SECTION 1

Laws of Motion

KEY TERMS

inertia

OBJECTIVES

- **Identify** the law that says that objects change their motion only when a net force is applied.
- **Relate** the first law of motion to important applications, such as seat belt safety issues.
- **Calculate** force, mass, and acceleration by using Newton's second law.

Every motion you observe or experience is related to a force. Sir Isaac Newton described the relationship between motion and force in three laws that we now call Newton's laws of motion. Newton's laws apply to a wide range of motion—a caterpillar crawling on a leaf, a person riding a bicycle, or a rocket blasting off into space.

inertia the tendency of an object to resist being moved or, if the object is moving, to resist a change in speed or direction until an outside force acts on the object

Newton's First Law

If you slide your book across a rough surface, such as carpet, the book will soon come to rest. On a smooth surface, such as ice, the book will slide much farther before stopping. Because there is less frictional force between the ice and the book, the force must act over a longer time before the book comes to a stop. Without friction, the book would keep sliding forever. This is an example of Newton's first law, which is stated as follows.

An object at rest remains at rest and an object in motion maintains its velocity unless it experiences an unbalanced force.

In a moving car, you experience the effect described by Newton's first law. As the car stops, your body continues forward, as the crash-test dummies in ***Figure 1*** do. Seat belts and other safety features are designed to counteract this effect.

Figure 1

Crash-test dummies, used by car manufacturers to test cars in crash situations, continue to travel forward when the car comes to a sudden stop, in accordance with Newton's first law.

Objects tend to maintain their state of motion

Inertia is the tendency of an object at rest to remain at rest or, if moving, to continue moving at a constant velocity. All objects resist changes in motion, so all objects have inertia. An object with a small mass, such as a baseball, can be accelerated with a small force. But a much larger force is required to accelerate a car, which has a relatively large mass.

Inertia is related to an object's mass

Newton's first law of motion is often summed up in one sentence: Matter resists any change in motion. An object at rest will remain at rest until something makes it move. Likewise, a moving object stays in motion at the same velocity unless a force acts on it to change its speed or direction. Since this property of matter is called inertia, Newton's first law is sometimes called the *law of inertia.*

Mass is a measure of inertia. An object with a small mass has less inertia than an object with a large mass. Therefore, it is easier to change the motion of an object with a small mass. For example, a softball has less mass and less inertia than a bowling ball does. Because the softball has a small amount of inertia, it is easy to pitch, and the softball's direction will change easily when it is hit with a bat. Imagine how difficult playing softball with a bowling ball would be! The bowling ball would be hard to pitch, and changing its direction with a bat would be very difficult.

Figure 2

During an abrupt stop, this baby would continue to move forward. The backward-facing car seat distributes the force that holds the baby in the car.

Seat belts and car seats provide protection

Because of inertia, you slide toward the side of a car when the driver makes a sharp turn. Inertia is also why it is impossible for a plane, car, or bicycle to stop instantaneously. There is always a time lag between the moment the brakes are applied and the moment the vehicle comes to rest.

When the car you are riding in comes to a stop, your seat belt and the friction between you and the seat stop your forward motion. They provide the unbalanced rearward force needed to bring you to a stop as the car stops.

Babies are placed in special backward-facing car seats, as shown in ***Figure 2.*** With this type of car seat, the force that is needed to bring the baby to a stop is safely spread out over the baby's entire body.

Quick ACTIVITY

Newton's First Law

1. Set an index card over a glass. Put a coin on top of the card.
2. With your thumb and forefinger, quickly flick the card sideways off the glass. Observe what happens to the coin. Does the coin move with the index card?
3. Try again, but this time slowly pull the card sideways and observe what happens to the coin.
4. Use Newton's first law of motion to explain your results.

Science *and the Consumer*

Should a Car's Air Bags Be Disconnected?

Air bags are standard equipment in every new automobile sold in the United States. These safety devices are credited with saving almost 1700 lives between 1986 and 1996. However, air bags have also been blamed for the deaths of 36 children and 20 adults during the same period. In response to public concern about the safety of air bags, the National Highway Traffic Safety Administration has proposed that drivers be allowed to disconnect the air bags on their vehicles.

In a collision, air bags explode from a compartment to cushion the passenger's upper body and head.

How Do Air Bags Work?

When a car equipped with air bags comes to an abrupt stop, sensors in the car detect the sudden change in speed (negative acceleration) and trigger a chemical reaction inside the air bags. This reaction very quickly produces nitrogen gas, which causes the bags to inflate and explode out of their storage compartments in a fraction of a second. The inflated air bags cushion the head and upper body of the driver and the passenger in the front seat, who keep moving forward at the time of impact because of their inertia. Also, the inflated air bags increase the amount of time over which the stopping forces act. So, as the riders move forward, the air bags absorb the impact.

What Are the Risks?

Because an air bag inflates suddenly and with great force, it can cause serious head and neck injuries in some circumstances. Seat belts reduce this risk by holding passengers against the seat backs. This allows the air bag to inflate before the passenger's head comes into contact with it. In fact, most of the people killed by air bags either were not using seat belts or had not adjusted the seat belts properly.

Two groups of people are at risk for injury by air bags even with seat belts on: drivers shorter than about 157 cm (5 ft 2 in) and infants riding next to the driver in a rear-facing safety seat.

Alternatives to Disconnecting Air Bags

Always wearing a seat belt and placing child safety seats in the back seat of the car are two easy ways to reduce the risk of injury from air bags. Shorter drivers can buy pedal extenders that allow them to sit farther back and still safely reach the pedals. Some vehicles without a back seat have a switch that can deactivate the passenger-side air bag. Automobile manufacturers are also working on air bags that inflate less forcefully.

Your Choice

1. **Critical Thinking** Are air bags useful if your car is struck from behind by another vehicle?
2. **Locating Information** Research "smart" air-bag systems, and prepare a report.

internetconnect

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Topic: Inertia SciLinks code: HK4072

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Newton's Second Law

Newton's first law describes what happens when the net force acting on an object is zero: the object either remains at rest or continues moving at a constant velocity. What happens when the net force is not zero? Newton's second law describes the effect of an unbalanced force on the motion of an object.

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Topic: Newton's Laws of Motion
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Force equals mass times acceleration

Newton's second law, which describes the relationship between mass, force, and acceleration, can be stated as follows.

The unbalanced force acting on an object equals the object's mass times its acceleration.

Mathematically, Newton's second law can be written as follows.

Newton's Second Law

$$force = mass \times acceleration$$
$$F = ma$$

Consider the difference between pushing an empty shopping cart and pushing the same cart filled with groceries, as shown in ***Figure 3***. If you push with the same amount of force in each situation, the empty cart will have a greater acceleration because it has a smaller mass than the full cart does. The same amount of force produces different accelerations because the masses are different. If the masses are the same, a greater force produces a greater acceleration, as shown in ***Figure 4*** on the next page.

Figure 3
Because the full cart has a larger mass than the empty cart does, the same force gives the empty cart a greater acceleration.

Figure 4

A A small force on an object causes a small acceleration.

B A larger force causes a larger acceleration.

Force is measured in newtons

Newton's second law can be used to derive the SI unit of force, the newton (N). One newton is the force that can give a mass of 1 kg an acceleration of 1 m/s^2, expressed as follows.

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2$$

The pound (lb) is sometimes used as a unit of force. One newton is equivalent to 0.225 lb. Conversely, 1 lb is equal to 4.448 N.

Math Skills

Newton's Second Law Zookeepers lift a stretcher that holds a sedated lion. The total mass of the lion and stretcher is 175 kg, and the lion's upward acceleration is 0.657 m/s^2. What is the unbalanced force necessary to produce this acceleration of the lion and the stretcher?

1 List the given and unknown values.

Given: *mass*, $m = 175$ kg

acceleration, $a = 0.657 \text{ m/s}^2$

Unknown: *force*, $F = ?$ N

2 Write the equation for Newton's second law.

force = *mass* × *acceleration*

$F = ma$

3 Insert the known values into the equation, and solve.

$F = 175 \text{ kg} \times 0.657 \text{ m/s}^2$

$F = 115 \text{ kg} \times \text{m/s}^2 = 115 \text{ N}$

Did You Know?

Sir Isaac Newton (1642–1727) was a central figure in the Scientific Revolution during the seventeenth century. He was born in 1642, the same year that Galileo died.

Practice

Newton's Second Law

1. What is the net force necessary for a 1.6×10^3 kg automobile to accelerate forward at 2.0 m/s^2?
2. A baseball accelerates downward at 9.8 m/s^2. If the gravitational force is the only force acting on the baseball and is 1.4 N, what is the baseball's mass?
3. A sailboat and its crew have a combined mass of 655 kg. Ignoring frictional forces, if the sailboat experiences a net force of 895 N pushing it forward, what is the sailboat's acceleration?

Practice HINT

- When a problem requires you to calculate the unbalanced force on an object, you can use Newton's second law ($F = ma$).
- The equation for Newton's second law can be rearranged to isolate mass on the left side as follows.

$$F = ma$$

Divide both sides by a.

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

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

You will need this form in Practice Problem 2.
- In Practice Problem 3, you will need to rearrange the equation to isolate acceleration on the left.

Newton's second law can also be stated as follows:

The acceleration of an object is proportional to the net force on the object and inversely proportional to the object's mass.

Therefore, the second law can be written as follows.

$$acceleration = \frac{force}{mass}$$

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

SECTION 1 REVIEW

SUMMARY

- An object at rest remains at rest and an object in motion maintains a constant velocity unless it experiences an unbalanced force (Newton's first law).
- Inertia is the property of matter that resists change in motion.
- Properly used seat belts protect passengers.
- The unbalanced force acting on an object equals the object's mass times its acceleration, or $F = ma$ (Newton's second law).

1. **State** Newton's first law of motion in your own words, and give an example that demonstrates that law.
2. **Explain** how the law of inertia relates to seat belt safety.
3. **Critical Thinking** Using Newton's laws, predict what will happen in the following situations:
   a. A car traveling on an icy road comes to a sharp bend.
   b. A car traveling on an icy road has to stop quickly.

Math Skills

4. What is the acceleration of a boy on a skateboard if the unbalanced forward force on the boy is 15 N? The total mass of the boy and the skateboard is 58 kg.
5. What force is necessary to accelerate a 1250 kg car at a rate of 40 m/s^2?
6. What is the mass of an object if a force of 34 N produces an acceleration of 4 m/s^2?

SECTION 2

Gravity

KEY TERMS

free fall
terminal velocity
projectile motion

OBJECTIVES

- **Explain** that gravitational force becomes stronger as the masses increase and rapidly becomes weaker as the distance between the masses increases, $F = G\frac{m_1m_2}{d^2}$
- **Evaluate** the concept that free-fall acceleration near Earth's surface is independent of the mass of the falling object.
- **Demonstrate** mathematically how free-fall acceleration relates to weight.
- **Describe** orbital motion as a combination of two motions.

Have you ever seen a videotape of the first astronauts on the moon? When they tried to walk on the lunar surface, they bounced all over the place! Why did the astronauts—who were wearing heavy spacesuits—bounce so easily on the moon, as shown in ***Figure 5***?

Figure 5
Because gravity is less on the moon than on Earth, the Apollo astronauts bounced as they walked on the moon's surface.

Law of Universal Gravitation

For thousands of years, two of the most puzzling scientific questions were "Why do objects fall toward Earth?" and "What keeps the planets in motion in the sky?" A British scientist, Sir Isaac Newton (1642–1727), realized that they were two parts of the same question. Newton generalized his observations on gravity in a law now known as the *law of universal gravitation.* The law states that all objects in the universe attract each other through gravitational force.

Universal Gravitation Equation

$$F = G\frac{m_1m_2}{d^2}$$

This equation says that the gravitational force increases as one or both masses increase. It also says that the gravitational force decreases as the distance between the masses increases. In fact, because distance is squared in the equation, even a small increase in distance can cause a large decrease in force. The symbol G in the equation represents a constant.

All matter is affected by gravity

Whether two objects are very large or very small, there is a gravitational force between them. When something is very large, such as Earth, the force is easy to detect. However, we do not notice that something as small as a toothpick exerts gravitational force. Yet no matter how small or how large the objects are, every object exerts a gravitational force, as illustrated by both parts of ***Figure 6.*** The force of gravity between two masses is easier to understand if you consider it in two parts: (1) the size of the masses and (2) the distance between them. So, these two ideas will be considered separately.

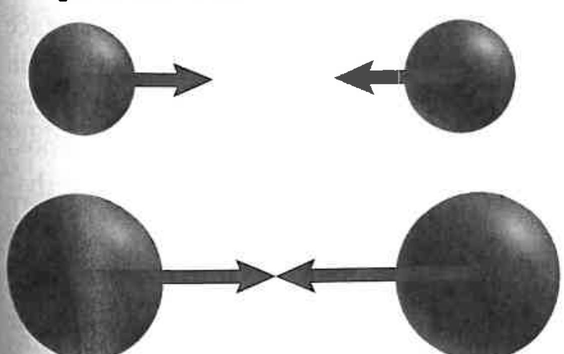
Gravitational force increases as mass increases

Gravity is given as the reason why an apple falls down from a tree. When an apple breaks its stem, it falls down because the gravitational force between Earth and the apple is much greater than the gravitational force between the apple and the tree.

Imagine an elephant and a cat. Because an elephant has a larger mass than a cat does, the gravitational force between an elephant and Earth is greater than the gravitational force between a cat and Earth. That is why a cat is much easier to pick up than an elephant! There is also gravitational force between the cat and the elephant, but it is very small because the cat's mass and the elephant's mass are so much smaller than Earth's mass. The gravitational force between most objects around you is relatively very small.

Figure 6

The arrows indicate the gravitational force between objects. The length of the arrows indicates the strength of the force.



A Gravitational force is small between objects that have small masses.

B Gravitational force is larger when one or both objects have larger masses.

INTEGRATING

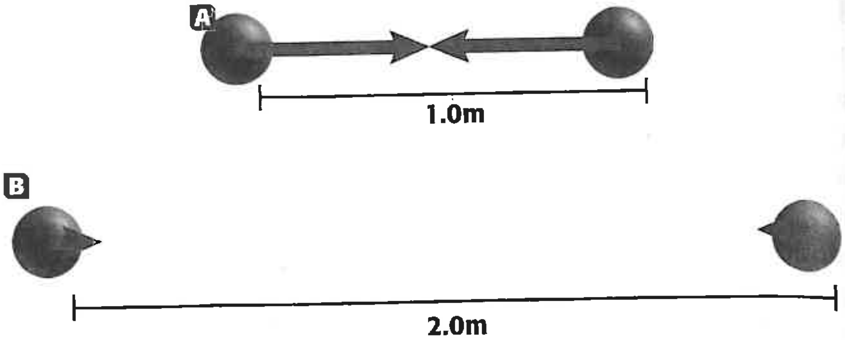
BIOLOGY

Gravity plays a role in your body. Blood pressure, for example, is affected by gravity. Therefore, your blood pressure will be greater in the lower part of your body than in the upper part. Doctors and nurses take your blood pressure on your arm at the level of your heart to see what the blood pressure is likely to be at your heart.

Figure 7

A Gravitational force rapidly becomes stronger as the distance between two objects decreases.

B Gravitational force rapidly becomes weaker as the distance between two objects increases.



Gravitational force decreases as distance increases

Gravitational force also depends on the distance between two objects, as shown in ***Figure 7.*** The force of gravity changes as the distance between the balls changes. If the distance between the two balls is doubled, the gravitational force between them decreases to one-fourth its original value. If the original distance is tripled, the gravitational force decreases to one-ninth its original value. Gravitational force is weaker than other types of forces, even though it holds the planets, stars, and galaxies together.

free fall the motion of a body when only the force of gravity is acting on the body

Free Fall and Weight

When gravity is the only force acting on an object, the object is said to be in **free fall.** The free-fall acceleration of an object is directed toward the center of Earth. Because free-fall acceleration results from gravity, it is often abbreviated as the letter *g*. Near Earth's surface, *g* is approximately 9.8 m/s^2.

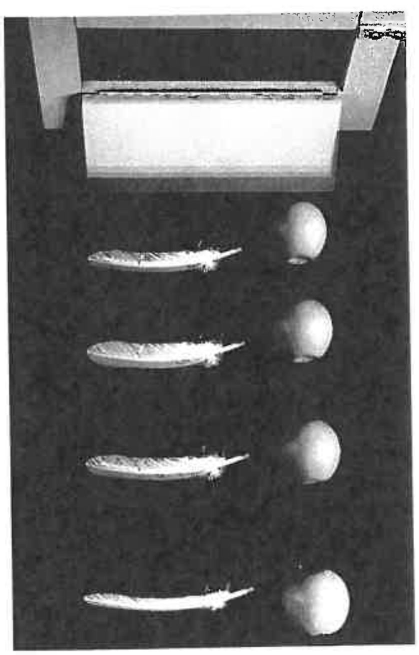


Figure 8

In a vacuum, a feather and an apple fall with the same acceleration because both are in free fall.

Free-fall acceleration near Earth's surface is constant

In the absence of air resistance, all objects near Earth's surface accelerate at the same rate, regardless of their mass. As shown in ***Figure 8,*** the feather and the apple, dropped from the same height, would hit the ground at the same moment. In this book, we disregard air resistance for all calculations. We assume that all objects on Earth accelerate at exactly 9.8 m/s^2.

Why do all objects have the same free-fall acceleration? Newton's second law shows that acceleration depends on both force and mass. A heavier object experiences a greater gravitational force than a lighter object does. But a heavier object is also harder to accelerate because it has more mass. The extra mass of the heavy object exactly compensates for the additional gravitational force.

Weight is equal to mass times free-fall acceleration

The force on an object due to gravity is called its *weight.* On Earth, your weight is simply the amount of gravitational force exerted on you by Earth. If you know the free-fall acceleration, g, acting on a body, you can use $F = ma$ (Newton's second law) to calculate the body's weight. Weight equals mass times free-fall acceleration. Mathematically, this is expressed as follows.

$$weight = mass \times free\text{-}fall\ acceleration$$
$$w = mg$$

Note that because weight is a force, the SI unit of weight is the newton. For example, a small apple weighs about 1 N. A 1.0 kg book has a weight of 1.0 kg $\times$ 9.8 m/s^2 = 9.8 N.

You may have seen pictures of astronauts floating in the air, as shown in ***Figure 9.*** Does this mean that they don't experience gravity? In orbit, astronauts, the space shuttle, and all objects on board experience free fall because of Earth's gravity. In fact, the astronauts and their surroundings all accelerate at the same rate. Therefore, the floor of the shuttle does not push up against the astronauts and the astronauts appear to be floating. This situation is referred to as *apparent weightlessness.*

Figure 9
In the low-gravity environment of the orbiting space shuttle, astronauts experience apparent weightlessness.

Weight is different from mass

Mass and weight are easy to confuse. Although mass and weight are directly proportional to one another, they are not the same. Mass is a measure of the amount of matter in an object. Weight is the gravitational force an object experiences because of its mass.

The weight of an object depends on gravity, so a change in an object's location will change the object's weight. For example, on Earth, a 66 kg astronaut weighs 66 kg $\times$ 9.8 m/s^2 = 650 N (about 150 lb), but on the moon's surface, where g is only 1.6 m/s^2, the astronaut would weigh 66 kg $\times$ 1.6 m/s^2, which equals 110 N (about 24 lb). The astronaut's mass remains the same everywhere, but the weight changes as the gravitational force acting on the astronaut changes in each place.

Weight influences shape

Gravitational force influences the shapes of living things. On land, large animals must have strong skeletons to support their mass against the force of gravity. The trunks of trees serve the same function. For organisms that live in water, however, the downward force of gravity is balanced by the upward force of the water. For many of these creatures, strong skeletons are unnecessary. Because a jellyfish has no skeleton, it can drift gracefully through the water but collapses if it washes up on the beach.

INTEGRATING

SPACE SCIENCE
Planets in our solar system have different masses and different diameters. Therefore, each has its own unique value for g. Find the weight of a 58 kg person on the following planets:

Earth, where g = 9.8 m/s^2

Venus, where g = 8.8 m/s^2

Mars, where g = 3.7 m/s^2

Neptune, where g = 11.8 m/s^2

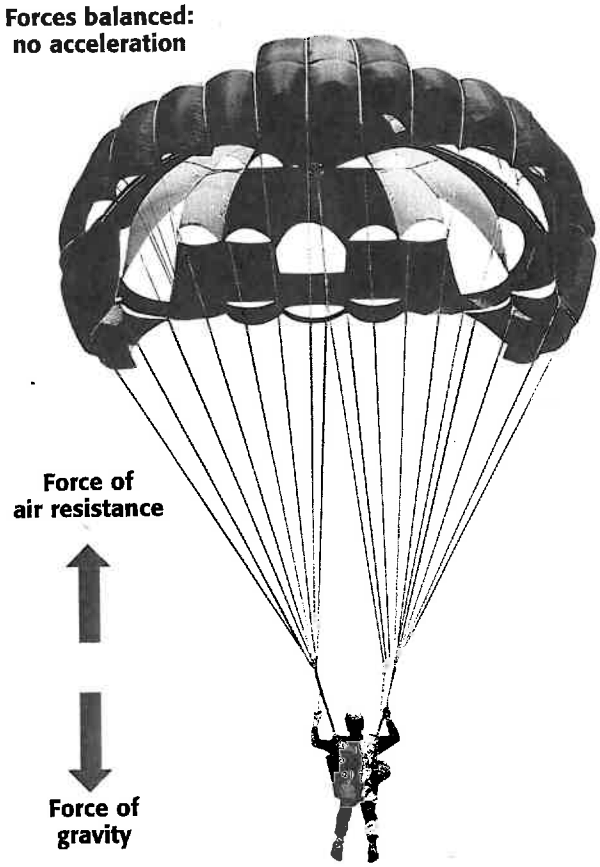


Figure 10

When a skydiver reaches terminal velocity, the force of gravity is balanced by air resistance.

Velocity is constant when air resistance balances weight

Both air resistance and gravity act on objects moving through Earth's atmosphere. A falling object stops accelerating when the force of air resistance becomes equal to the gravitational force on the object (the weight of the object), as shown in ***Figure 10.*** This happens because the air resistance acts in the opposite direction to the weight. When these two forces are equal, the object stops accelerating and reaches its maximum velocity, which is called the **terminal velocity.**

When skydivers start a jump, their parachutes are closed, and they are accelerated toward Earth by the force of gravity. As their velocity increases, the force they experience because of air resistance increases. When air resistance and the force of gravity are equal, skydivers reach a terminal velocity of about 320 km/h (200 mi/h). But when they open the parachute, air resistance increases greatly. For a while, this increased air resistance slows them down. Eventually, they reach a new terminal velocity of several kilometers per hour, which allows them to land safely.

terminal velocity the constant velocity of a falling object when the force of air resistance is equal in magnitude and opposite in direction to the force of gravity

Free Fall and Motion

Skydivers are often described as being in free fall before they open their parachutes. However, that is an incorrect description, because air resistance is always acting on the skydiver. An object is in free fall only if gravity is pulling it down and no other forces are acting on it. Because air resistance is a force, free fall can occur only where there is no air—in a vacuum (a place in which there is no matter) or in space. Thus, a skydiver falling to Earth is not in free fall.

Because there is no air resistance in space, objects in space are in free fall. Consider a group of astronauts riding in a spacecraft. When they are in space, gravity is the only force acting on the spacecraft and the astronauts. As a result, the spacecraft and the astronauts are in free fall. They all fall at the same rate of acceleration, no matter how great or small their individual masses are.

Orbiting objects are in free fall

Why do astronauts appear to float inside a space shuttle? Is it because they are "weightless" in space? You may have heard that objects are weightless in space, but this is not true. It is impossible to be weightless anywhere in the universe.

As you learned earlier in this section, weight—a measure of gravitational force—depends on the masses of objects and the distances between them. If you traveled in space far away from all the stars and planets, the gravitational force acting on you would be almost undetectable because the distance between you and other objects would be great. But you would still have mass, and so would all the other objects in the universe. Therefore, gravity would still attract you to other objects—even if just slightly—so you would still have weight.

Astronauts "float" in orbiting spaceships, not because they are weightless but because they are in free fall. The moon stays in orbit around Earth, as in ***Figure 11,*** and the planets stay in orbit around the sun, all because of free fall. To better understand why these objects continue to orbit and do not fall to Earth, you need to learn more about what orbiting means.

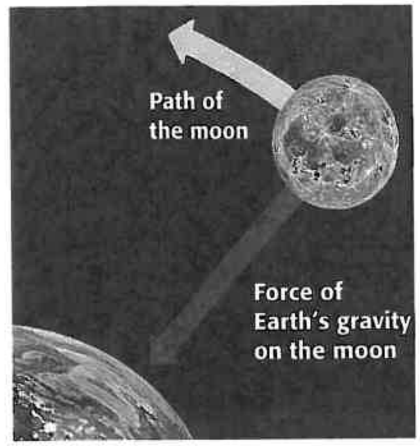
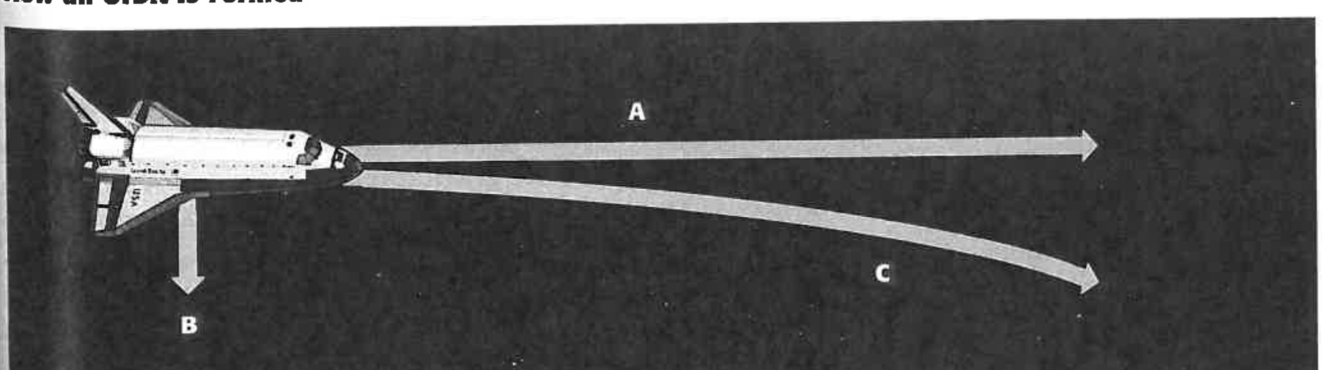


Figure 11
The moon stays in orbit around Earth because Earth's gravitational force provides a pull on the moon.

Two motions combine to cause orbiting

An object is said to be orbiting when it is traveling in a circular or nearly circular path around another object. When a spaceship orbits Earth, it is moving forward but it is also in free fall toward Earth. ***Figure 12*** shows how these two motions combine to cause orbiting.

Figure 12
How an Orbit Is Formed



A The shuttle moves forward at a constant speed. This would be its path if there were no gravitational pull from Earth.

B The shuttle is in free fall because gravity pulls it toward Earth. This would be its path if it were not traveling forward.

C When the forward motion combines with free fall, the shuttle follows the curve of Earth's surface. This is known as *orbiting*.

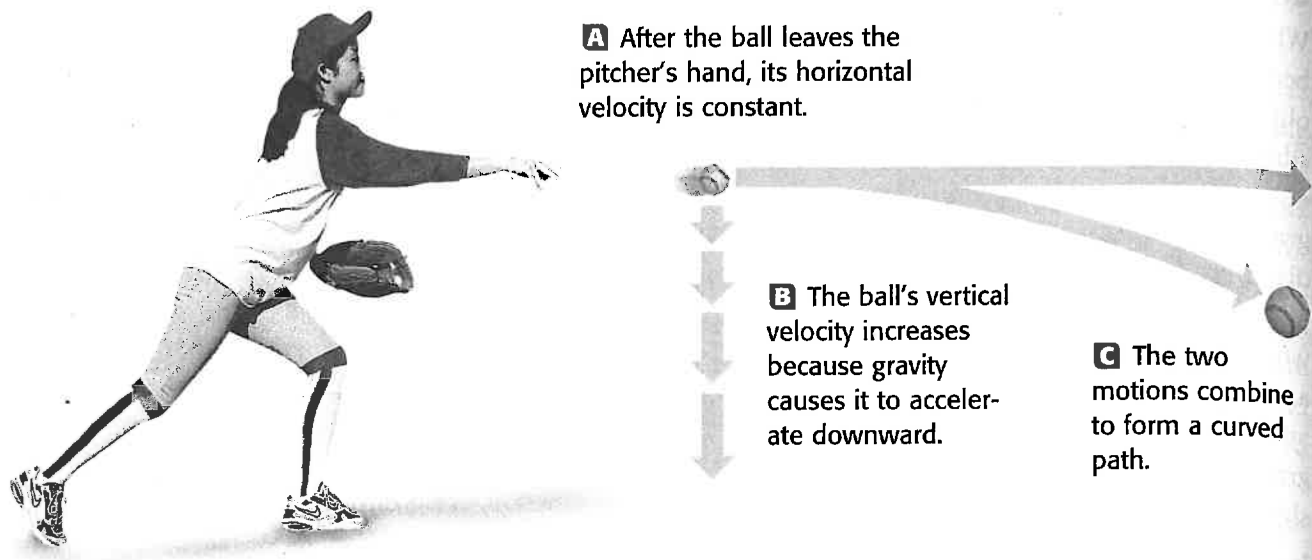


Figure 13
Two motions combine to form projectile motion.

projectile motion the curved path that an object follows when thrown, launched, or otherwise projected near the surface of Earth; the motion of objects that are moving in two dimensions under the influence of gravity

Projectile Motion and Gravity

The orbit of the space shuttle around Earth is an example of **projectile motion.** Projectile motion is the curved path an object follows when thrown, launched, or otherwise projected near the surface of Earth. The motions of leaping frogs, thrown balls, and arrows shot from a bow are all examples of projectile motion. Projectile motion has two components—horizontal and vertical. The two components are independent; that is, they have no effect on each other. In other words, the downward acceleration due to gravity does not change a projectile's horizontal motion, and the horizontal motion does not affect the downward motion. When the two motions are combined, they form a curved path, as shown in ***Figure 13.***

Projectile motion has some horizontal motion

When you throw a ball, your hand and arm exert a force on the ball that makes the ball move forward. This force gives the ball its horizontal motion. Horizontal motion is motion that is perpendicular (90°) to Earth's gravitational field.

After you have thrown the ball, there are no horizontal forces acting against the ball (if you ignore air resistance). Therefore, there are no forces to change the ball's horizontal motion. So, the horizontal velocity of the ball is constant after the ball leaves your hand, as shown in ***Figure 13.***

Ignoring air resistance allows you to simplify projectile motion so that you can understand the horizontal and then the vertical components of projectile motion. Then, you can put them together to understand projectile motion as a whole.

Projectile motion also has some vertical motion

In addition to horizontal motion, vertical motion is involved in the movement of a ball that has been thrown. If it were not, the ball would continue moving in a straight line, never falling. Again imagine that you are throwing the ball as in ***Figure 13.*** When you let go of the ball, gravity pulls it downward, which gives the ball vertical motion. Vertical motion is motion in the direction in which the force of Earth's gravity acts.

In the absence of air resistance, gravity on Earth pulls downward with an acceleration of 9.8 m/s^2 on objects that are in projectile motion, just as it does on all falling objects. ***Figure 14*** shows that the downward accelerations of a thrown object and of a falling object are identical.

Because objects in projectile motion accelerate downward, you should always aim above a target if you want to hit it with a thrown or propelled object. This is why archers point their arrows above the bull's eye on a target. If they aimed an arrow directly at a bull's eye, the arrow would strike below the center of the target rather than the middle.

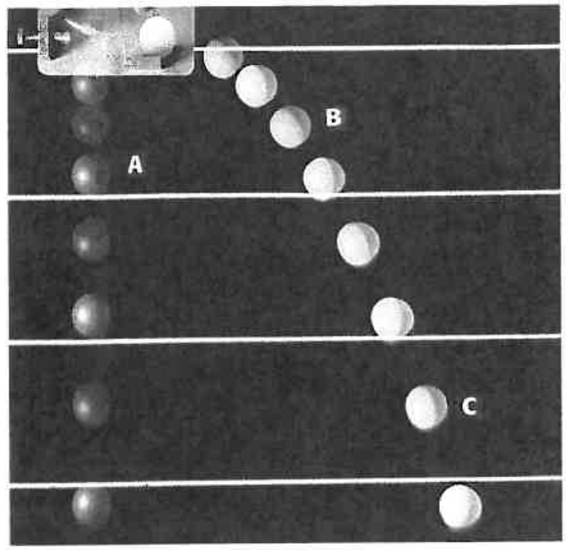


Figure 14

A The red ball was dropped without a horizontal push.

B The yellow ball was given a horizontal push off the ledge at the same time it was dropped. It follows a projectile-motion path.

C The two balls have the same acceleration downward because of gravity. The horizontal motion of the yellow ball does not affect its vertical motion.

SECTION 2 REVIEW

SUMMARY

- Gravitational force between two masses strengthens as the masses become more massive and rapidly weakens as the distance between them increases.
- Gravitational acceleration results from gravitational force, is constant, and does not depend on mass.
- Mathematically, *weight* = *mass* × *free-fall acceleration*, or $w = mg$.
- Projectile motion is a combination of a downward free-fall motion and a forward horizontal motion.

1. **State** the law of universal gravitation, and use examples to explain the effect of changing mass and changing distance on gravitational force.
2. **Explain** why your weight would be less on the moon than on Earth even though your mass would not change. Use the law of universal gravitation in your explanation.
3. **Describe** the difference between mass and weight.
4. **Name** the two components that make up orbital motion, and explain how they do so.
5. **Critical Thinking** Using Newton's second law, explain why the gravitational acceleration of any object near Earth is the same no matter what the mass of the object is.

Math Skills

6. The force between a planet and a spacecraft is 1 million newtons. What will the force be if the spacecraft moves to half its original distance from the planet?

SECTION 3

Newton's Third Law

KEY TERMS

momentum

OBJECTIVES

- **Explain** that when one object exerts a force on a second object, the second object exerts a force equal in size and opposite in direction on the first object.
- **Show** that all forces come in pairs commonly called *action* and *reaction pairs.*
- **Recognize** that all moving objects have momentum.

When you kick a soccer ball, as shown in ***Figure 15,*** you notice the effect of the force exerted by your foot on the ball. The ball experiences a change in motion. Is this the only force present? Do you feel a force on your foot? In fact, the soccer ball exerts an equal and opposite force on your foot. The force exerted on the ball by your foot is called the *action force,* and the force exerted on your foot by the ball is called the *reaction force.*

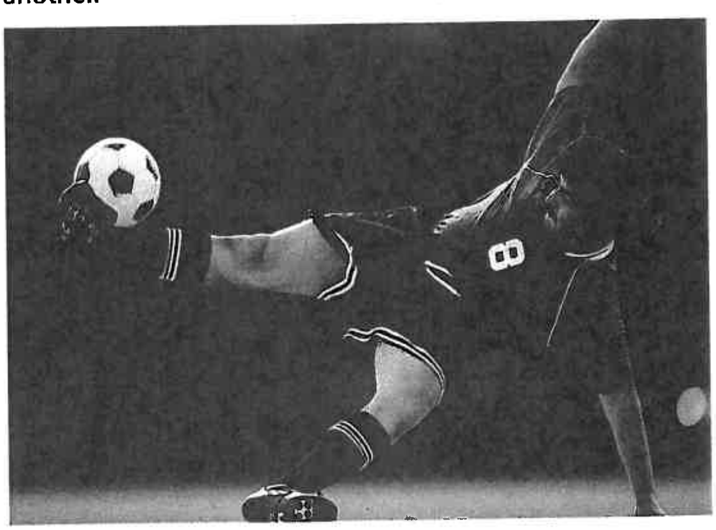
Action and Reaction Forces

Notice that the action and reaction forces are applied to different objects. These forces are equal and opposite. The action force acts on the ball, and the reaction force acts on the foot. This is an example of Newton's third law of motion, also called the *law of action and reaction.*

For every action force, there is an equal and opposite reaction force.

Figure 15

According to Newton's third law, the soccer ball and the foot exert equal and opposite forces on one another.



Forces always occur in pairs

Newton's third law can be stated as follows: All forces act in pairs. Whenever a force is exerted, another force occurs that is equal in size and opposite in direction. Action and reaction force pairs occur even when there is no motion. For example, when you sit on a chair, your weight pushes down on the chair. This is the action force. The chair pushing back up with a force equal to your weight is the reaction force.

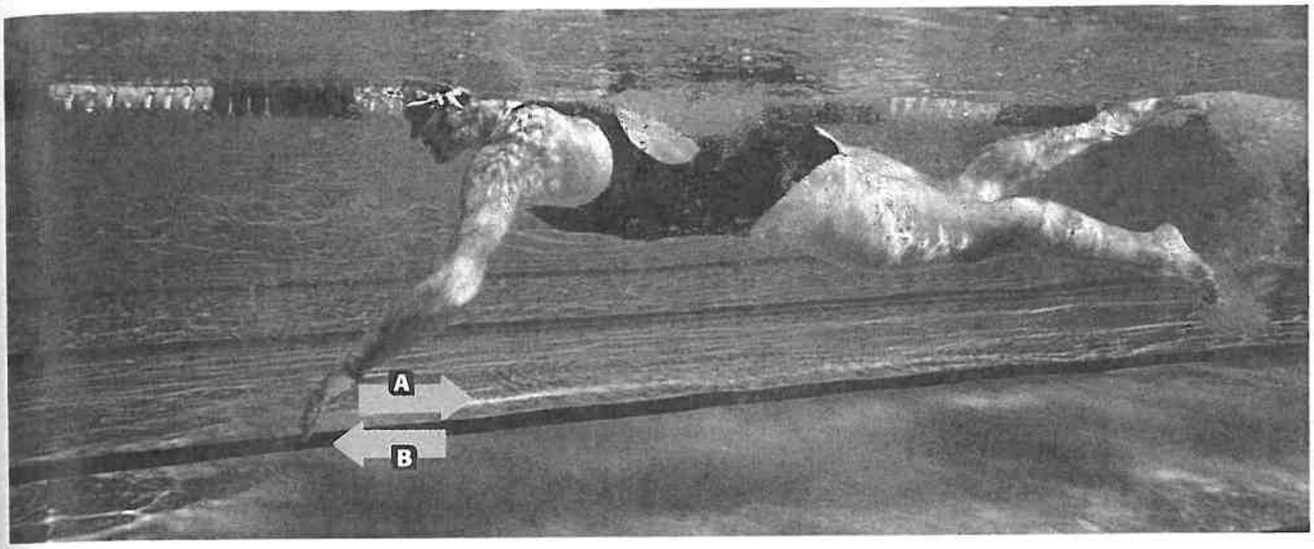


Figure 16

A The action force is the swimmer pushing the water backward.

B The reaction force is the water pushing the swimmer forward.

Force pairs do not act on the same object

Newton's third law indicates that forces always occur in pairs. In other words, every force is part of an action and reaction force pair. Although the forces are equal and opposite, they do not cancel one another because they are acting on different objects. In the example shown in ***Figure 16,*** the swimmer's hands and feet exert the action force on the water. The water exerts the reaction force on the swimmer's hands and feet. In this and all other examples, the action and reaction forces do not act on the same object. Also note that action and reaction forces always occur at the same time.

Equal forces don't always have equal effects

Another example of an action-reaction force pair is shown in ***Figure 17.*** If you drop a ball, the force of gravity pulls the ball toward Earth. This force is the action force exerted by Earth on the ball. But the force of gravity also pulls Earth toward the ball. That force is the reaction force exerted by the ball on Earth.

It's easy to see the effect of the action force—the ball falls to Earth. Why don't you notice the effect of the reaction force—Earth being pulled upward? Remember Newton's second law: an object's acceleration is found by dividing the force applied to the object by the object's mass. The force applied to Earth is equal to the force applied to the ball. However, Earth's mass is much larger than the ball's mass, so Earth's acceleration is much smaller than the ball's acceleration.

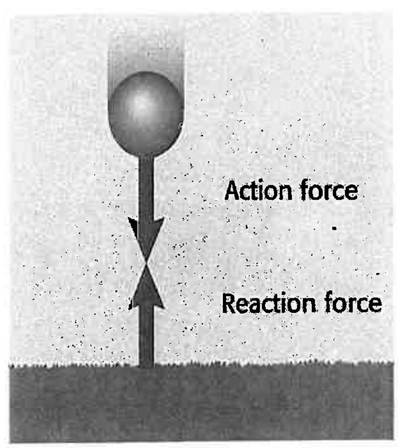


Figure 17

The two forces of gravity between Earth and a falling object are an example of a force pair.

Momentum

If a compact car and a large truck are traveling with the same velocity and the same braking force is applied to each, the truck takes more time to stop than the car does. Likewise, a fast-moving car takes more time to stop than a slow-moving car with the same mass does. The truck and the fast-moving car have more **momentum** than the compact car and the slow-moving car do. Momentum is a property of all moving objects, which is equal to the product of the mass and the velocity of the object.

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momentum a quantity defined as the product of the mass and velocity of an object

Moving objects have momentum

For movement along a straight line, momentum is calculated by multiplying an object's mass by its velocity. The SI unit for momentum is kilograms times meters per second (kg•m/s).

Momentum Equation

$$\text{momentum} = \text{mass} \times \text{velocity}$$

$$p = mv$$

The momentum equation shows that for a given velocity, the more mass an object has, the greater its momentum is. A massive semi truck on the highway, for example, has much more momentum than a sports car traveling at the same velocity has. The momentum equation also shows that the faster an object is moving, the greater its momentum is. For instance, a fast-moving train has much more momentum than a slow-moving train with the same mass has. If an object is not moving, its momentum is zero.

Like velocity, momentum has direction. An object's momentum is in the same direction as its velocity. The momentum of the bowling ball shown in ***Figure 18*** is directed toward the pins.

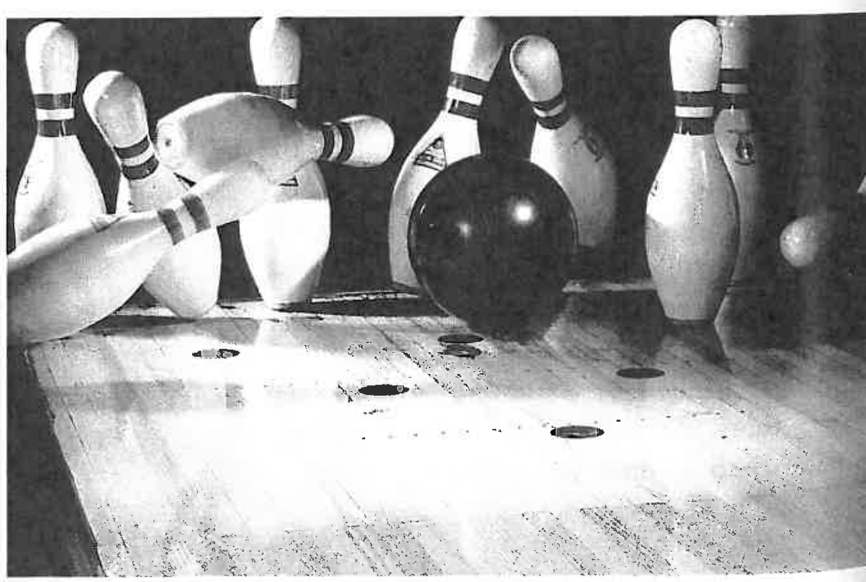


Figure 18
Because of the large mass and high speed of this bowling ball, it has a lot of momentum and is able to knock over the pins easily.

Math Skills

Momentum Calculate the momentum of a 6.00 kg bowling ball moving at 10.0 m/s down the alley toward the pins.

1 List the given and unknown values.

Given: *mass*, $m = 6.00$ kg

velocity, $v = 10.0$ m/s down the alley

Unknown: *momentum*, $p = ?$ kg • m/s (and direction)

2 Write the equation for momentum.

$momentum = mass \times velocity,\ p = mv$

3 Insert the known values into the equation, and solve.

$p = mv = 6.00 \text{ kg} \times 10.0 \text{ m/s}$

$p = 60.0$ kg • m/s down the alley

Practice HINT

- When a problem requires that you calculate velocity when you know momentum and mass, you can use the momentum equation.
- You may rearrange the equation to isolate velocity on the left side, as follows: $v = \frac{p}{m}$. You will need this form of the momentum equation for Practice Problem 2.

Practice

Momentum

1. Calculate the momentum of the following objects.
   - **a.** a 75 kg speed skater moving forward at 16 m/s
   - **b.** a 135 kg ostrich running north at 16.2 m/s
   - **c.** a 5.0 kg baby on a train moving eastward at 72 m/s
   - **d.** a seated 48.5 kg passenger on a train that is stopped
2. Calculate the velocity of a 0.8 kg kitten with a momentum of 5 kg • m/s forward.

Force is related to change in momentum

To catch a baseball, you must apply a force on the ball to make it stop moving. When you force an object to change its motion, you force it to change its momentum. In fact, you are actually changing the momentum of the ball over a period of time.

As the time period of the momentum's change becomes longer, the force needed to cause this change in momentum becomes smaller. So, if you pull your glove back while you are catching the ball, as in ***Figure 19,*** you are extending the time for changing the ball's momentum. Extending the time causes the ball to put less force on your hand. As a result, the sting to your hand is reduced.

As another example, when pole-vaulters, high jumpers, and gymnasts land after jumping, they move in the direction of the motion. This motion extends the time of the momentum change. As a result, the impact force decreases.

Figure 19
Moving the glove back during the catch increases the time of the momentum's change and decreases the impact force.

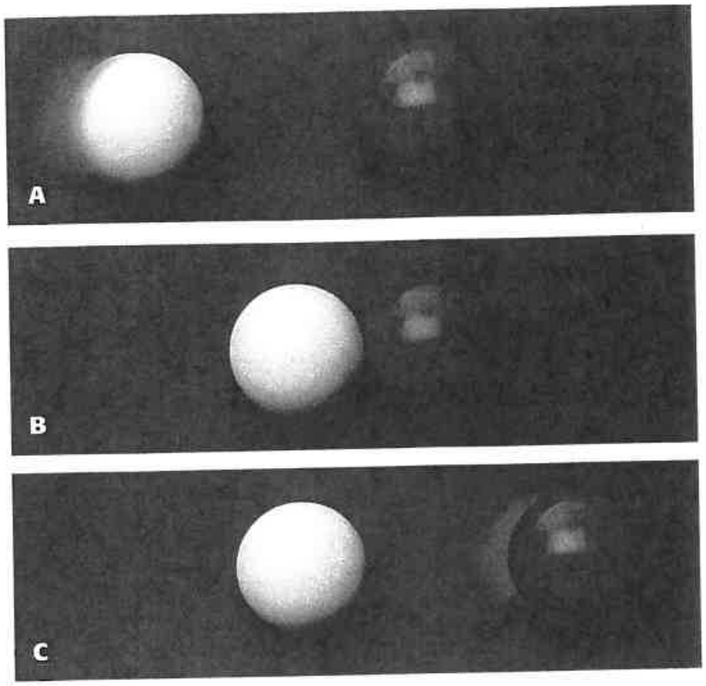


Figure 20

A The cue ball is moving forward with momentum. The billiard ball's momentum is zero.

B When the cue ball hits the billiard ball, the action force makes the billiard ball move forward. The reaction force stops the cue ball.

C Because the cue ball's momentum was transferred to the billiard ball, the cue ball's momentum after the collision is zero.

Momentum is conserved in collisions

Imagine that two cars of different masses traveling with different velocities collide head on. Can you predict what will happen after the collision? The momentum of the cars after the collision can be predicted. This prediction can be made because, in the absence of outside influences, momentum is conserved. Some momentum may be transferred from one vehicle to the other, but the total momentum remains the same. This principle is known as the law of conservation of momentum.

The total amount of momentum in an isolated system is conserved.

The total momentum of the two cars before a collision is the same as the total momentum after the collision. This law applies whether the cars bounce off each other or stick together. In some cases, cars bounce off each other to move in opposite directions. If the cars stick together after a collision, the cars will continue in the direction of the car that originally had the greater momentum.

Momentum is transferred

When a moving object hits a second object, some or all of the momentum of the first object is transferred to the second object. If only some of the momentum is transferred, the rest of the momentum stays with the first object.

Imagine you hit a billiard ball with a cue ball so that the billiard ball starts moving and the cue ball stops, as shown in ***Figure 20.*** The cue ball had a certain amount of momentum before the collision. During the collision, all of the cue ball's momentum was transferred to the billiard ball. After the collision, the billiard ball moved away with the same amount of momentum the cue ball had originally. This example illustrates the law of conservation of momentum. Any time two or more objects interact, they may exchange momentum, but the total momentum stays the same.

Newton's third law can explain conservation of momentum. In the example of the billiard ball, the cue ball hit the billiard ball with a certain force. This force was the action force. The reaction force was the equal but opposite force exerted by the billiard ball on the cue ball. The action force made the billiard ball start moving, and the reaction force made the cue ball stop moving.

Conservation of momentum explains rocket propulsion

Newton's third law and the conservation of momentum are used in rocketry. Rockets have many different sizes and designs, but the basic principle remains the same. The push of the hot gases through the nozzle is matched by an equal push in the opposite direction on the combustion (burning) chamber, which accelerates the rocket forward, as shown in ***Figure 21.***

Many people wrongly believe that rockets work because the hot gases flowing out the nozzle push against the atmosphere. If this were true, rockets couldn't travel in outer space where there is no atmosphere. What really happens is that momentum is conserved. Together, the rocket and fuel form a system. When the fuel is pushed out the back, they remain a system. The change in the fuel's momentum must be matched by a change in the rocket's momentum in the opposite direction for the overall momentum to stay the same. This example shows the conservation of momentum. Also, the upward force on the rocket and the downward force on the fuel are an action-reaction pair.

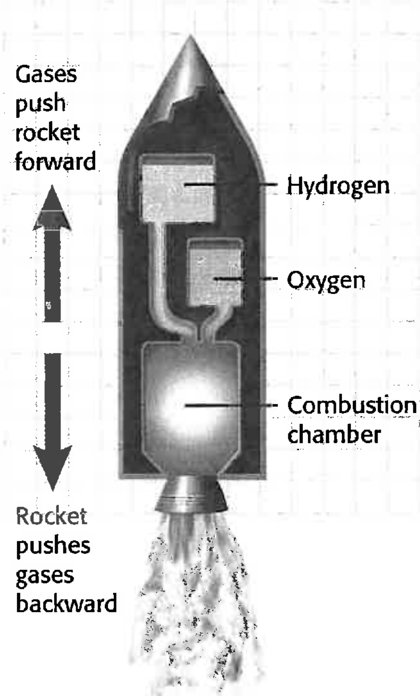
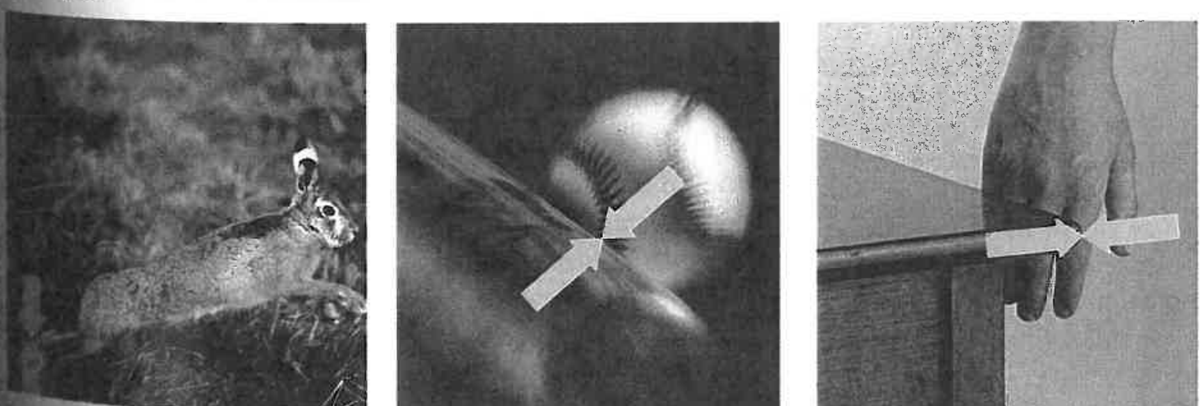


Figure 21
All forces occur in action-reaction pairs. In this case, the upward push on the rocket equals the downward push on the exhaust gases.

Action and reaction force pairs are everywhere

Figure 22 gives more examples of action-reaction pairs. In each example, notice which object exerts the action force and which object exerts the reaction force. Even though we are concentrating on just the action and reaction force pairs, there are other forces at work, each of which is also part of an action-reaction pair. For example, when the bat and ball exert action and reaction forces, the bat does not fly toward the catcher, because the batter is exerting yet another force on the bat.

Figure 22
Examples of Third Law Forces



A The rabbit's legs exert a force on Earth. Earth exerts an equal force on the rabbit's legs, which causes the rabbit to accelerate upward.

B The bat exerts a force on the ball, which sends the ball into the outfield. The ball exerts an equal force on the bat.

C When your hand hits the table with a force, the table's force on your hand is equal in size and opposite in direction.

Quick Lab

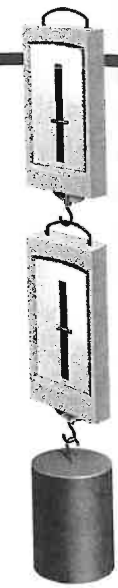
How are action and reaction forces related?

Materials 2 spring scales 2 kg mass

1. Hang the 2 kg mass from one of the spring scales.
2. Observe the reading on the spring scale.
3. While keeping the mass connected to the first spring scale, link the two scales together. The first spring scale and the mass should hang from the second spring scale, as shown in the figure at right.
4. Observe the readings on each spring scale.

Analysis

1. What are the action and reaction forces involved in the spring scale–mass system you have constructed?
2. How did the readings on the two spring scales in step 4 compare? Explain how this is an example of Newton's third law.



SECTION 3 REVIEW

SUMMARY

- When one object exerts an action force on a second object, the second object exerts a reaction force on the first object. Forces always occur in action-reaction force pairs.
- Action-reaction force pairs are equal in size and opposite in direction.
- Every moving object has momentum, which is the product of the object's mass and velocity.
- Momentum can be transferred in collisions, but the total momentum before and after a collision is the same. This is the law of conservation of momentum.
- Rocket propulsion can be explained in terms of conservation of momentum.

1. **State** Newton's third law of motion, and give an example that shows how this law works.
2. **List** three examples of action-reaction force pairs that are not mentioned in the chapter.
3. **Define** momentum, and explain what the law of conservation of momentum means.
4. **Explain** why, when a soccer ball is kicked, the action and reaction forces don't cancel each other.
   a. The force of the player's foot on the ball is greater than the force of the ball on the player's foot.
   b. They act on two different objects.
   c. The reaction force happens after the action force.
5. **Critical Thinking** The forces exerted by Earth and a skier become an action-reaction force pair when the skier pushes the ski poles against Earth. Explain why the skier accelerates while Earth does not seem to move at all. (**Hint:** Think about the math equation for Newton's second law of motion for each of the forces.)

Math Skills

6. **Calculate** the momentum of a 1.0 kg ball traveling eastward at 12 m/s.

Math Skills

Algebraic Rearrangements

A car's engine exerts a force of 1.5×10^4 N in the forward direction, while friction exerts an opposing force of 9.0×10^3 N. If the car's mass is 1.5×10^3 kg, what is the magnitude and direction of the car's net acceleration?

1 List all given and unknown values.

Given: *forward force,* $F_1 = 1.5 \times 10^4$ N

opposing force, $F_2 = 9.0 \times 10^3$ N

mass, $m = 1.5 \times 10^3$ kg

Unknown: acceleration (m/s^2)

2 Write down the equation for force, and rearrange it for calculating the acceleration.

$$F = ma$$

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

3 Solve for acceleration.

The net acceleration must be obtained from the net force, which is the overall, unbalanced force acting on the car.

$$F_{net} = F_1 - F_2 \text{, so}$$

$$ma_{net} = F_1 - F_2$$

The net acceleration is therefore

$$a_{net} = \frac{(F_1 - F_2)}{m} = \frac{(1.5 \times 10^4 \text{ N} - 9.0 \times 10^3 \text{ N})}{1.5 \times 10^3 \text{ kg}} = \frac{6.0 \times 10^3 \text{ N}}{1.5 \times 10^3 \text{ kg}} = 4.0 \text{ m/s}^2$$

The net acceleration is 4.0 m/s^2, and like the net force, it is in the forward direction.

Practice

Following the example above, calculate the following:

1. A car has a mass of 1.50×10^3 kg. If the net force acting on the car is 6.75×10^3 N to the east, what is the car's acceleration?
2. A bicyclist decelerates with a force of 3.5×10^2 N. If the bicyclist and bicycle have a total mass of 1.0×10^2 kg, what is the acceleration?
3. Roberto and Laura are studying across from each other at a wide table. Laura slides a 2.2 kg book toward Roberto with a force of 11.0 N straight ahead. If the force of friction opposing the movement is 8.4 N, what is the magnitude and direction of the book's acceleration?

CHAPTER 11 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found at the end of each section. The vocabulary terms are listed on the first page of each section.

UNDERSTANDING CONCEPTS

1. Newton's first law of motion states that an object
- **a.** at rest remains at rest unless it experiences an unbalanced force.
- **b.** in motion maintains its velocity unless it experiences an unbalanced force.
- **c.** will tend to maintain its motion unless it experiences an unbalanced force.
- **d.** All of the above

2. The first law of motion applies to
- **a.** only objects that are moving.
- **b.** only objects that are not moving.
- **c.** all objects, whether moving or not.
- **d.** no object, whether moving or not.

3. A measure of inertia is an object's
- **a.** mass.
- **b.** weight.
- **c.** velocity.
- **d.** acceleration.

4. Automobile seat belts are necessary for safety because of a passenger's
- **a.** weight.
- **b.** inertia.
- **c.** speed.
- **d.** gravity.

5. The newton is a measure of
- **a.** mass.
- **b.** length.
- **c.** force.
- **d.** acceleration.

6. Any change in an object's velocity is caused by
- **a.** the object's mass.
- **b.** the object's direction.
- **c.** a balanced force.
- **d.** an unbalanced force.

7. __________ is a force that opposes the motion between two objects in contact with each other.
- **a.** Motion
- **b.** Friction
- **c.** Acceleration
- **d.** Velocity

8. An object's acceleration is
- **a.** directly proportional to the net force.
- **b.** inversely proportional to the object's mass.
- **c.** in the same direction as the net force.
- **d.** All of the above

9. Suppose you are pushing a car with a certain net force. If you then push with twice the net force, the car's acceleration
- **a.** becomes four times as much.
- **b.** becomes two times as much.
- **c.** stays the same.
- **d.** becomes half as much.

10. Gravitational force between two masses __________ as the masses increase and rapidly __________ as the distance between the masses increases.
- **a.** strengthens, strengthens
- **b.** weakens, weakens
- **c.** weakens, strengthens
- **d.** strengthens, weakens

11. According to Newton's third law, when a 450 N teacher stands on the floor, that teacher applies a force of 450 N on the floor, and
- **a.** the floor applies a force of 450 N on the teacher.
- **b.** the floor applies a force of 450 N on the ground.
- **c.** the floor applies a force of 450 N in all directions.
- **d.** the floor applies an undetermined force on the teacher.

12. An example of action-reaction forces is
   a. air escaping from a toy balloon.
   b. a rocket traveling through the air.
   c. a ball bouncing off a wall.
   d. All of the above

13. A baseball player catches a line-drive hit. If the reaction force is the force of the player's glove stopping the ball, the action force is
   a. the force of the player's hand on the glove.
   b. the force applied by the player's arm.
   c. the force of the ball pushing on the glove.
   d. the force of the player's shoes on the dirt.

14. Which of the following objects has the smallest amount of momentum?
   a. a loaded tractor-trailer driven at highway speeds
   b. a track athlete running a race
   c. a motionless mountain
   d. a child walking slowly on the playground

15. The force that causes a space shuttle to accelerate is exerted on the shuttle by
   a. the exhaust gases pushing against the atmosphere.
   b. the exhaust gases pushing against the shuttle.
   c. the shuttle's engines.
   d. the shuttle's wings.

USING VOCABULARY

16. What is *inertia,* and why is it important in the laws of motion?

17. What is the unit of measure of force, and how is it related to other measurement units?

18. What is the difference between *free fall* and *weightlessness*?

19. A wrestler weighs in for the first match on the moon. Will the athlete weigh more or less on the moon than he does on Earth? Explain your answer by using the terms *weight, mass, force,* and *gravity.*

20. Describe a skydiver's jump from the airplane to the ground. In your answer, use the terms *air resistance, gravity,* and *terminal velocity.*

21. Give an example of *projectile motion,* and explain how the example demonstrates that a vertical force does not influence horizontal motion.

BUILDING MATH SKILLS

22. **Force** The net force acting on a 5 kg discus is 50 N. What is the acceleration of the discus?

23. **Force** A 5.5 kg watermelon is pushed across a table. If the acceleration of the watermelon is 4.2 m/s^2 to the right, what is the net force exerted on the watermelon?

24. **Force** A block pushed with a force of 13.5 N accelerates at 6.5 m/s^2 to the left. What is the mass of the block?

25. **Force** The net force on a 925 kg car is 37 N as it pulls away from a stop sign. Find the car's acceleration.

26. **Force** What is the unbalanced force on a boy and his skateboard if the total mass of the boy and skateboard is 58 kg and their acceleration is 0.26 m/s^2 forward?

27. **Force** A student tests the second law of motion by accelerating a block of ice at a rate of 3.5 m/s^2. If the ice has a mass of 12.5 kg, what force must the student apply to the ice?

28. **Weight** A bag of sugar has a mass of 2.26 kg. What is its weight in newtons on the moon, where the acceleration due to gravity is one-sixth of that on Earth? (**Hint:** On Earth, $g = 9.8\ m/s^2$.)

29. **Weight** What would the 2.26 kg bag of sugar from the previous problem weigh on Jupiter, where the acceleration due to gravity is 2.64 times that on Earth?

30. **Momentum** Calculate the momentum of an 85 kg man jogging north along the highway at a rate of 2.65 m/s.

31. **Momentum** Calculate the momentum of a 9.1 kg toddler who is riding in a car moving east at 89 km/h.

32. **Momentum** Calculate the momentum of the following objects:
   a. a 65 kg skateboarder moving forward at the rate of 3.0 m/s
   b. a 20.0 kg toddler in a car traveling west at the rate of 22 m/s
   c. a 16 kg penguin at rest
   d. a 2.5 kg puppy running to the right at the rate of 4.8 m/s

BUILDING GRAPHING SKILLS

33. **Graphing** An experiment is done with a lab cart. Varying forces are applied to the cart and measured while the cart is accelerating. These forces are all in the direction of the movement of the cart, such as pushes to make the cart accelerate. Each push is made after the cart has stopped from the previous push. The following data were obtained in the experiment.

Trial	Acceleration	Applied force
1	0.70 m/s^2	0.35 N
2	1.70 m/s^2	0.85 N
3	2.70 m/s^2	1.35 N
4	3.70 m/s^2	1.85 N
5	4.70 m/s^2	2.35 N

Graph the data in the table. Place acceleration on the x-axis and applied force on the y-axis. Because $F = ma$ and therefore $m = \frac{F}{a}$, what does the line on the graph represent? Use your graph to determine the mass of the lab cart.

THINKING CRITICALLY

34. **Critical Thinking** What happens to the gravitational force between two objects if their masses do not change but the distance between them becomes four times as much?

35. **Critical Thinking** What will happen to the gravitational force between two objects if one of the objects gains 50% in mass while the mass of the other object does not change? Assume that the distance between the two objects does not change.

36. **Critical Thinking** There is no gravity in outer space. Write a paragraph explaining whether this statement is true or false. WRITING SKILL

37. **Problem Solving** How will acceleration change if the mass being accelerated is multiplied by three but the net force is cut in half?

38. **Problem Solving** If Earth's mass decreased to half its current mass but its radius (your distance to its center) did not change, your weight would be
   a. twice as big as it is now.
   b. the same as it is now.
   c. half as big as it is now.
   d. one-fourth as big as it is now.

39. **Applying Knowledge** If you doubled the net force acting on a moving object, how would the object's acceleration be affected?

40. **Applying Knowledge** For each pair, determine whether the objects have the same momentum. If the objects have different momentums, determine which object has more momentum.
   a. a car and train that have the same velocity
   b. a moving ball and a still bat
   c. two identical balls moving at the same speed in the same direction
   d. two identical balls moving at the same speed in opposite directions

DEVELOPING LIFE/WORK SKILLS

41. Locating Information Use the library and/or the Internet to find out about the physiological effects of free fall. Also find out how astronauts counter the effects of living in a free-fall environment, sometimes called *microgravity.* Use your information to propose a minimum acceleration for a space shuttle to Mars that would minimize physiological problems for the crew, both during flight and upon return to Earth's atmosphere.

42. Interpreting Data At home, use a garden hose to investigate the laws of projectile motion. Design experiments to investigate how the angle of the hose affects the range of the water stream. (Assume that the initial speed of water is constant.) How can you make the water reach the maximum range? How can you make the water reach the highest point? What is the shape of the water stream at each angle? Present your results to the rest of the class, and discuss the conclusions with regard to projectile motion and its components.

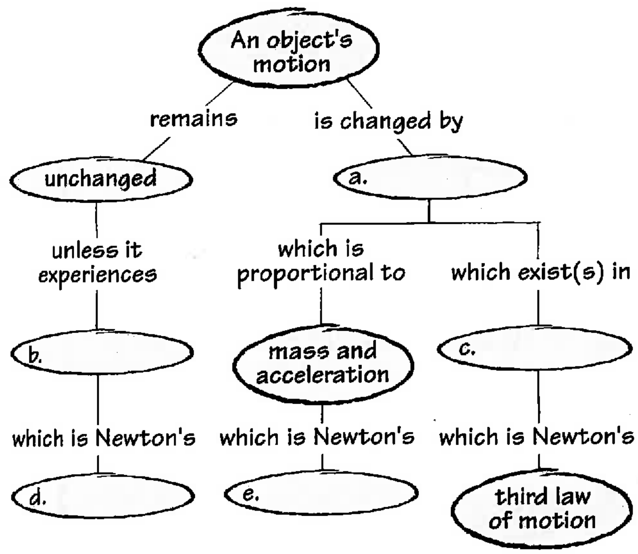
43. Working Cooperatively Read the following arguments about rocket propulsion. With a small group, determine which of the following statements is correct. Use a diagram to explain your answer.

- **a.** Rockets cannot travel in space because there is nothing for the gas exiting the rocket to push against.
- **b.** Rockets can travel because gas exerts an unbalanced force on the front of the rocket. This net force causes the acceleration.
- **c.** Argument b can not be true. The action and reaction forces will be equal and opposite. Therefore, the forces will balance, and no movement will be possible.

INTEGRATING CONCEPTS

44. Connection to Social Studies Research Galileo's work on falling bodies. What did he want to demonstrate? What theories did he try to refute?

45. Concept Mapping Copy the concept map below onto a sheet of paper. Write the correct phrase in each lettered box.



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Skills Practice Lab

Measuring Forces

Introduction

How can you use a rubber band to measure the force necessary to break a human hair?

Objectives

- USING SCIENTIFIC METHODS ***Design*** an experiment to test a hypothesis.
- ***Build*** and calibrate an instrument that measures force.
- ***Use*** your instrument to measure how much force it takes to stretch a human hair until it breaks.

Materials

comb or hairbrush
metal paper clips, large and small
metric ruler
pen or pencil
rubber bands of various sizes
standard hooked masses ranging from 10 to 200 g

▶ Procedure

Testing the Strength of a Human Hair

1. Obtain a rubber band and a paper clip.
2. Carefully straighten the paper clip so that it forms a double hook. Cut the rubber band and tie one end to the ring stand and the other end to one of the paper clip hooks. Let the paper clip dangle.
3. In your lab report, prepare a table as shown below.
4. Measure the length of the rubber band. Record this length in ***Table 1.***
5. Hang a hooked mass from the lower paper clip hook. Supporting the mass with your hand, allow the rubber band to stretch downward slowly. Then remove your hand carefully so the rubber band does not move.
6. Measure the stretched rubber band's length. Record the mass that is attached and the rubber band's length in ***Table 1.*** Calculate the change in length by subtracting your initial reading of the rubber band's length from the new length.
7. Repeat steps 5 and 6 three more times using different masses each time.
8. Convert each mass (in grams) to kilograms using the following equation.

   $$mass \text{ (in kg)} = mass \text{ (in g)} \div 1000$$

   Record your answers in ***Table 1.***
9. Calculate the force (weight) of each mass in newtons using the following equation.

   $$force \text{ (in N)} = mass \text{ (in kg)} \times 9.8 \text{ m/s}^2$$

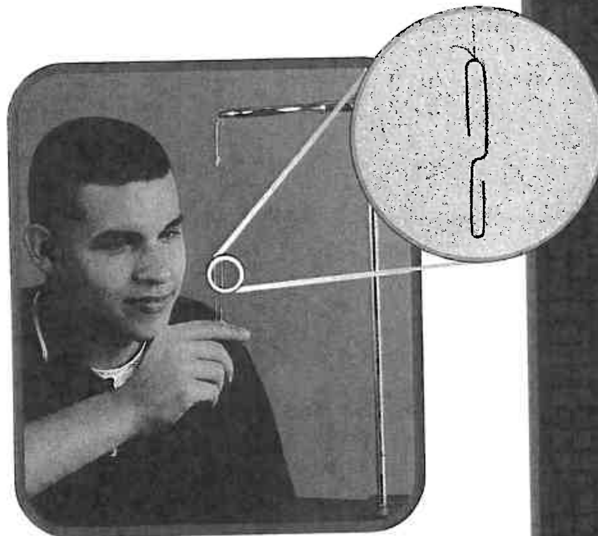
   Record your answers in ***Table 1.***

Table 1 **Calibration**

Rubber-band length (cm)	Change in length (cm)	Mass on hook (g)	Mass on hook (kg)	Force (N)
	0	0	0	0

Designing Your Experiment

10. With your lab partner(s), devise a plan to measure the force required to break a human hair using the instrument you just calibrated. How will you attach the hair to your instrument? How will you apply force to the hair?
11. In your lab report, list each step you will perform in your experiment.
12. Have your teacher approve your plan before you carry out your experiment.



Performing Your Experiment

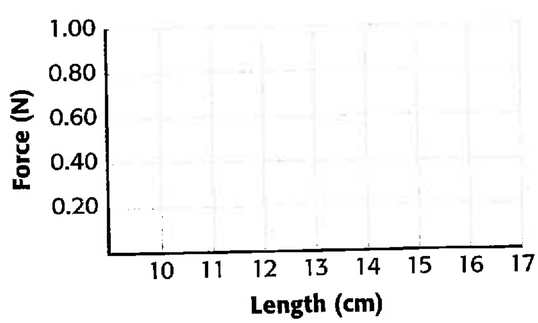
13. After your teacher approves your plan, gently run a comb or brush through a group member's hair several times until you find a loose hair at least 10 cm long that you can test.
14. In your lab report, prepare a data table similar to the one shown at right to record your experimental data.
15. Perform your experiment on three different hairs from the same person. Record the maximum rubber-band length before the hair snaps for each trial in Table 2.

Table 2 **Experimentation**

Trial	Rubber-band length (cm)	Force (N)
Hair 1		
Hair 2		
Hair 3		

▶ Analysis

1. Plot your calibration data in your lab report in the form of a graph like the one shown at right. On your graph draw the line or smooth curve that fits the points best.
2. Use the graph and the length of the rubber band for each trial of your experiment to determine the force that was necessary to break each of the three hairs. Record your answers in ***Table 2.***



▶ Conclusions

3. Suppose someone tells you that your results are flawed because you measured length and not force. How can you show that your results are valid?