Going Down

You might expect a sky diver to plummet to Earth in a rapid, uncontrolled descent. Yet a group of sky divers can perform beautiful maneuvers as they drop toward Earth at high speeds. How do sky divers control their velocities?

Look at the text on page 134 for the answer.

CHAPTER

6 Forces

From previous chapters, you've learned that acceleration describes a change in velocity of an object. Velocity, in turn, describes a change in the object's position. But what causes acceleration in the first place? In other words, why do things move? What is the cause of motion?

The answer was given by Sir Isaac Newton more than 300 years ago. He explained the way in which forces—pushes and pulls—influence motion. Newton summed up his explanations in three clear and concise laws. These laws explain what—and how much—is needed to make an object move. They also explain what happens when a moving object crashes into something.

For example, Newton's laws explain why sky divers fall rapidly downward when they first leap from a plane. The laws also explain why after a time, the divers continue their fall at a rapid, but steady, speed. Sky divers understand, and you will, too, how changing the position of their arms and legs changes their motion, allowing them the freedom to perform extraordinary feats in the sky.

As you study Chapter 6, you will be introduced to each of Newton's three laws. Although researchers have completed hundreds of experiments showing that real objects move the way that Newton said they do, the laws sometimes seem contrary to common sense. To fully understand the laws that govern the motion of every moving object you can see around you, you'll have to do experiments and observe the evidence yourself.

WHAT YOU'LL LEARN

- You will use Newton's laws of motion to solve motion problems.
- You will determine the magnitude and direction of the net force that determines the motion of an object.

WHY IT'S IMPORTANT

- The extent to which your environment can withstand the forces of nature depends upon how well the magnitudes of those forces can be predicted and upon the building of homes, bridges, and other structures that are capable of withstanding those forces.

PHYSICS Online

To find out more about forces, visit the Glencoe Science Web site at science.glencoe.com

CLICK HERE

6.1 Force and Motion

Push your book slowly across your desk. Then fasten a string to the book and pull it. By pushing or pulling the book, you are exerting a force on the book. An object that experiences a push or a pull has a **force** exerted on it. Notice that it is the object that is considered. The object is called the **system.** The world around the object that exerts forces on it is called the **environment.**

You can push hard or gently, left or right, so force has both magnitude and direction. Force is a vector quantity. The symbol $\boldsymbol{F}$ is used to represent the force vector, and F represents its magnitude, or size. How many different kinds of forces can you identify?

OBJECTIVES

- **Define** a force and **differentiate** between contact forces and long-range forces.
- **Recognize** the significance of Newton's second law of motion and use it to solve motion problems.
- **Explain** the meaning of Newton's first law and **describe** an object in equilibrium.

Color Conventions

- Force vectors are **blue.**
- Position vectors are **green.**
- Velocity vectors are **red.**
- Acceleration vectors are **violet.**

Contact Versus Long-Range Forces

Forces exerted by the environment on a system can be divided into two types. The first type is a contact force. A **contact force** acts on an object only by touching it. Either the desk or your hands are probably touching your physics book right now, exerting a contact force on it. Your hand and the desk exert forces only when they touch the book.

The second kind of force is a **long-range force.** A long-range force is exerted without contact. If you have ever played with magnets, you know that they exert forces without touching.

Suppose that you are holding a ball in your hand. The ball has a contact force exerted on it, the force of your hand. Now, suppose that you let go of the ball. Although nothing is touching the ball, it moves because there is a long-range force, the **force of gravity,** acting on the ball. The force of gravity is an attractive force that exists between all objects. In the first half of this book, the only long-range force that will be considered is the force of gravity.

Forces have agents Each force has a specific, identifiable, immediate cause called the **agent.** You should be able to name the agent of each force, for example, the force of the desk or your hand on your book. The agent can be animate, such as a person, or inanimate, such as a desk, floor, or a magnet. The agent for the force of gravity is Earth's mass. If you can't name an agent, the force doesn't exist!

The first step in solving any problem is to create a pictorial model. To represent the forces on a book as it rests on a table, sketch the situation, as shown in **Figure 6–1.** Circle the system and identify every place where the system touches the environment. It is at these places that contact forces are exerted. Identify the contact forces. Then identify any long-range forces on the system.

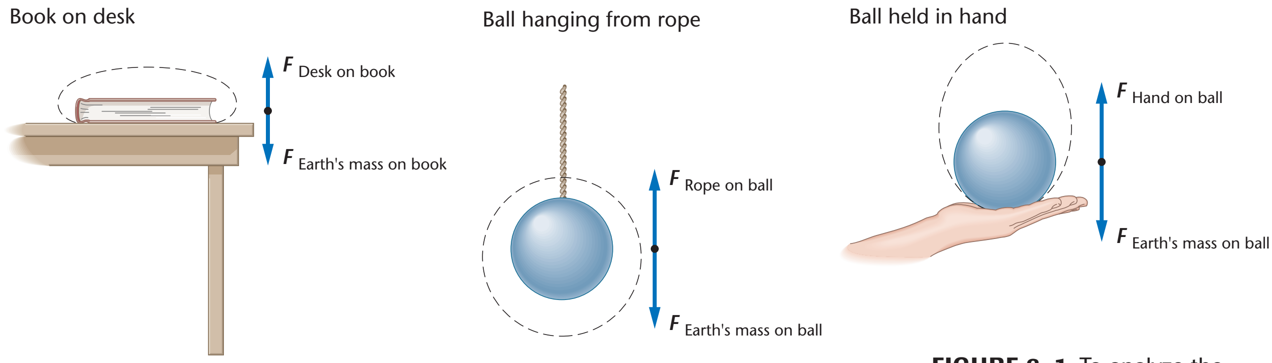


FIGURE 6–1 To analyze the forces on an object, sketch the situation, circle the system, and identify the agents and the directions of all the forces. Earth's mass is the agent for the force of gravity.

Next, replace the object by a dot, that is, use the particle model. Each force is represented as a blue arrow that points in the correct direction. The length of the arrow is proportional to the size of the force. The tail of the force vector is always on the particle, even when the force is a push. Finally, label the force. For now, use the symbol $\boldsymbol{F}$ with a subscript label to identify both the agent and the object on which the force is exerted. **Figure 6–1** shows pictorial models of the three situations.

Practice Problems

1. Draw pictorial models for the following situations. Circle each system. Draw the forces exerted on the system. Name the agent for each force acting on each system.
   a. a book held in your hand
   b. a book pushed across the desk by your hand
   c. a book pulled across the desk by a string
   d. a book on a desk when your hand is pushing down on it
   e. a ball just after the string that was holding it broke

Newton's Second Law of Motion

How does an object move when one or more forces are exerted on it? The only way to find out is by doing experiments. Experiments are easier when the influences of gravity and friction can be avoided or minimized. A good way to begin is by studying horizontal forces because gravity does not act in the horizontal direction, and friction can be minimized by doing the experiments either on ice or with carts with low-friction wheels.

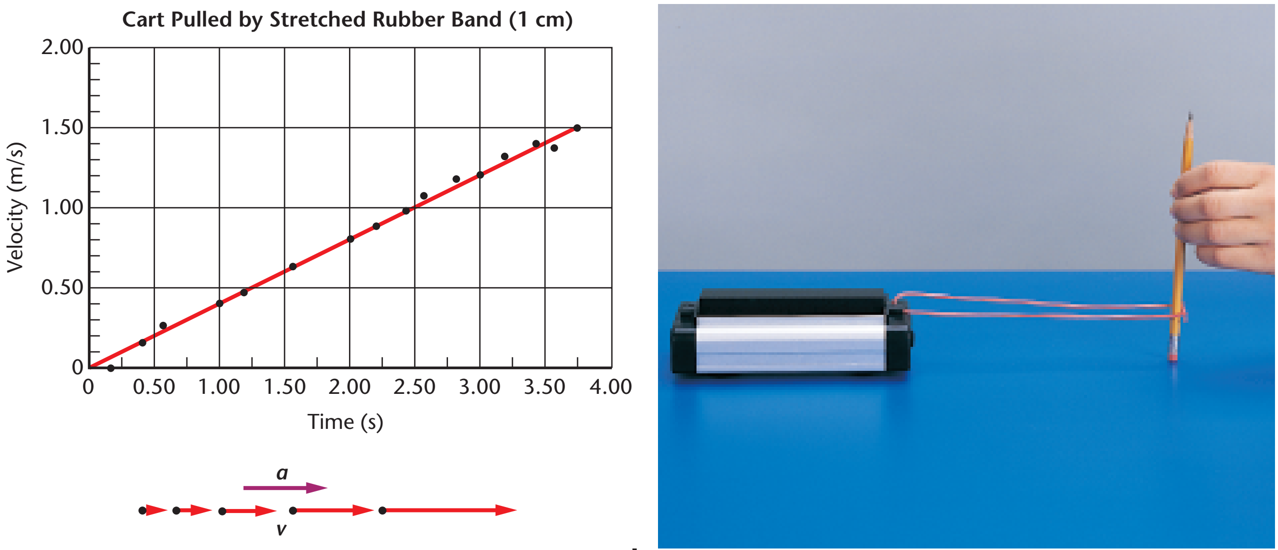
How can you exert a controlled force? A stretched rubber band exerts a pulling force; the farther you stretch it, the larger the force. If you always stretch the rubber band the same amount, you always have the same force.

Pocket Lab

How far is forever?

Galileo proposed that if a perfectly smooth ball were rolled on a perfectly smooth surface in a vacuum, it would roll forever at a steady speed. Use a stopwatch with a lap or split timer and measure the time it takes a ball to roll the first meter and then the total time it takes to roll 2.0 m.

Analyze and Conclude Make a motion diagram to describe the motion and a free-body diagram showing the forces acting on the ball. Indicate the direction of the net force, $\boldsymbol{F}_{net}$, and the acceleration.



a

b

FIGURE 6–2 The constant slope of the line indicates that the acceleration of the cart is constant. The cart used in this experiment is shown in **b.** It is designed to minimize friction.

The graph in **Figure 6–2a** shows some typical data taken when a rubber band, stretched a constant 1 cm, was used to pull the low-friction cart shown in **Figure 6–2b.** Notice that the velocity-time graph is linear so the cart's acceleration is constant. You can determine the acceleration by calculating the slope of the line. What is it?

How does acceleration depend upon the force? You could repeat the experiment, this time with the rubber band stretched to a constant 2 cm, and then repeat it again with the rubber band stretched longer and longer. For each experiment, you could determine the acceleration from a velocity-time graph like the one in **Figure 6–2,** and then plot the accelerations for all the trials, as shown in **Figure 6–3a.** Note that this is a force-acceleration graph, and that the acceleration, a, and force, F, are proportional. The larger the force, the greater the acceleration. A linear relationship that goes through the origin, is represented by the equation $F = ka$, where k is the slope of the line.

How does acceleration depend upon the object? This experiment shows that the acceleration of an object is proportional to the net force exerted on it. What happens if the object changes? Suppose that a second cart is placed on top of the first, and then a third cart is added. The rubber band would be pulling two carts, then three. A plot of the force versus the acceleration for one, two, and three carts, is shown in **Figure 6–3b.** The graph shows that for an equal force, the acceleration of two carts is 1/2 the acceleration of one, and the acceleration of three carts is 1/3 the acceleration of one. This means that as the number of carts is increased, a greater force is needed to produce the same acceleration. The slopes of the lines in **Figure 6–3b** depend upon the number of carts, or upon mass. If the mass is defined as the slope of the F-a graph, then, $m = F/a$, or $F = ma$.

F.Y.I.

Small insects have very little mass, but the ratio of the surface areas of their bodies to their mass (surface-to-mass ratio) is large. When they are in free fall, their bodies act like parachutes quickly reaching a terminal velocity of only a few cm/s. An ant falling from a 50-story building will walk away unharmed after hitting the sidewalk.

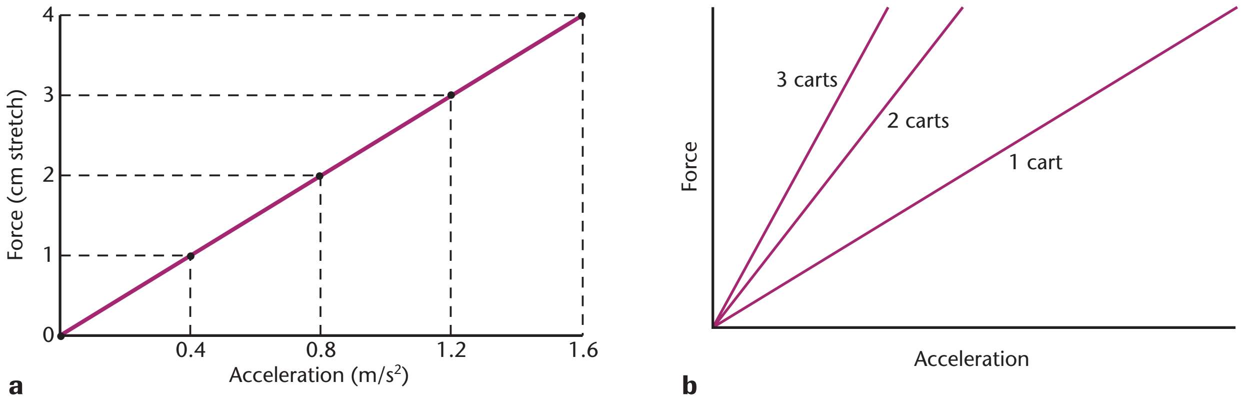


FIGURE 6–3 The graph in **a** shows that as the force increases, so does the acceleration. In **b,** you can see that the slope of the force-acceleration graph depends upon the number of carts.

Combining forces What if two or more rubber bands exert forces on a cart? They could act in the same direction, in opposite directions, or in directions at an angle to one another. In **Figure 6–4,** the carts are represented by dots, and the forces operating on each dot (cart) are drawn in the direction of the force with their tails on the dot. This is called a **free-body diagram.**

Because forces are vectors, the total force on an object is the vector sum of all forces exerted on the object. You have learned how to add vectors and find the resultant as shown in **Figure 6–4.** The vector sum of two or more forces on an object is called the **net force.** Experiments show that the acceleration of an object is proportional to the net force exerted on the object and inversely proportional to the mass of the object being accelerated. This is a statement of **Newton's second law,** which can be written as an equation.

Newton's Second Law $\boldsymbol{a} = \frac{\boldsymbol{F}_{\text{net}}}{m}$

Here is a strategy for finding how the motion of an object depends on the forces exerted on the object. First, identify all the forces on the object. Draw a free-body diagram showing the direction and relative magnitude of each force acting on the system. Then, add the force vectors to find the net force. Next, use Newton's second law to calculate the acceleration. Finally, use kinematics to find the velocity and position of the object. You learned about kinematics in Chapters 3, 4, and 5 when you studied the motion of objects without regard for the causes of motion. You now know that an unbalanced force is the cause of a change in velocity.

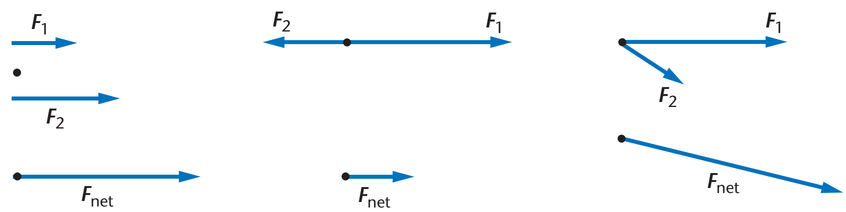


FIGURE 6–4 The net force is the vector sum of $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$.

TABLE 6–1	
Description	***F* (N)**
Force of gravity on coin (nickel)	0.05
Force of gravity on 1 lb sugar	4.5
Force of gravity on 150-lb person	668
Force accelerating a car	3000
Force of a rocket motor	5 000 000

Measuring Force: The Newton

Before trying the strategy, you need to know how to measure the force. One unit of force causes a 1-kg mass to accelerate at 1 m/s^2. Because force is equal to mass times acceleration, $F = ma$, one force unit has the dimensions 1 $kg \cdot m/s^2$. The unit of force, in the SI system, is the newton, N. **Table 6–1** shows some typical forces.

Practice Problems

2. Two horizontal forces, 225 N and 165 N, are exerted in the same direction on a crate. Find the net horizontal force on the crate.

3. If the same two forces are exerted in opposite directions, what is the net horizontal force on the crate? Be sure to indicate the direction of the net force.

4. The 225-N force is exerted on the crate toward the north and the 165-N force is exerted toward the east. Find the magnitude and direction of the net force.

5. Your hand exerts a 6.5-N upward force on a pound of sugar. Considering the force of gravity on the sugar, what is the net force on the sugar? Give the magnitude and direction.

6. Calculate the force you exert as you stand on the floor (1 lb = 0.454 kg). Is the force the same if you lie on the floor?

HELP WANTED

PHYSICS TEACHER

To qualify, you must enjoy science and math and be skilled in explaining technical concepts clearly. You must be able to tailor your explanations and demonstrations to individual student's needs. The position requires a bachelor's degree in physics, chemistry, biology, math, or a related area. You may be required to teach any of these courses in addition to physics. Knowledge of computers is vital. A master's degree in education or administration is a plus. For more information, contact:

American Association of Physics Teachers
One Physics Ellipse
College Park,
MD 20740-3845

Newton's First Law of Motion

What is the motion of an object with no net force on it? Think of a ball rolling on a surface. How long will the ball continue to roll? That depends on the quality of the surface. If you roll it on thick carpet or soft sand, it will quickly come to rest. If you roll it on a surface that is hard and smooth, such as a bowling alley, the ball will roll for a long time with little change in velocity. You could imagine that if all friction were eliminated, the ball might roll at the same velocity forever. Galileo did many experiments on the motion of balls on very smooth surfaces. He concluded that in the ideal case, horizontal motion was eternal: it would never stop. Galileo was the first to recognize that the general principles of motion could be found only by extrapolating experimental results to the ideal case, in which there is no friction or other drag force.

Newton generalized Galileo's results to motion in any direction. He stated, "An object that is at rest will remain at rest or an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero." This statement is called **Newton's first law** of motion.

CONTENTS

Inertia Newton's first law is often called the law of inertia. **Inertia** is the tendency of an object to resist change. If an object is at rest, it tends to remain at rest. If it is moving at a constant velocity, it tends to continue moving at that velocity.

Equilibrium If the net force on an object is zero, then the object is in equilibrium. An object is in **equilibrium** if it is at rest or if it is moving at constant velocity. Note that being at rest is just a special case of constant velocity. Newton's first law identifies a net force as something that disturbs a state of equilibrium. That means that a net force changes the velocity of an object. Thus, change in velocity, or acceleration, is the result of a net force acting on an object.

The physical model: Free-body diagrams Because the net force on an object causes the acceleration of the object, it is important to know how to find the net force. The net force is the sum of all the forces on an object. **Table 6-2** will help you identify some common types of forces.

Pocket Lab

Tug-of-War Challenge

In a tug-of-war, predict how the force you exert on your end of the rope compares to the force your opponent exerts if you pull and your opponent just holds the end of the rope. Predict how the forces compare if the rope moves in your direction. Try it.

Analyze and Conclude What did you notice about the forces? What happened when you started to move your opponent in your direction?

TABLE 6–2

Some Types of Forces

Force	Symbol	Definition	Direction
Friction	$\boldsymbol{F}_{\mathrm{f}}$	The contact force that acts to oppose sliding motion between surfaces	Parallel to the surface and opposite the direction of sliding
Normal	$\boldsymbol{F}_{\mathrm{N}}$	The contact force exerted by a surface on an object	Perpendicular to and away from the surface
Spring	$\boldsymbol{F}_{\mathrm{sp}}$	A restoring force, that is, the push or pull a spring exerts on an object	Opposite the displacement of the object at the end of the spring
Tension	$\boldsymbol{F}_{\mathrm{T}}$	The pull exerted by a string, rope, or cable when attached to a body and pulled taut	Away from the object and parallel to the string, rope, or cable at the point of attachment
Thrust	$\boldsymbol{F}_{\mathrm{thrust}}$	A general term for the forces that move objects such as rockets, planes, cars, and people	In the same direction as the acceleration of the object barring any resistive forces
Weight	$\boldsymbol{F}_{\mathrm{g}}$	A long-range force due to gravitational attraction between two objects, generally Earth and an object	Straight down toward the center of Earth

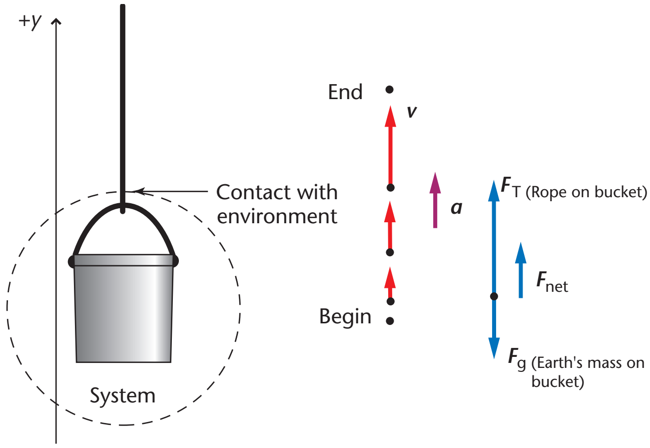
CONTENTS

Example Problem

Constructing a Free-Body Diagram

A rope is lifting a heavy bucket. The speed of the bucket is increasing. How can the forces on the bucket be related to the change in speed?

Sketch the Problem



- Choose a coordinate system defining the positive direction of the velocity.
- Locate every point at which the environment touches the system.
- Draw a motion diagram including the velocity and acceleration. The bucket is moving upward, so the direction of $\boldsymbol{v}$ is upward. The speed is increasing so the direction of $\boldsymbol{a}$ is upward. Indicate "begin" and "end."
- Draw the free-body diagram. Replace the bucket by a dot and draw arrows to represent $\boldsymbol{F}_{\text{T (rope on bucket)}}$ and $\boldsymbol{F}_{\text{g (Earth's mass on bucket)}}$.

Check Your Answer

- Velocity is increasing in the upward direction, so acceleration is upward.
- According to Newton's second law, $\boldsymbol{F}_{\text{net}}$ and $\boldsymbol{a}$ are in the same direction.
- Therefore, vector addition of the positive $\boldsymbol{F}_{\text{T}}$ and the negative $\boldsymbol{F}_{\text{g}}$ results in a positive $\boldsymbol{F}_{\text{net}}$.
- Draw an arrow showing $\boldsymbol{F}_{\text{net}}$.

Practice Problems

For each problem, draw a motion diagram and a free-body diagram labeling all forces with their agents and indicating the direction of the acceleration and the net force. Draw arrows the appropriate lengths.

7. A sky diver falls downward through the air at constant velocity (air drag is important).

8. A cable pulls a crate at constant speed across a horizontal surface (there is friction).

9. A rope lifts a bucket upward at constant speed (ignore air drag).

10. A rope lowers a bucket at constant speed (ignore air drag).

11. A rocket blasts off and its vertical velocity increases with time (ignore air drag).

Common misconceptions about forces The world is dominated by friction, and so Newton's ideal, friction-free world is not easy to visualize. In addition, many terms used in physics have everyday meanings that are different from those understood in physics. Here are some examples of common, but mistaken ideas about forces.

- **When a ball has been thrown, the force of the hand that threw it remains on it.** No, the force of the hand is a contact force; therefore, once contact is broken, the force is no longer exerted.
- **A force is needed to keep an object moving.** If there is no net force, then the object keeps moving with unchanged velocity. If friction is a factor, then there is a net force and the object's velocity will change.
- **Inertia is a force.** Inertia is the tendency of an object to resist changing its velocity. Forces are exerted on objects by the environment; they are not properties of objects.
- **Air does not exert a force.** Air exerts a huge force, but because it is balanced on all sides, it usually exerts no net force unless an object is moving. You can experience this force only if you remove the air from one side. For example, when you stick a suction cup on a wall or table, you remove air from one side. The suction cup is difficult to remove because of the large unbalanced force of the air on the other side.
- **The quantity *ma* is a force.** The equals sign in $F = ma$ does not define ma as a force. Rather, the equal sign means that experiments have shown that the two sides of the equation are equal.

6.1 Section Review

1. Identify each of the following as either **a, b,** or **c:** weight, mass, inertia, the push of a hand, thrust, tension, friction, air drag, spring force, acceleration, and mass times acceleration.
   a. a contact force
   b. a long-range force
   c. not a force
2. Can you feel the inertia of a pencil? Of a book? If you can, describe how.
3. Research and describe Newton's contributions to physics.
4. If you push a book in the forward direction, does that mean its velocity has to be forward?
5. Draw a free-body diagram of a water bucket being lifted by a rope at a decreasing speed. Label all forces with their agents and make the arrows the correct lengths.
6. **Critical Thinking** A force of 1 N is the only force exerted on a block, and the acceleration of the block is measured. When the same force is the only force exerted on a second block, the acceleration is three times as large. What can you conclude about the masses of the two blocks?

6.2 Using Newton's Laws

Newton's second law describes the connection between the net force exerted on an object and its acceleration. The second law identifies the cause of a change in velocity and the resulting displacement. Newton called this *a law of nature* because he thought it held true for all motions. Early in the twentieth century, more than 200 years after Newton's time, physicists discovered that the second law is not true for velocities close to the speed of light, nor for objects the size of atoms. Nevertheless, all of our everyday experiences are governed by this physical law which was formulated over 300 years ago.

OBJECTIVES

- **Describe** how the weight and the mass of an object are related.
- **Differentiate** between the gravitational force weight and what is experienced as apparent weight.
- **Define** the friction force and **distinguish** between static and kinetic friction.
- **Describe** simple harmonic motion and **explain** how the acceleration due to gravity influences such motion.

Using Newton's Second Law

Aristotle's followers believed that the heavier an object is, the faster it falls. Test this idea yourself. Drop a feather and a coin. Doesn't the coin fall faster? You can see for yourself that the evidence seems to be in Aristotle's favor. But Galileo knew that if he was to understand the nature of the force that causes an object to fall, he had to simulate an idealized world in which there is no air drag.

Mass and weight While there is no evidence that Galileo actually dropped two balls from the Leaning Tower of Pisa to test his ideas, he did describe the following thought experiment. Two cannon balls of equal weight, dropped side by side, should fall at an equal rate. But what happens if the cannon balls are tied together? According to Aristotle, they should fall twice as fast. But Galileo hypothesized that all objects, no matter what their weight, gain speed at the same rate, which means that they have the same downward acceleration. This hypothesis has been tested and found to be true.

What is the weight force, $\boldsymbol{F}_g$, exerted on an object of mass m? Galileo's hypothesis and Newton's second law can answer this question. Consider the pictorial and physical models in **Figure 6–5,** which show a falling ball in midair. Because it is touching nothing and air resistance can be neglected, there are no contact forces on it, only $\boldsymbol{F}_g$. The ball's acceleration is $\boldsymbol{g}$. Newton's second law then becomes $\boldsymbol{F}_g = m\boldsymbol{g}$. Both the force and the acceleration are downward. The magnitude of an object's weight is equal to its mass times the acceleration it would have if it were falling freely.

This result is true on Earth, as well as on any other planet, although the magnitude of g will be different on other planets. Future astronauts will find that their weights vary from planet to planet, but their masses will not change.

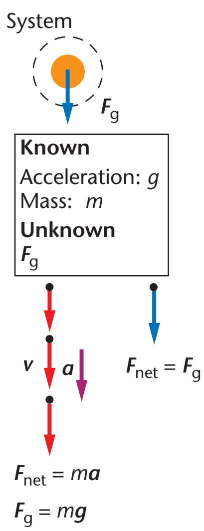
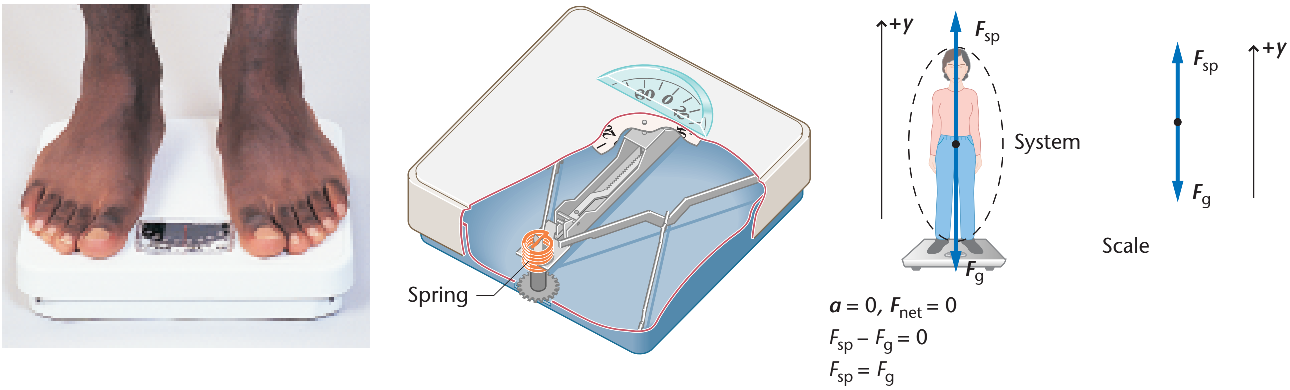


FIGURE 6–5 The net force on the ball is the weight force, $\boldsymbol{F}_g$.



a

b

FIGURE 6–6 The upward force of the spring in the scale is equal to your weight, F_g, when you step on the bathroom scale. The sketch and free-body diagram in **b** show that the system is in equilibrium, so $F_g = F_{sp}$.

Scales **Figure 6–6a** asks this question: "What is being measured, mass or weight?" A bathroom scale contains springs. When you step on the scale, the scale exerts an upward force on you. The pictorial and physical models in **Figure 6–6b** show that, because you are not accelerating, the net force is zero. Therefore, the magnitude of the spring force, F_{sp}, is equal to your weight, F_g. A spring scale, therefore, measures weight, not mass. If you were on a different planet, the compression of the spring would be different, and consequently, the scale's reading would be different.

Problem Solving Strategies

Force and Motion

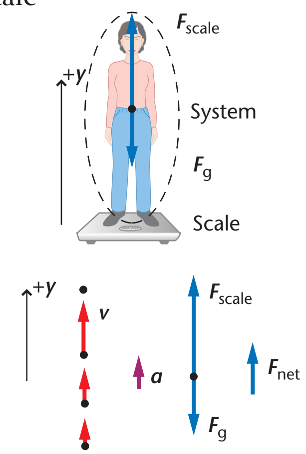
When using Newton's laws to solve force and motion problems, use the following strategy.

1. Read the problem carefully. Visualize the situation and create the pictorial model with a sketch.
2. Circle the system and choose a coordinate system.
3. Decide which quantities are known and which quantity you need to find. Assign symbols to the known and unknown quantities.
4. Create the physical model, which includes a motion diagram showing the direction of the acceleration, and a free-body diagram, which includes the net force.
5. To calculate your answer, use Newton's laws to link acceleration and net force.
6. Rearrange the equation to solve for the unknown quantity, $\boldsymbol{a}$ or $\boldsymbol{F}_{net}$. Newton's second law involves vectors, so the equation must be solved separately in the x and y directions.
7. Substitute the known quantities with their units in the equation and solve.
8. Check your results to see if they are reasonable.

Example Problem

Weighing Yourself in an Accelerating Elevator

Your mass is 75 kg. You stand on a bathroom scale in an elevator. Going up! Starting from rest, the elevator accelerates at 2.0 m/s^2 for 2.0 s, then continues at a constant speed. What is the scale reading during the acceleration? Is it larger than, equal to, or less than the scale reading when the elevator is at rest?



Sketch the Problem

- Sketch the situation as in **Figure 6–6b.**
- Draw the motion diagram. Label $\boldsymbol{v}$ and $\boldsymbol{a}$.
- Choose a coordinate system with the positive direction up.
- The net force is in the same direction as the acceleration, so the upward force is greater than the downward force.

Calculate Your Answer

Known:	**Unknown:**
$m = 75$ kg	$F_{scale} = ?$
$a = +2.0$ m/s^2	
$t = 2.0$ s	

Strategy:

F_{net} is the sum of the positive force of the scale on you, F_{scale}, and the negative weight force, $F_{net} = F_{scale} - F_g$.

Solve for F_{scale} and substitute ma for F_{net} and mg for F_g.

Calculations:

$$F_{scale} = ma + mg$$

$$F_{scale} = m(a + g)$$

$$= (75\text{ kg})(2.0\text{ m/s}^2 + 9.80\text{ m/s}^2)$$

$$F_{scale} = 890\text{ N}$$

Check Your Answer

- Are the units correct? kg·m/s^2 is the force unit, N.
- Does the sign make sense? The positive sign agrees with the diagram.
- Is the magnitude realistic? F_{scale} is larger than it would be at rest when F_{scale} would be 7.4×10^2 N, so the magnitude is reasonable.

Example Problem

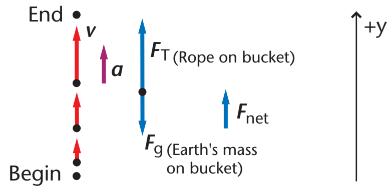
Lifting a Bucket

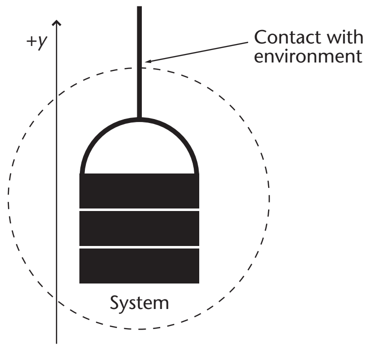
A 50-kg bucket is being lifted by a rope. The rope is guaranteed not to break if the tension is 500 N or less. The bucket started at rest, and after being lifted 3.0 m, it is moving at 3.0 m/s. Assuming that the acceleration is constant, is the rope in danger of breaking?

Sketch the Problem

- Draw the situation; identify the forces on the system.

- Establish a coordinate system with a positive axis up.
- Draw a motion diagram including $\boldsymbol{v}$ and $\boldsymbol{a}$.
- Draw the free-body diagram. Position the force vectors with their tails on the dot.





Calculate Your Answer

Known:		**Unknown:**
$m = 50$ kg	$v = 3.0$ m/s	$F_T = ?$
$v_0 = 0.0$ m/s	$d = 3.0$ m	

Strategy:

The net force is the vector sum of $\boldsymbol{F}_T$ (positive) and $\boldsymbol{F}_g$ (negative). $F_{net} = F_T - F_g$.

Rearrange the equation: $F_T = F_{net} + F_g = ma + mg$

Because v_0 is zero, $a = v^2/2d$

Calculations:

$$F_T = m(a + g) = m(v^2/2d + g)$$

$$F_T = (50\text{ kg})\left(\frac{9.0\text{ m}^2/\text{s}^2}{2(3.0\text{ m})} + 9.80\text{ m/s}^2\right)$$

$F_T = 570$ N; the rope is in danger of breaking because the tension exceeds 500 N.

Check Your Answer

- Are the units correct? Performing algebra on the units verifies kg·m/s^2 which is N.
- Does the sign make sense? The upward force should be positive.
- Is the magnitude realistic? Yes, the magnitude is a little larger than 490 N, which is the weight of the bucket.

Practice Problems

12. On Earth, a scale shows that you weigh 585 N.
  a. What is your mass?
  b. What would the scale read on the moon ($g = 1.60$ m/s^2)?

13. Use the results from the first example problem to answer these questions about a scale in an elevator on Earth. What force would the scale exert when
  a. the elevator moves up at a constant speed?
  b. it slows at 2.0 m/s^2 while moving upward?
  c. it speeds up at 2.0 m/s^2 while moving downward?
  d. it moves downward at a constant speed?
  e. it slows to a stop at a constant magnitude of acceleration?

Pocket Lab

Friction depends on what?

Find out! Tape a 0.5-kg mass to a 10-cm × 10-cm piece of cardboard. Tie one end of a string to the mass and the other end to a spring scale. Pull until the mass begins to move. Record the maximum force before the mass began to slide as the static force of friction. Repeat for a 1.0-kg mass. Repeat with the two masses on a 10-cm × 20-cm piece of cardboard.

Analyze and Conclude
Describe your results. Does the force of friction depend on the mass? Does the force of friction depend on the surface area?

EARTH SCIENCE CONNECTION

Earthquake Forces The San Andreas Fault in California is a series of fractures in Earth's crust. Forces in Earth's interior cause the rocks to slide past each other in a horizontal direction. At first, the forces of friction between the two surfaces are greater than the forces that cause the slide, so the rocks stretch and twist. Eventually, forces within the rocks become greater than the forces of friction, and, much like the release of a stretched rubber band, the rocks snap back in place. This movement, with the resulting release of tremendous amounts of energy, is an earthquake.

Apparent weight What is weight? What does a bathroom scale measure? The weight force is defined as $F_g = mg$, so F_g changes when g varies. On or near the surface of Earth, however, g is approximately constant. If a bathroom scale supports you—it provides the only upward force on you—then it reads your weight. But, suppose you stood with one foot on the scale and one foot off? Or what if a friend pushed down on your shoulders or pushed up on your elbows? Then there would be other contact forces on you, and the scale would not read your weight.

What happens if you are standing on a scale in an elevator? As long as the elevator is in equilibrium, that is, at rest or moving at constant speed, the scale reads your weight. But if the elevator accelerates upward, then the scale reads a larger force. What does it feel like to be in an elevator like this? You feel heavier; the floor presses harder on your feet. On the other hand, if the acceleration is downward, then you feel lighter, and the scale reads less. The force exerted by the scale is called the **apparent weight.**

Imagine that the cable holding the elevator breaks. The scale with you on it would accelerate with $a = -g$. According to the solution to the first example problem, the scale would read zero! Your apparent weight would be zero. That is, you would be weightless. However, **weightlessness** doesn't mean your weight is zero, but that there are no contact forces pushing up on you. Weightlessness means that your apparent weight is zero.

The Friction Force

Push your hand across your desktop and feel the force called friction opposing the motion. Friction is often minimized in solving force and motion problems, but in the real world, friction is everywhere. You need it to both start and stop a bike and a car. If you've ever walked on ice, you know how important friction is. Friction lets a pencil make a mark on paper and an eraser fix mistakes.

Static and kinetic friction Think about friction as you push a heavy crate across the floor. You give the crate a push, but it doesn't move. Newton's laws tell you it should move unless there is a second horizontal force on the crate, opposite in direction to your force, and equal in size. That force is called the **static friction force.** It is exerted on one surface by the other when there is no relative motion between the two surfaces. You can push harder and harder, as shown in **Figure 6–7,** but if the crate still doesn't move, the friction force also must be getting larger. The static friction force acts in response to other forces. Finally, when your push gets hard enough, the crate begins to move. Evidently, the static friction force can grow only so large.

The crate may be moving, but friction is still acting because if you stop pushing, the crate slows. The force that is acting is called the kinetic friction force. The **kinetic friction force** is the force exerted on one surface by the other when the surfaces are in relative motion.

A model for friction forces Although friction forces are complicated, a simplified model can be used to find solutions close to those found by experiments. The model assumes that friction depends on the surfaces in contact, but not on the area of the surfaces nor the speed of their relative motion. In the model, the magnitude of the friction force is proportional to the magnitude of the force pushing one surface against the other. That force, perpendicular to the surface, is the normal force, F_N.

Kinetic Friction Force $F_{f,\ kinetic} = \mu_k F_N$

In this equation, μ_k is a proportionality constant called the kinetic coefficient of friction.

The static friction force is related to the normal force by this expression.

Static Friction Force $0 \leq F_{f,\ static} \leq \mu_s F_N$

where μ_s is the static coefficient of friction. The equation tells you that the static friction force can vary from zero to $\mu_s F_N$ where $\mu_s F_N$ is the maximum static friction force that must be balanced before motion can begin. In **Figure 6-7c,** the static friction force has just been balanced the instant before the box begins to move.

Note that the preceding equations involve the magnitudes of the forces only. The forces themselves, $\mathbf{F_f}$ and $\mathbf{F_N}$, are at right angles to each other. **Table 6–3** shows coefficients of friction for various surfaces. You will need to use these in solving problems. Although all the listed coefficients are less than 1, this doesn't mean that the coefficient of friction must be less than 1. Coefficients as large as 5.0 are experienced in drag racing.

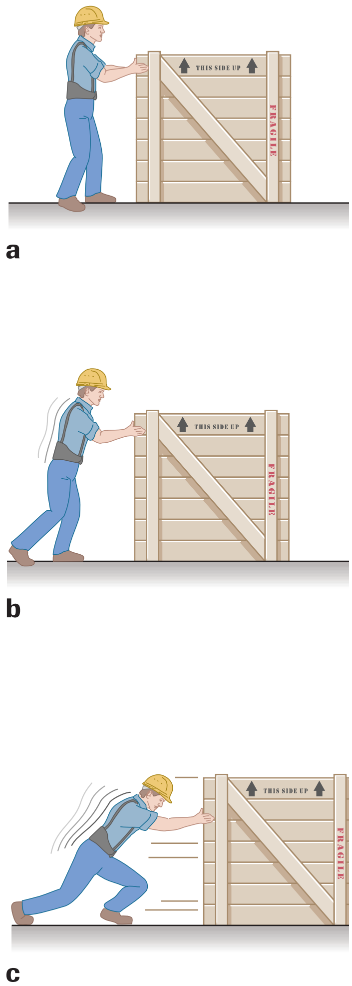


FIGURE 6–7 There is a limit to the ability of the static friction force to match the applied force.

TABLE 6–3

Typical Coefficients of Friction

Surface	μ_s	μ_k
Rubber on concrete	0.80	0.65
Rubber on wet concrete	0.60	0.40
Wood on wood	0.50	0.20
Steel on steel (dry)	0.78	0.58
Steel on steel (with oil)	0.15	0.06
Teflon on steel	0.04	0.04

Example Problem

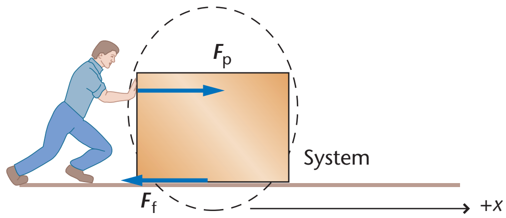
Balanced Friction Forces

You push a 25-kg wooden box across a wooden floor at a constant speed of 1.0 m/s. How much force do you exert on the box?

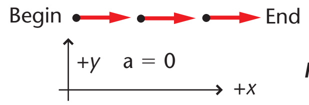
Continued on next page

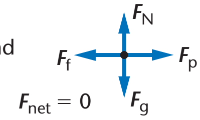
Sketch the Problem

- Identify the forces and establish a coordinate system.
- Draw a motion diagram indicating constant $\boldsymbol{v}$ and $\boldsymbol{a}$ = zero.
- Draw the free-body diagram with the tails of the four forces ($\boldsymbol{F}_f$, $\boldsymbol{F}_N$, $\boldsymbol{F}_g$, and $\boldsymbol{F}_p$, your pushing force) on the dot.



Calculate Your Answer





Known:	**Unknown:**
$m = 25$ kg	$F_p = ?$
$v = 1.0$ m/s	
$a = 0.0$ m/s^2	

Strategy:

y-direction: Because there is no acceleration, $F_N = F_g = mg$.

x-direction: Because v is constant, there is no acceleration. Therefore, the pushing force, $F_p = F_f = \mu_k mg$.

Calculations:

$F_p = \mu_k mg$

$$F_p = (0.20)(25 \text{ kg})(9.80 \text{ m/s}^2) = 49 \text{ N}$$

Check Your Answer

- Are the units correct? Performing algebra on the units verifies that force = kg·m/s^2 or N.
- Does the sign make sense? The positive sign agrees with the sketch.
- Is the magnitude realistic? It is a reasonable force for moving a 25-kg box.

Example Problem

Unbalanced Friction Forces

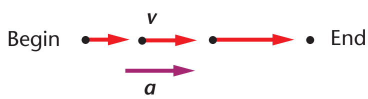
If the force you exert on the box is doubled, what is the resulting acceleration of the box?

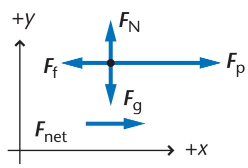
Sketch the Problem

- The sketch is the same as in the preceding example problem.
- Draw a motion diagram showing increasing $\boldsymbol{v}$ and the direction of $\boldsymbol{a}$.
- Draw the free-body diagram with doubled pushing force, $\boldsymbol{F}_p$.

Calculate Your Answer

Known:	**Unknown:**
$m = 25$ kg	$a = ?$
$v = 1.0$ m/s	
$\mu_k = 0.20$	
$F_p = 2(49 \text{ N}) = 98$ N	





Strategy:

Friction force is the same; it is independent of speed.

There is a net horizontal force; the crate accelerates.

Apply Newton's laws separately in two directions.

Calculations:

y-direction: $F_N = F_g = mg$; $F_N = mg$

x-direction: $F_p - F_f = ma$

$F_f = \mu_k F_N = \mu_k mg$

$$a = \frac{F_{net}}{m} = \frac{F_p - \mu_k mg}{m} = \frac{F_p}{m} - \mu_k g$$

$$a = \frac{98\ \text{N}}{25\ \text{kg}} - (0.20)(9.80\ \text{m/s}^2)$$

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

Check Your Answer

- Are the units correct? Performing algebra on units verifies that a is in m/s^2.
- Does the sign make sense? For the chosen coordinate system, the sign should be positive.
- Is the magnitude realistic? In the calculation of a, if the force were cut in two, a would be zero as in the preceding example problem.

Practice Problems

14. A boy exerts a 36–N horizontal force as he pulls a 52-N sled across a cement sidewalk at constant speed. What is the coefficient of kinetic friction between the sidewalk and the metal sled runners? Ignore air resistance.

15. Suppose the sled runs on packed snow. The coefficient of friction is now only 0.12. If a person weighing 650 N sits on the sled, what force is needed to pull the sled across the snow at constant speed?

16. Consider the doubled force pushing the crate in the example problem *Unbalanced Friction Forces*. How long would it take for the velocity of the crate to double to 2.0 m/s?

Pocket Lab

Upside-Down Parachute

How long does it take for a falling object to reach a terminal velocity? How fast is the terminal velocity? Does the terminal velocity depend on the mass? Find out.

Use coffee filters, a meterstick, a stopwatch, and your creativity to answer each question.

Analyze and Conclude Describe your procedures, results, and conclusions to the class.

Causes of friction All surfaces, even those that appear to be smooth, are rough at a microscopic level as shown in **Figure 6–8.** When two surfaces touch, the high points on each are in contact and temporarily bond. When you try to move one of the pieces, you must break the bonds. This is the origin of static friction. As the surfaces move past each other, the electrostatic forces that caused the bonds continue to create an attraction between the high points on the moving surfaces and this results in the weaker kinetic friction. The details of this process are still unknown and are the subject of research in both physics and engineering.

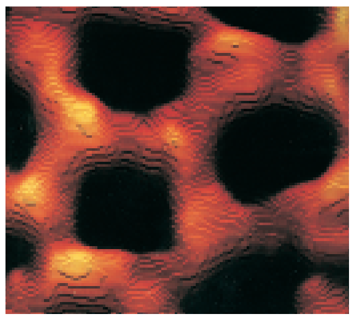


FIGURE 6–8 This photograph of a graphite crystal, magnified by a scanning tunneling microscope, reveals the surface irregularities of the crystal at the atomic level.

Answers question from page 116.

Systems messages for a
description or ask your
administrator.

Air drag and terminal velocity When an object moves through air or any other fluid, the fluid exerts a frictionlike force on the moving object. Unlike the friction between surfaces, however, this force depends upon the speed of the motion, becoming larger as the speed increases. It also depends upon the size and shape of the object and the density and kind of fluid.

If you drop a table tennis ball from a tower, it has very little velocity at the start, and thus only a small drag force. The downward force of gravity is much stronger than the upward drag force, so there is a downward acceleration. As the ball's velocity increases, so does the drag force. Soon, the drag force equals the force of gravity. With no net force, there is no acceleration. The velocity of the ball becomes constant. The constant velocity that is reached when the drag force equals the force of gravity is called the **terminal velocity.**

The terminal velocity of table tennis ball in air is 9 m/s. A basketball has a terminal velocity of 20 m/s; the terminal velocity of a baseball is 42 m/s. Skiers increase their terminal velocities by decreasing the drag force. They hold their bodies in an egg shape and wear smooth clothing and streamlined helmets. How do sky divers control their velocities? By changing body orientation and shape, sky divers can both increase and decrease their terminal velocity so that they can perform maneuvers in the air. A horizontal spread-eagle shape gives the slowest terminal velocity, about 60 m/s. When the parachute opens, the sky diver becomes part of a very large object with a correspondingly large drag force and a terminal velocity of about 5 m/s.

Periodic Motion

A playground swing, moving back and forth over the same path, is one example of vibrational motion. Other examples are a pendulum, a metal block bobbing up and down on a spring, and a vibrating guitar string, as shown in **Figure 6–9.**

FIGURE 6–9 A plucked guitar string continues to move rapidly back and forth in simple harmonic motion.

In each example, the object has one position in which the net force on it is zero. At that position, the object is in equilibrium. Whenever the object is pulled away from its equilibrium position, the net force on the system becomes nonzero and pulls it back toward equilibrium. If the force that restores the object to its equilibrium position is directly proportional to the displacement of the object, the motion that results is called **simple harmonic motion**.

Two quantities describe simple harmonic motion. One is the period, represented by the symbol T. The **period** is the time needed to repeat one complete cycle of motion. The other quantity, called the **amplitude** of the motion, is the maximum distance the object moves from equilibrium.

The mass on a spring How do you describe the simple harmonic motion of objects? **Figure 6–10a** shows a block hanging on a spring.

Two forces are exerted on the block. The weight force is a constant downward force, $\boldsymbol{F}_g$. The upward force of the spring is directly proportional to the amount the spring is stretched. A spring that acts this way is said to obey Hooke's law.

How does the net force depend upon position? When a block hangs on a spring, the spring stretches until its force balances the object's weight as shown in **Figure 6–10a.** The block is then in its equilibrium position. If you pull the block down, as in **Figure 6–10b,** the spring force increases, producing a net force upward. When you let go of the block, it accelerates upward, as in **Figure 6–10c.** But as the spring stretch is reduced, the upward force decreases. In **Figure 6–10d,** the upward force of the spring and the object's weight are equal; there is no acceleration. But with no net force, the block's inertia causes it to continue its upward motion above the equilibrium position. In **Figure 6–10e,** the net force is in the direction opposite the displacement of the block and is directly proportional to the displacement, so the motion is simple harmonic. The block returns to the equilibrium position, as in **Figure 6–10f.**

Again, at this position, the net force is zero and so is the acceleration. Does the block stop? No, it would take a net upward force to slow the block, and that doesn't exist until the block falls below the equilibrium position. When it comes to the position at which it was released, the net force and acceleration are at their maximum in the upward direction. The block moves up and continues to move in this vibratory manner. The period of oscillation, T, depends upon the mass of the block and the strength of the spring, but not on the amplitude of the motion.

The pendulum The swing of a pendulum also demonstrates simple harmonic motion. A simple pendulum consists of a massive object, called the bob, suspended by a string or rod of length l. After the bob is pulled to one side and released, it swings back and forth, as shown in **Figure 6–11.** The string or rod exerts a tension force, F_T, and gravity exerts the weight force, F_g, on the bob. The vector sum of the two forces produces the net force, shown at three positions in **Figure 6–11.** You can see that the net force is restoring, that is, it is opposite the direction of the displacement of the bob. For small angles (under about 15°) the force is linear to the displacement, so the motion is simple harmonic.

The period of a pendulum of length l is given by the following equation.

Period of a Pendulum $$T = 2\pi\sqrt{\frac{l}{g}}$$

Notice that the period depends only upon the length of the pendulum and the acceleration due to gravity, not on the mass of the bob or the amplitude of oscillation. One application of the pendulum is to measure g, which can vary slightly at different locations on Earth.

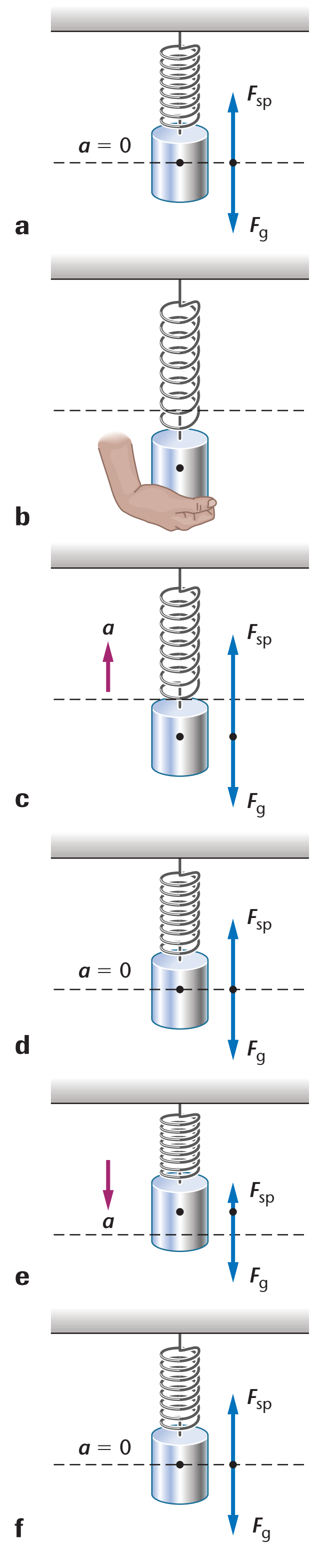


FIGURE 6–10 Simple harmonic motion is demonstrated by the vibration of a block hanging on a spring.

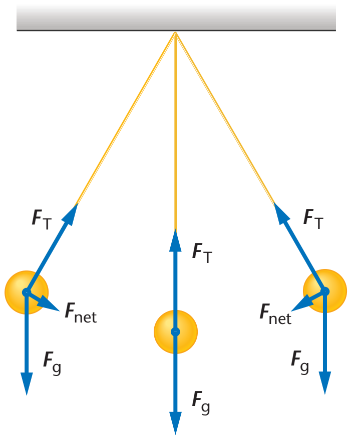


FIGURE 6–11 F_{net}, the vector sum of F_T and F_g, is the restoring force of the pendulum.

Practice Problems

17. What is the length of a pendulum with a period of 1.00 s?

18. Would it be practical to make a pendulum with a period of 10.0 s? Calculate the length and explain.

19. On a planet with an unknown value of g, the period of a 0.65-m -long pendulum is 2.8 s. What is g for this planet?

Resonance To get a playground swing going, you "pump" it by leaning back and pulling the chains at the same point in each swing, or your friend gives you repeated pushes at just the right times. When small forces are applied at regular intervals to a vibrating or oscillating object, the amplitude of the vibration increases. Such an increase in amplitude is called **mechanical resonance.** The time interval between applications of the force is equal to the period of oscillation. Other familiar examples of resonance include rocking a car to free it from a snow bank and jumping rhythmically on a trampoline or diving board. The large amplitude oscillations caused by resonance can create stresses. Audiences in theater balconies, for example, have damaged the structures by jumping up and down with a period equal to the natural oscillation period of the balcony.

6.2 Section Review

1. Compare the force needed to hold a 10.0-kg rock on Earth and on the moon. (The acceleration due to gravity on the moon is 1.62 m/s^2.) Then compare the force needed to throw the same rock horizontally at the same speed in the two locations.
2. You take a ride in a fast elevator to the top of a tall building and ride back down while standing on a bathroom scale. During which parts of the ride will your apparent and real weights be the same? During which parts will your apparent weight be less than your real weight? More than your real weight?
3. A box is in the back of a pickup truck when the truck accelerates forward. What force accelerates the box? Under what circumstances could the box slide? In which direction?
4. A skydiver falling at constant speed in the spread-eagle position opens the parachute. Is the skydiver accelerated? In which direction? Explain your answer using Newton's laws.
5. **Critical Thinking** The speed of a pendulum bob is largest when it is directly below the support. Give two ways you could increase this speed.

The Elevator Ride

Problem

Why do you feel heavier or lighter when riding in an elevator?

Materials

1-kg mass
20-N spring scale
10 cm masking tape

Procedure

1. Imagine that you take an upward elevator ride. Write a few sentences describing when you feel normal, heavier than normal, and lighter than normal. Repeat for a downward elevator ride.
2. Hold the 1-kg mass in your hand and give it an upward elevator ride. Describe when the mass feels normal, heavier than normal, and lighter than normal.
3. Hold the mass in your hand and give it a downward elevator ride. Describe when the mass feels normal, heavier than normal, and lighter than normal.
4. Securely tape the mass to the hook on the spring scale. **Caution:** *A falling mass can cause serious damage to feet or toes.*
5. Start with the mass just above the floor and take it on an upward and then a downward elevator ride.
6. When complete, unwrap the tape and throw it away. Put away the mass and the spring scale.

Data and Observations

1. Watch the spring scale and record the readings for different parts of the ride.

Analyze and Conclude

1. **Interpreting Data** Identify those places in the ride when the spring scale records a normal value for the mass. Describe the motion of the mass. Are the forces balanced or unbalanced?
2. **Interpreting Data** Identify those places in the ride when the spring scale records a heavier value. Which direction is the F_{net}? Which direction is the acceleration?
3. **Interpreting Data** Identify those places in the ride when the spring scale records a lighter value. Which direction is the F_{net}? Which direction is the acceleration?

Apply

1. Based on the trends in your data, predict how riding in an elevator while standing on a scale will affect your weight measurement. Try it, and describe the forces on you.
2. Do you feel heavier or lighter when riding on an escalator? Explain your answer in terms of the motion and the forces.
3. Identify the places on a roller coaster where you feel heavier or lighter. Explain your answer in terms of the motion and the forces.

6.3 Interaction Forces

You have explored the acceleration given an object when a net force acts on it, $\boldsymbol{a} = \boldsymbol{F}_{net}/m$. You know that forces are exerted on objects by agents, and that forces can be either contact or long-range. But what causes the force? If a rope pulls on a block, something or someone has to pull the rope. If you pull a rope, you feel the rope pulling you. Which is the object? Which is the agent? Long-range forces are similar. If you play with two magnets you feel each magnet pushing or pulling the other. Forces are the pushing or pulling of two objects on each other.

OBJECTIVES

- **Explain** the meaning of interaction pairs of forces and how they are related by Newton's third law.
- **List** the four fundamental forces and **illustrate** the environment in which each can be observed.
- **Explain** the tension in ropes and strings in terms of Newton's third law.

Identifying Interaction Forces

When a fast-moving baseball is caught, the motion of the ball is stopped. That requires a force, a force the catcher exerts on the ball. But the ball also exerts a force on the catcher, a force that can be felt. How do those forces compare? You've probably heard the answer for every action there is an equal and opposite reaction. But what is an action, what is a reaction, and why are they equal?

Systems and the environment You have already studied the situation diagrammed in **Figure 6–12a.** A system, whose motion you want to study, is isolated, and agents that exert forces on the system are identified. Now, consider the two systems whose motion you want to study, illustrated in **Figure 6–12b.** They are interacting with each other as well as with other agents. Recall that the environment consists of all the other systems whose motion is not being studied.

Now look at the interaction of the catcher's hand with a baseball illustrated in **Figure 6–13.** The ball is one system, the catcher's hand is the other. What forces act on each of the two systems? The weight forces on the ball and the hand, and the force of the arm on the hand, are considered external forces. The two forces, $\boldsymbol{F}_{\text{hand on ball}}$ and $\boldsymbol{F}_{\text{ball on hand}}$, are the forces of interaction between the ball and the hand. Notice the symmetry in the subscripts: hand on ball and ball on hand, or more generally, A on B and B on A.

The forces $\boldsymbol{F}_{\text{A on B}}$ and $\boldsymbol{F}_{\text{B on A}}$ are sometimes called action-reaction pairs of forces. This suggests that one causes the other, but this is not true. The force of the hand on the ball doesn't cause the ball to exert a

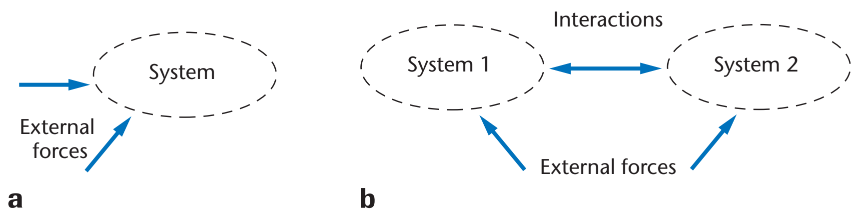


FIGURE 6–12 In **a**, external forces act on the system that is isolated for study. In **b**, two isolated systems are acted on by external forces and they also interact with each other.

force on the hand. The two forces either exist together or not at all. What about the directions and magnitudes of the forces?

Newton's Third Law

According to Newton, an **interaction pair** is two forces that are in opposite directions and have equal magnitude. The force of the catcher's hand on the ball is equal in magnitude and opposite in direction to the force of the ball on the catcher's hand. This is summarized in **Newton's third law** of motion, which states that all forces come in pairs. The two forces in the pair act on different objects and are equal in magnitude and opposite in direction: $\boldsymbol{F}_{\text{A on B}} = -\boldsymbol{F}_{\text{B on A}}$.

To illustrate Newton's third law, consider how a car accelerates. First, treat the car as a system, as in **Figure 6–14.** The car touches the road, so the road exerts contact forces on the car. There is the upward normal force and the forward friction force in the direction of the acceleration. There is also the downward, long-range weight force on the car. To keep the picture simple, ignore forces on the rear car tires.

But all of these forces are part of force pairs. If the road exerts forces on the car, then the car must exert equal and opposite forces on the road. Thus, the car exerts a downward normal force, and a backward friction force on the road. Finally, the car exerts an upward force on Earth. In **Figure 6–14,** dashed lines connect the three pairs of forces.

These forces can be confusing. You accelerate a car by pressing on the "accelerator." Through a variety of gears and rods, the engine turns the wheels. The wheels exert a backwards force on the road. But it is not this force that accelerates the car. First, it is in the wrong direction. Second, it is exerted on the road, not the car. It is the forward force of the road on the car that propels the car forward. If it weren't for the interaction between the car and the road, the car wouldn't move. If you've ever tried to accelerate a car on ice or on loose sand, where the frictional interaction is reduced, you can appreciate the importance of Newton's third law.

Thus, there is a backward force on the road and an upward force on Earth. As a result of this force, does Earth accelerate upward? Consider the simpler case of the interaction of a ball and Earth in the next example problem using the following problem solving strategy.

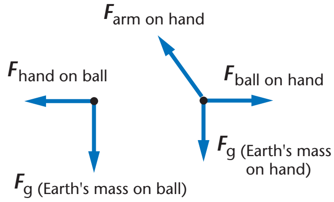


FIGURE 6–13 In addition to the external forces on the two systems, there are forces of interaction between the hand and the ball.

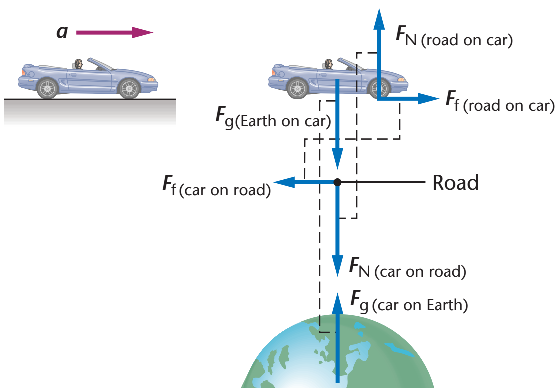


FIGURE 6–14 In the diagram, you can identify three interaction pairs.

PROBLEM SOLVING STRATEGIES

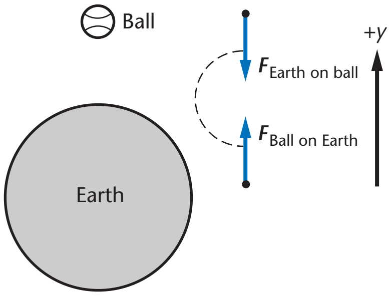
Interaction Pairs

1. Separate the system or systems from the environment.
2. Draw a pictorial model with coordinate systems for each system and a physical model which includes free-body diagrams for each system.
3. Connect interaction pairs by dashed lines.
4. To calculate your answer, use Newton's second law to relate the net force and acceleration for each system.
5. Newton's third law equates the magnitudes of the force pairs and gives the relative directions.
6. Solve the problem and check the units, signs, and magnitudes for reasonableness.

Example Problem

Earth's Acceleration

When a softball with a mass of 0.18 kg is dropped, its acceleration toward Earth is equal to g, the acceleration due to gravity. What is the force on Earth due to the ball, and what is Earth's acceleration? Earth's mass is 6.0×10^{24} kg.



Sketch the Problem

- Draw the forces on the two systems, ball and Earth, and connect them by dotted lines as an interactive pair.

Calculate Your Answer

Known:

$m_{\text{ball}} = 0.18$ kg

$m_{\text{Earth}} = 6.0 \times 10^{24}$ kg

$g = 9.80$ m/s^2

Unknown:

$F_{\text{Earth on ball}} = ?$

$a_{\text{Earth}} = ?$

Strategy:

Use Newton's second law to find the weight of the ball.

Calculations:

$$F_{(\text{Earth on ball})} = m_{\text{ball}} \times g = (0.18\text{ kg})(-9.80\text{ m/s}^2) = -1.8\text{ N}$$

Use Newton's third law to find $F_{(\text{ball on Earth})}$.

$$F_{(\text{Earth on ball})} = -F_{\text{Earth on ball}} = -(-1.8\text{ N}) = +\,1.8\text{ N}$$

Use Newton's second law to find a_{Earth}.

$$a_{\text{Earth}} = \frac{F_{\text{net}}}{m_{\text{Earth}}} = \frac{1.8\text{ N}}{6.0 \times 10^{24}\text{ kg}} = 2.9 \times 10^{-25}\text{ m/s}^2$$

Check Your Answer

- Are the units correct? Performing algebra on the units verifies force in N and acceleration in m/s^2.
- Do the signs make sense? Yes, force and acceleration should be positive for the directions of the force vectors in the diagram.
- Is the magnitude realistic? Because of Earth's large mass, the acceleration should be small.

The acceleration is such a small number that there is no question that, when doing problems involving falling objects, Earth can be treated as part of the environment rather than as a second system.

Practice Problems

20. You lift a bowling ball with your hand, accelerating it upward. What are the forces on the ball? What are the other parts of the action-reaction pairs? On what objects are they exerted?

21. A car brakes to a halt. What forces act on the car? What are the other parts of the action-reaction pairs? On what objects are they exerted?

The four fundamental forces You have investigated several contact interactions and one long-range interaction. Are they all different, or are they the result of a single, fundamental force? At this time, physicists recognize four fundamental forces. One is the gravitational interaction. All objects attract one another through the gravitational interaction, which is an attractive force due to the masses of the objects. You'll learn more about this in Chapter 8. Magnetic forces and the electric forces, such as those that cause static cling, are part of the electromagnetic interaction that you will learn more about in later chapters. The electromagnetic interaction is a force that holds atoms and molecules together, so it is actually responsible for all the contact forces. Two more fundamental interactions occur within the nucleus of the atom. The strong nuclear interaction acts between the protons and neutrons that hold the nucleus together. The weak nuclear interaction makes itself known in some kinds of radioactive decay.

Physicists have long searched for ways in which these interactions might be related. The unification of electric and magnetic interactions was a triumph of nineteenth-century physics. In the 1970s, physicists showed that the electromagnetic and weak interactions were part of a single electro-weak interaction. The ultimate goal is to show that at some level, all four interactions are really one.

Pocket Lab

Stopping Forces

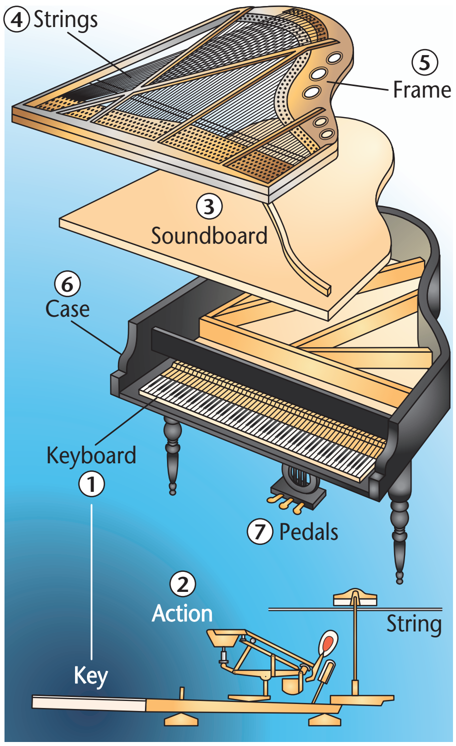
Tie two 1-m long strings to the backs of two lab carts and attach 0.2 kg masses to the other ends. Hang the masses over the end of a lab table so that the masses are just above the floor. Add mass to one of the carts so that its mass is about twice its original mass. Predict how the motion of the carts might be different when you push them at the same speed and then let them coast. Try it. Predict how you could change the mass on one of the strings so that the motion of the carts would be the same when given the same initial speed. Test your prediction.

Analyze and Conclude Describe your observations in words and in a motion diagram. Explain your results in terms of inertia, force, mass, and acceleration.

How It Works

Piano

The forerunner of the modern piano was invented in the early 1700s by an Italian instrument maker named Bartolommeo Cristofori. Cristofori's instrument consisted of a keyboard and strings that were struck with hammers. The *gravicembalo col piano e forte*, as the instrument was called, was unique in that it had the ability to vary the loudness of its tone, which, of course, depended on the force exerted by the player's fingers.



1 Keyboard On nearly all pianos, the keyboard consists of 36 black keys and 52 white keys. The force from the pianist's fingers causes the keys to move a set of felt-covered hammers in the piano's action.

2 Action Attached to the keyboard is a complex mechanism called the action, which consists of thousands of wooden parts. Various pieces of the action make it possible for the hammers to strike any of the over 220 strings in a typical piano.

3 Soundboard A piano's soundboard is a thin sheet of wood that amplifies the sound created by the vibrating strings.

4 Strings The strings of most pianos are made of steel and vary in length from about 15 to 200 cm. The pitch of a tone depends primarily upon the length of the strings, the longest being lowest in pitch. But pitch also depends on the thickness of the strings and their tension.

5 Frame To sustain the tremendous tension of the hundreds of taut strings, the frame of a piano is made of cast iron.

6 Case A piano's case houses the instrument's strings, action, frame, and soundboard and is made of a hard wood.

7 Pedals Most pianos have three pedals. Force from the pianist's foot moves the pedals, which varies the quality of the piano's tones.

Thinking Critically

1. The bridge is the wooden ridge that runs diagonally across the soundboard. What do you think is the function of this bridge?
2. The damper pedal lifts all of the dampers in the piano's action. In terms of force and motion, what happens to the strings when the damper pedal is depressed?

Forces of Ropes and Strings

You have already dealt with problems involving the force called tension which is exerted by strings or ropes. For example, **Figure 6–15** shows a bucket hanging from a rope attached to the ceiling. If the rope breaks, the bucket will fall, so before it breaks, there must be forces holding the rope together. The force that the top part of the rope exerts on the bottom part is $\boldsymbol{F}_{\text{T(top on bottom)}}$. Newton's third law states that this force must be part of an interaction pair. The other member of the pair is the force the bottom part exerts on the top, $\boldsymbol{F}_{\text{T(bottom on top)}}$. These forces, equal in magnitude but opposite in direction, are shown in **Figure 6–15.**

The origin of the tension forces holding the rope together are the electromagnetic forces between the molecules and atoms of the rope. At any point in the rope, the tension forces are pulling equally in both directions. But the bucket is in equilibrium, so according to Newton's second law, the net force on the bucket is zero. That is, $F_{\text{T(top on bottom)}} - F_{\text{g}} = 0$, or $F_{\text{T(top on bottom)}} = F_{\text{g}}$. Thus, the tension in the rope is the weight of all objects below it.

Tension forces are also at work in a tug-of-war. If team A on the left is exerting a force of 500 N and the rope doesn't move, then team B on the right must also be pulling with a force of 500 N.

But, what is the tension in the rope? If each team pulls with 500 N of force, is the tension 1000 N? To decide, think of the rope about to break into two pieces. The left-hand end isn't moving, so the net force on it is zero. That is, $F_{\text{T(A on rope)}} = F_{\text{T(right on left)}} = 500$ N. Similarly, $F_{\text{T(B on rope)}} = F_{\text{T(left on right)}} = 500$ N. But the two tensions, $F_{\text{T(right on left)}}$ and $F_{\text{T(left on right)}}$, are an interaction pair, so they are equal and opposite. Thus, the tension in the rope equals the force with which each team pulls, or 500 N.

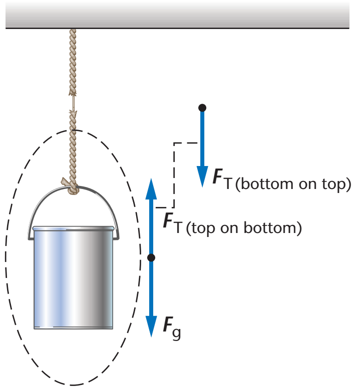


FIGURE 6–15 The tension in the rope is equal to the weight of all objects hanging from it.

6.3 Section Review

1. You hold a book in your hand, motionless in the air. Identify the forces on the book. For each force, identify the other force that makes up the interaction pair.
2. You now lower the book at increasing speed. Do any of the forces on the book change? Explain. Do their interaction pair partners change? Explain.
3. Evaluate the impact that research unifying the electric and magnetic interactions has on the scientific thought of unifying all four fundamental forces.
4. **Critical Thinking** Suppose a curtain prevented each tug-of-war team from seeing its opposing team. One team ties its end of the rope to a tree. If the opposing team pulls with a 500-N force, what is the tension in the rope? Explain.

CHAPTER 6 REVIEW

Key Terms

6.1
- force
- system
- environment
- contact force
- long-range force
- force of gravity
- agent
- free-body diagram
- net force
- Newton's second law
- Newton's first law
- inertia
- equilibrium

6.2
- apparent weight
- weightlessness
- static friction force
- kinetic friction force
- terminal velocity
- simple harmonic motion
- period
- amplitude
- mechanical resonance

6.3
- interaction pair
- Newton's third law

Summary

6.1 Force and Motion
- An object that experiences a push or a pull has a force exerted on it.
- Forces are vector quantities, having both direction and magnitude.
- Forces may be divided into contact and long-range forces.
- Newton's second law states that the acceleration of a system equals the net force on it divided by its mass.
- Newton's first law states that if, and only if, an object has no net force on it, then its velocity will not change.
- The inertia of an object is its resistance to changing velocity.

6.2 Using Newton's Laws
- The weight of an object depends upon the acceleration due to gravity and the mass of the object.
- An object's apparent weight is what is sensed as a result of contact forces on it.
- The friction force acts when two surfaces touch.
- The friction force is proportional to the force pushing the surfaces together.
- An object undergoes simple harmonic motion if the net restoring force on it is directly proportional to the object's displacement.
- Mechanical resonance can greatly increase the amplitude of simple harmonic motion when a small, periodic force acts on an oscillating object at its natural frequency.

6.3 Interaction Forces
- All forces result from interactions between objects.
- Newton's third law states that the two forces that make up an interaction pair of forces are equal in magnitude but opposite in direction and act on different objects.
- Although there are many different forces, they are all forms of the four fundamental forces.

Key Equations

6.1

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

6.2

$$F_{\text{f, kinetic}} = \mu_k F_N$$

$$0 \le F_{\text{f, static}} \le \mu_s F_N$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

6.3

$$\boldsymbol{F}_{\text{A on B}} = -\boldsymbol{F}_{\text{B on A}}$$

Reviewing Concepts

Section 6.1

1. A physics book is motionless on the top of a table. If you give it a hard push with your hand, it slides across the table and slowly comes to a stop. Use Newton's laws of motion to answer the following questions.

   a. Why does the book remain motionless before the force of the hand is applied?

   b. Why does the book begin to move when your hand pushes hard enough on it?

   c. Why does the book eventually come to a stop?

d. Under what conditions would the book remain in motion at constant speed?

2. Why do you have to push harder on the pedals of a single-speed bicycle to start it moving than to keep it moving at a constant velocity?
3. Suppose the acceleration of an object is zero. Does this mean that there are no forces acting on it? Give an example supporting your answer.
4. When a basketball player dribbles a ball, it falls to the floor and bounces up. Is a force required to make it bounce? Why? If a force is needed, what is the agent involved?

Section 6.2

5. Before a sky diver opens his parachute, he may be falling at a velocity higher than the terminal velocity he will have after the parachute opens.
   - **a.** Describe what happens to his velocity as he opens the parachute.
   - **b.** Describe his velocity from after his parachute has been open for a time until he is about to land.
6. What is the difference between the period and the amplitude of a pendulum?
7. When an object is vibrating on a spring and passes through the equilibrium position, there is no net force on it. Why is the velocity not zero at this point? What quantity is zero?

Section 6.3

8. A rock is dropped from a bridge into a valley. Earth pulls on the rock and accelerates it downward. According to Newton's third law, the rock must also be pulling on Earth, yet Earth doesn't seem to accelerate. Explain.
9. All forces can be divided into just four fundamental kinds. Name the fundamental force that best describes the following.
   - **a.** holds the nucleus together
   - **b.** holds molecules together
   - **c.** holds the solar system together

Applying Concepts

10. If you are in a car that is struck from behind, you can receive a serious neck injury called whiplash.
    - **a.** Using Newton's laws of motion, explain what happens to cause the injury.
    - **b.** How does a headrest reduce whiplash?
11. Should astronauts choose pencils with hard or soft lead for making notes in space? Explain.
12. If you find a pendulum clock running slightly fast, how can you adjust it to keep better time?
13. Review, analyze, and critique Newton's first law of motion. Can we prove this law? Explain. Be sure to consider the role of friction.
14. What is the meaning of a coefficient of friction that is greater than 1? How would you measure it?
15. Using the model of friction described in this book, would the friction between the tire and the road be increased by a wide rather than a narrow tire? Explain.
16. From the top of a tall building, you drop two table tennis balls, one filled with air and the other with water. Both experience air resistance as they fall. Which ball reaches terminal velocity first? Do both hit the ground at the same time?
17. It is often said that 1 kg equals 2.2 lb. What does this statement mean? What would be the proper way of making the comparison?
18. Which of the four fundamental forces makes paint cling to a wall? Which force makes adhesive sticky? Which force makes wax stick to a car?
19. According to legend, a horse learned Newton's laws. When the horse was told to pull a cart, it refused, saying that if it pulled the cart forward, according to Newton's third law there would be an equal force backwards. Thus, there would be balanced forces, and, according to Newton's second law, the cart wouldn't accelerate. How would you reason with this horse?

Problems

Section 6.1

20. A 873-kg (1930-lb) dragster, starting from rest, attains a speed of 26.3 m/s (58.9 mph) in 0.59 s.
    - **a.** Find the average acceleration of the dragster during this time interval.
    - **b.** What is the magnitude of the average net force on the dragster during this time?

c. Assume that the driver has a mass of 68 kg. What horizontal force does the seat exert on the driver?

21. The dragster in problem 20 completed the 402.3 m (0.2500 mile) run in 4.936 s. If the car had a constant acceleration, what would be its acceleration and final velocity?

22. After a day of testing race cars, you decide to take your own 1550-kg car onto the test track. While moving down the track at 10.0 m/s, you uniformly accelerate to 30.0 m/s in 10.0 s. What is the average net force that the track has applied to the car during the 10.0-s interval?

23. A 65-kg swimmer jumps off a 10.0-m tower.
   a. Find the swimmer's velocity on hitting the water.
   b. The swimmer comes to a stop 2.0 m below the surface. Find the net force exerted by the water.

24. The dragster in problem 21 crossed the finish line going 126.6 m/s (283.1 mph). Does the assumption of constant acceleration hold true? What other piece of evidence could you use to see if the acceleration is constant?

25. A race car has a mass of 710 kg. It starts from rest and travels 40.0 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is exerted on it?

Section 6.2

26. What is your weight in newtons?

27. Your new motorcycle weighs 2450 N. What is its mass in kg?

28. A pendulum has a length of 0.67 m.
   a. Find its period.
   b. How long would the pendulum have to be to double the period?

29. You place a 7.50-kg television set on a spring scale. If the scale reads 78.4 N, what is the acceleration due to gravity at that location?

30. If you use a horizontal force of 30.0 N to slide a 12.0-kg wooden crate across a floor at a constant velocity, what is the coefficient of kinetic friction between the crate and the floor?

31. A 4500-kg helicopter accelerates upward at 2.0 m/s^2. What lift force is exerted by the air on the propellers?

32. The maximum force a grocery sack can withstand and not rip is 250 N. If 20.0 kg of groceries are lifted from the floor to the table with an acceleration of 5.0 m/s^2, will the sack hold?

33. A force of 40.0 N accelerates a 5.0-kg block at 6.0 m/s^2 along a horizontal surface.
   a. How large is the frictional force?
   b. What is the coefficient of friction?

34. A 225-kg crate is pushed horizontally with a force of 710 N. If the coefficient of friction is 0.20, calculate the acceleration of the crate.

35. You are driving a 2500.0-kg car at a constant speed of 14.0 m/s along an icy, but straight, level road. As you approach an intersection, the traffic light turns red. You slam on the brakes. Your wheels lock, the tires begin skidding, and the car slides to a halt in a distance of 25.0 m. What is the coefficient of kinetic friction between your tires and the icy road?

36. A student stands on a bathroom scale in an elevator at rest on the 64th floor of a building. The scale reads 836 N.
   a. As the elevator moves up, the scale reading increases to 936 N, then decreases back to 836 N. Find the acceleration of the elevator.
   b. As the elevator approaches the 74th floor, the scale reading drops to 782 N. What is the acceleration of the elevator?
   c. Using your results from parts **a** and **b,** explain which change in velocity, starting or stopping, would take the longer time.
   d. What changes would you expect in the scale readings on the ride back down?

37. A sled of mass 50.0 kg is pulled along flat, snow-covered ground. The static friction coefficient is 0.30, and the kinetic friction coefficient is 0.10.
   a. What does the sled weigh?
   b. What force will be needed to start the sled moving?
   c. What force is needed to keep the sled moving at a constant velocity?
   d. Once moving, what total force must be applied to the sled to accelerate it at 3.0 m/s^2?

38. The instruments attached to a weather balloon have a mass of 5.0 kg. The balloon is released and exerts an upward force of 98 N on the instruments.

a. What is the acceleration of the balloon and instruments?

b. After the balloon has accelerated for 10.0 s, the instruments are released. What is the velocity of the instruments at the moment of their release?

c. What net force acts on the instruments after their release?

d. When does the direction of their velocity first become downward?

Section 6.3

39. A 65-kg boy and a 45-kg girl use an elastic rope while engaged in a tug-of-war on an icy, frictionless surface. If the acceleration of the girl toward the boy is 3.0 m/s^2, find the magnitude of the acceleration of the boy toward the girl.

40. As a baseball is being caught, its speed goes from 30.0 m/s to 0.0 m/s in about 0.0050 s. The mass of the baseball is 0.145 kg.

a. What are the baseball's acceleration?

b. What are the magnitude and direction of the force acting on it?

c. What is the magnitude and direction of the force acting on the player who caught it?

41. A 2.0-kg mass (m_A) and a 3.0-kg mass (m_B) are attached to a lightweight cord that passes over a frictionless pulley. The hanging masses are free to move. Choose coordinate systems for the two masses with the positive direction up for m_A and down for m_B.

a. Create a pictorial model.

b. Create a physical model with motion and free-body diagrams.

c. Find the acceleration of the smaller mass.

42. Suppose the masses in problem 41 are now 1.00 kg and 4.00 kg. Find the acceleration of the larger mass.

Extra Practice For more practice solving problems, go to Extra Practice Problems, Appendix B.

Critical Thinking Problems

43. The force exerted on a 0.145-kg baseball by a bat changes from 0.0 N to 1.0×10^4 N over 0.0010 s, then drops back to zero in the same amount of time. The baseball was going toward the bat at 25 m/s.

a. Draw a graph of force versus time. What is the average force exerted on the ball by the bat?

b. What is the acceleration of the ball?

c. What is the final velocity of the ball, assuming that it reverses direction?

Going Further

Team Project Using the example problems in this chapter as models, write an example problem to solve the following problem. Include Sketch the Problem, Calculate Your Answer (with a complete strategy), and Check Your Answer.

A driver of a 975-kg car, traveling 25 m/s, puts on the brakes. What is the shortest distance it will take for the car to stop? Assume that the road is concrete and that the frictional force of the road on the tires is constant. Assume that the tires don't slip.

Applying CBLs Develop a CBL lab, using a motion detector, that graphs the distance a freely falling object moves over equal intervals of time. Also graph velocity versus time. Compare and contrast your graphs. Using your velocity graph, determine the acceleration. Does it equal *g*?

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