greater than the magnitude of $\vec{w}$, which is just what we've drawn.

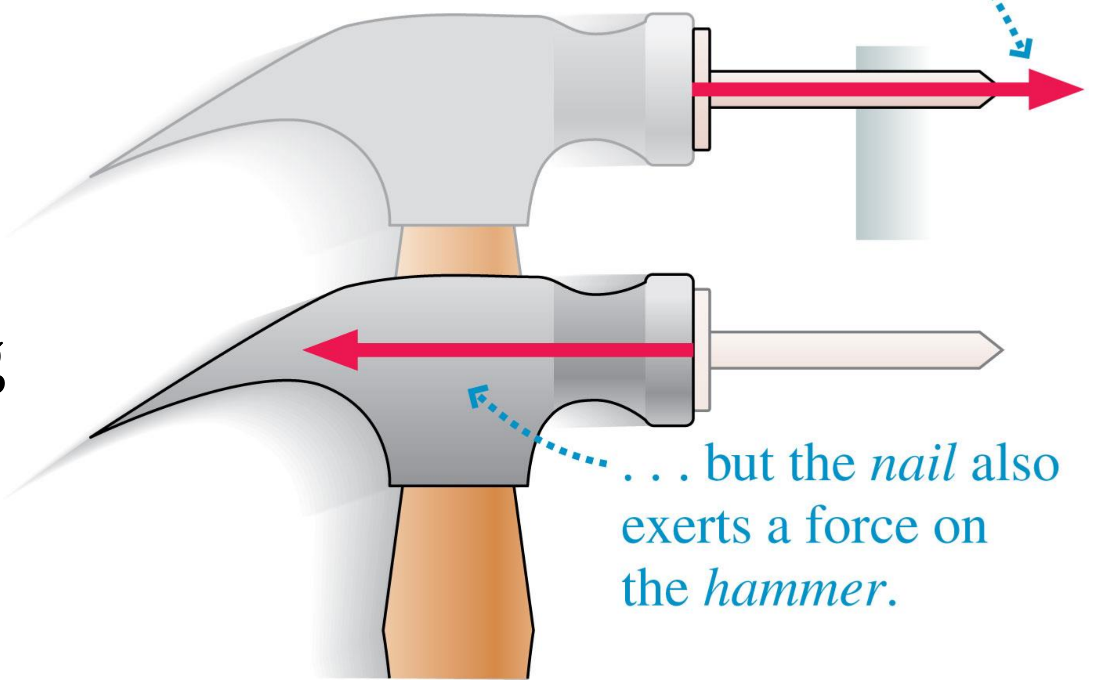
Free-body diagram



Section 4.7 Newton's Third Law

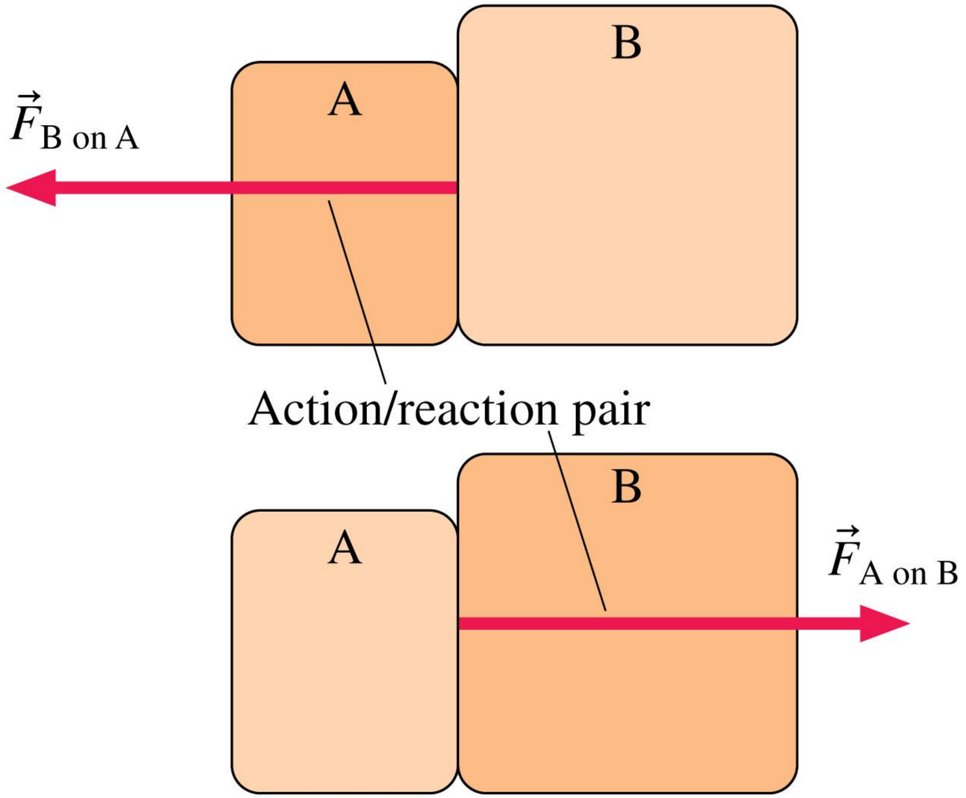
Newton's Third Law

- Motion often involves two or more objects *interacting* with each other.
- As the hammer hits the nail, the nail pushes back on the hammer.
- A bat and a ball, your foot and a soccer ball, and the earth-moon system are other examples of interacting objects.



Interacting Objects

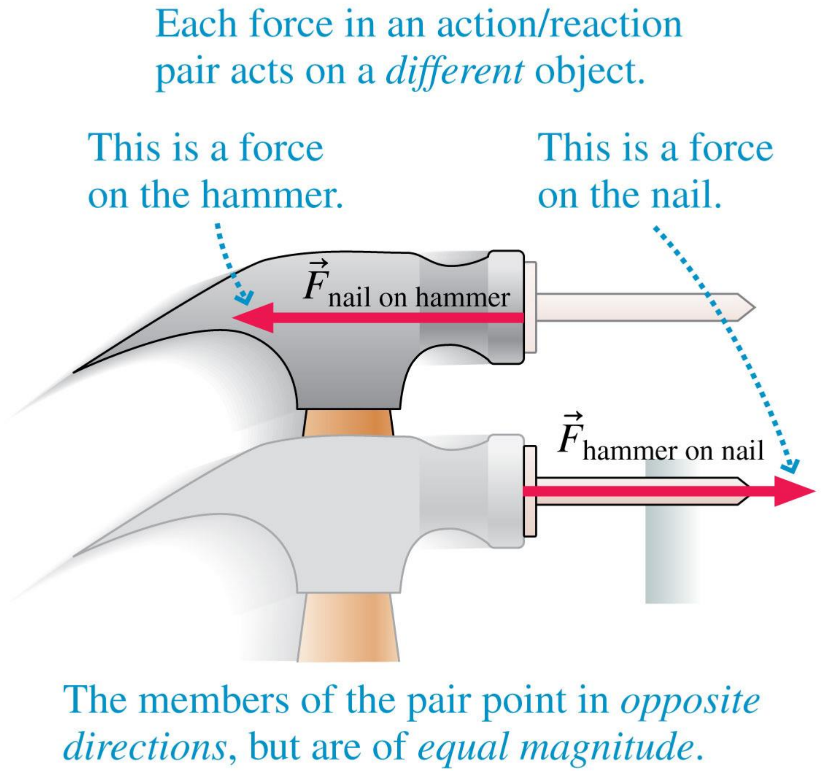
- An **interaction** is the mutual influence of two objects on each other.
- The pair of forces shown in the figure is called an **action/reaction pair**.
- **An action/reaction pair of forces exists as a pair, or not at all.**



Reasoning with Newton's Third Law

Newton's third law Every force occurs as one member of an action/reaction pair of forces.

- The two members of an action/reaction pair act on two *different* objects.
- The two members of an action/reaction pair point in *opposite* directions and are *equal in magnitude*.



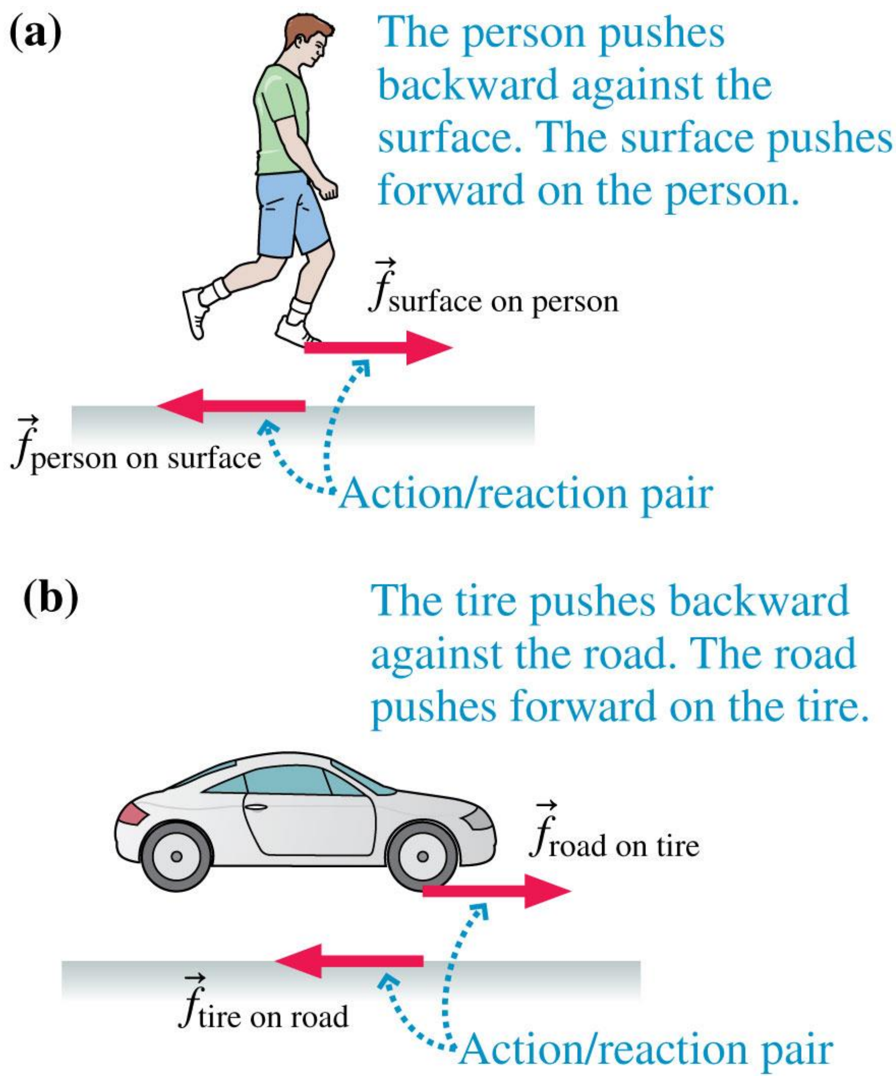
Reading Question 4.6

An action/reaction pair of forces

A. Points in the same direction.
B. Acts on the same object.
C. Are always long-range forces.
D. Acts on two different objects.

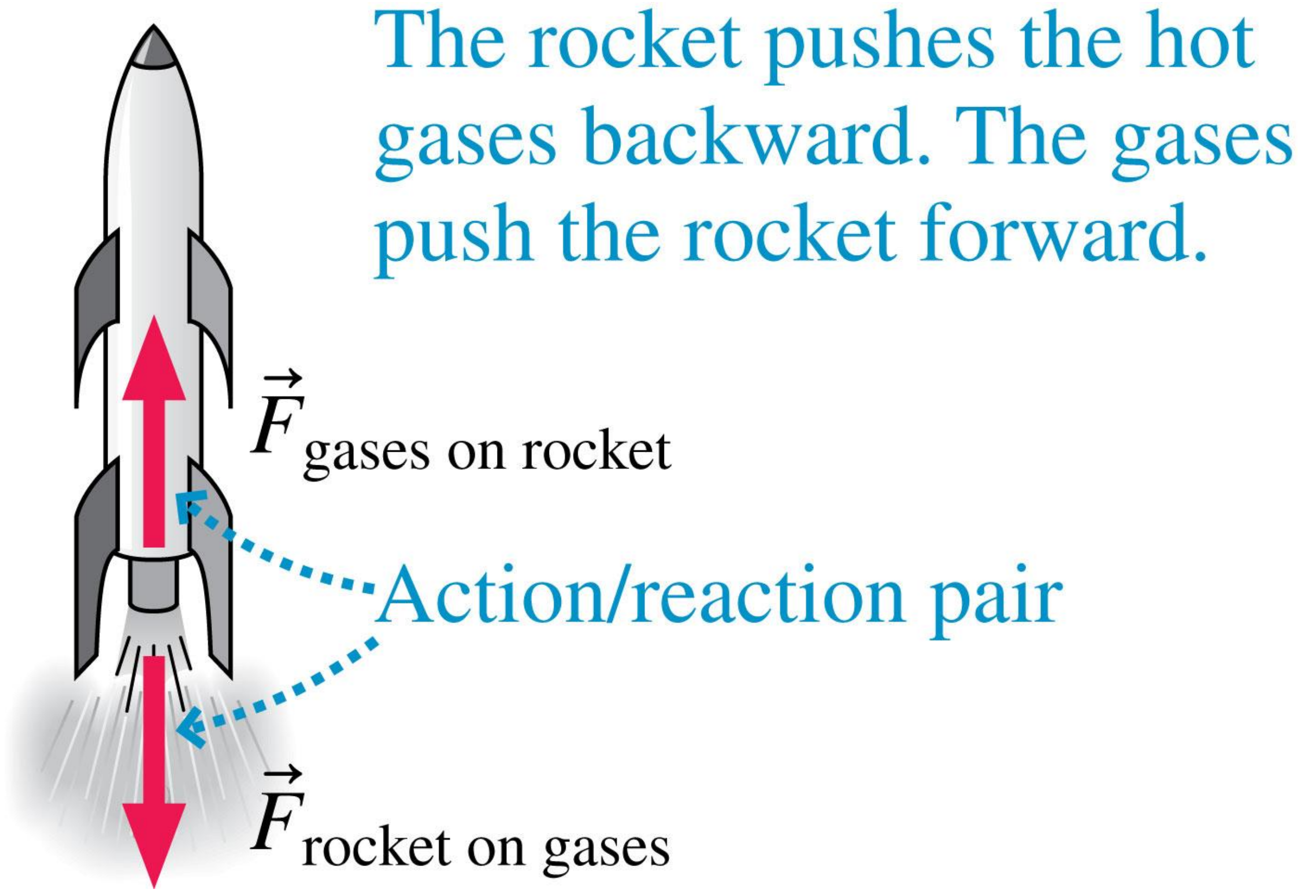
Runners and Rockets

- In order for you to walk, the floor needs to have friction so that your foot sticks to the floor as you straighten your leg, moving your body forward.
- The friction that prevents slipping is *static* friction.
- The static friction has to point in the forward direction to prevent your foot from slipping.



Runners and Rockets

- The rocket pushes hot gases out the back, and this results in a forward force (*thrust*) on the rocket.



QuickCheck 4.16

10-year-old Sarah stands on a skateboard.

Her older brother Ali starts pushing her backward and she starts speeding up.

The force of Ali on Sarah is

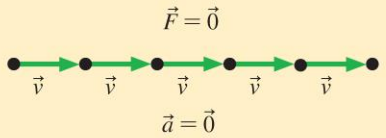
A. Greater than the force of Sarah on Ali.
B. Equal to the force of Sarah on Ali.
C. Less than the force of Sarah on Ali.

Summary

GENERAL PRINCIPLES

Newton's First Law

Consider an object with no force acting on it. If it is at rest, it will remain at rest. If it is in motion, then it will continue to move in a straight line at a constant speed.



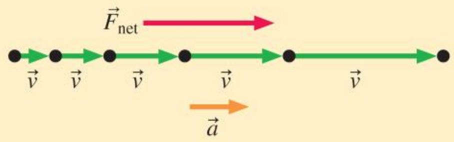
The first law tells us that an object that experiences no force will experience no acceleration.

Newton's Second Law

An object with mass m will undergo acceleration

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

where the net force $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all the individual forces acting on the object.



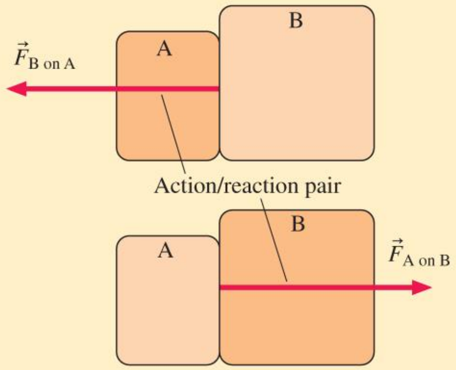
The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion. The acceleration points in the direction of $\vec{F}_{net}$.

Newton's Third Law

Every force occurs as one member of an **action/reaction** pair of forces. The two members of an action/reaction pair:

- act on two *different* objects.
- point in opposite directions and are equal in magnitude:

$$\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A}$$



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