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8: Forces and Motion

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Contents

CHAPTER 1 Motion

Chapter Outline

A frog flicks out its long tongue to catch insects. In this photo, you can't actually see the frog's tongue moving. But even if you were to witness it in person, you still wouldn't be able to see it. That's because a frog's tongue moves incredibly fast. It travels out and back in about 0.15 seconds, too fast for the human eye to detect. Other organisms can also move at very high speeds. For example, the fastest land animal, the cheetah, can sprint at an amazing 120 kilometers (75 miles) per hour. Speed is one way of measuring motion. What is motion, and what are other ways of measuring it? In this chapter, you'll find out.

1.1 Distance and Direction.

Lesson Objectives

- Define motion, and relate it to frame of reference.
- Describe how to measure distance.
- Explain how to represent direction.

Lesson Vocabulary

- distance
- frame of reference
- motion
- vector

Introduction

You can see several examples of people or things in motion in **Figure** 1.1. You can probably think of many other examples. You know from experience what motion is, so it may seem like a straightforward concept. **Motion** can also be defined simply, as a change in position. But if you think about examples of motion in more depth, you'll find that the idea of motion is not quite as simple and straightforward as it seems.

Frame of Reference

Assume that a school bus, like the one in **Figure** 1.2, passes by as you stand on the sidewalk. It's obvious to you that the bus is moving. It is moving relative to you and the trees across the street. But what about to the children inside the bus? They aren't moving relative to each other. If they look only at the other children sitting near them, they will not appear to be moving. They may only be able to tell that the bus is moving by looking out the window and seeing you and the trees whizzing by.

This example shows that how we perceive motion depends on our frame of reference. **Frame of reference** refers to something that is not moving with respect to an observer that can be used to detect motion. For the children on the bus, if they use other children riding the bus as their frame of reference, they do not appear to be moving. But if they use objects outside the bus as their frame of reference, they can tell they are moving. What is your frame of reference if you are standing on the sidewalk and see the bus go by? How can you tell the bus is moving? The video at the URL below illustrates other examples of how frame of reference is related to motion.

http://www.youtube.com/watch?v=7FYBG5GSklU (6:45)

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5019

FIGURE 1.1
These are just a few examples of people or things in motion. If you look around, you're likely to see many more.

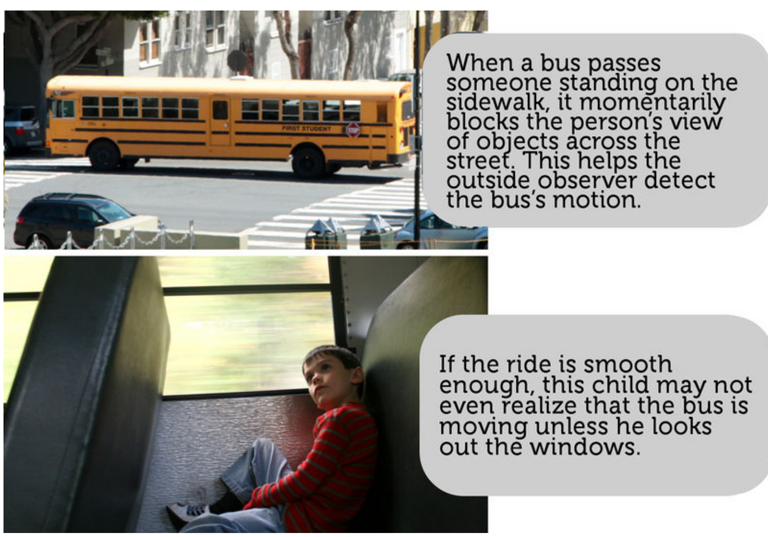


FIGURE 1.2
To a person outside the bus, the bus's motion is obvious. To children riding the bus, its motion may not be as obvious.

Distance

Did you ever go to a track meet like the one pictured in **Figure** 1.3? Running events in track include 100-meter sprints and 2000-meter races. Races are named for their distance. **Distance** is the length of the route between two points. The length of the route in a race is the distance between the starting and finishing lines. In a 100-meter sprint, for example, the distance is 100 meters.

FIGURE 1.3
These students are running a 100-meter sprint.

SI Unit for Distance

The SI unit for distance is the meter (1 m = 3.28 ft). Short distances may be measured in centimeters (1 cm = 0.01 m). Long distances may be measured in kilometers (1 km = 1000 m). For example, you might measure the distance a frog's tongue moves in centimeters and the distance a cheetah moves in kilometers.

Using Maps to Measure Distance

Maps can often be used to measure distance. Look at the map in **Figure** 1.4. Find Mia's house and the school. You can use the map key to directly measure the distance between these two points. The distance is 2 kilometers. Measure it yourself to see if you agree.

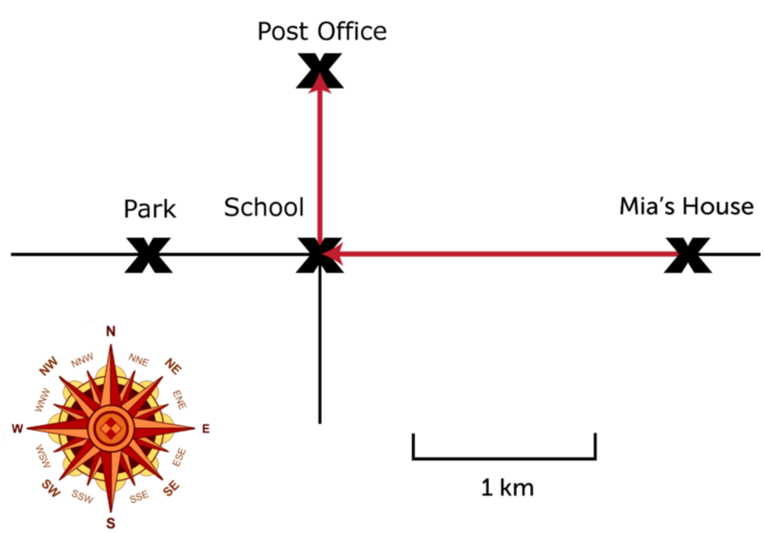


FIGURE 1.4
This map shows the routes from Mia's house to the school, post office, and park.

Direction

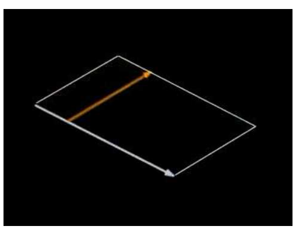
Things don't always move in straight lines like the route from Mia's house to the school. Sometimes they change direction as they move. For example, the route from Mia's house to the post office changes from west to north at the school (see **Figure** 1.4). To find the total distance of a route that changes direction, you must add up the distances traveled in each direction. From Mia's house to the school, for example, the distance is 2 kilometers. From the school to the post office, the distance is 1 kilometer. Therefore, the total distance from Mia's house to the post office is 3 kilometers.

You Try It!

Problem: What is the distance from the post office to the park in **Figure** 1.4?

Direction is just as important as distance in describing motion. For example, if Mia told a friend how to reach the post office from her house, she couldn't just say, "go 3 kilometers." The friend might end up at the park instead of the post office. Mia would have to be more specific. She could say, "go west for 2 kilometers and then go north for 1 kilometer." When both distance and direction are considered, motion is a vector. A **vector** is a quantity that includes both size and direction. A vector is represented by an arrow. The length of the arrow represents distance. The way the arrow points shows direction. The red arrows in **Figure** 1.4 are vectors for Mia's route to the school and post office. If you want to learn more about vectors, watch the videos at these URLs:

- http://www.youtube.com/watch?v=B-iBbcFwFOk (5:27)



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URL: http://www.ck12.org/flx/render/embeddedobject/5020

- http://www.youtube.com/watch?v=tSOz3xaHKLs

You Try It!

Problem: Why would the route from the post office to the park in the **Figure** 1.4 be considered a vector?

Lesson Summary

- Motion is a change of position. The perception of motion depends on a person's frame of reference.
- Distance is the length of the route between two points. The SI unit for distance is the meter (m).
- Direction is just as important as distance in describing motion. A vector is a quantity that has both size and direction. It can be used to represent the distance and direction of motion.

Lesson Review Questions

Recall

1. Define motion.
2. What is distance?
3. Describe how a vector represents distance and direction.

Apply Concepts

4. In **Figure** 1.4, what is the distance from Mia's house to the park?
5. Draw vectors to represent the following route from point A to point B:
   a. Starting at point A, go 2 km east.
   b. Then go 1 km south.
   c. Finally, go 3 km west to point B.

Think Critically

6. Explain how frame of reference is related to motion.

Points to Consider

A snail might travel 2 centimeters in a minute. A cheetah might travel 2 kilometers in the same amount of time. The distance something travels in a given amount of time is its speed.

- How could you calculate the speed of a snail or cheetah?
- Speed just takes distance and time into account. How might direction be considered as well?

1.2 Speed and Velocity

Lesson Objectives

- Outline how to calculate the speed of a moving object.
- Explain how velocity differs from speed.

Lesson Vocabulary

- speed
- velocity

Introduction

Did you ever play fast-pitch softball? If you did, then you probably have some idea of how fast the pitcher throws the ball. For a female athlete, like the one in **Figure** 1.5, the ball may reach a speed of 120 km/h (about 75 mi/h). For a male athlete, the ball may travel even faster. The speed of the ball makes it hard to hit. If the ball changes course, the batter may not have time to adjust the swing to meet the ball.

FIGURE 1.5
In fast-pitch softball, the pitcher uses a "windmill" motion to throw the ball. This is a different technique than other softball pitches. It explains why the ball travels so fast.

Speed

Speed is an important aspect of motion. It is a measure of how fast or slow something moves. It depends on how far something travels and how long it takes to travel that far. Speed can be calculated using this general formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

A familiar example is the speed of a car. In the U.S., this is usually expressed in miles per hour (see **Figure** 1.6). If your family makes a car trip that covers 120 miles and takes 3 hours, then the car's speed is:

$$\text{speed} = \frac{120 \text{ mi}}{3 \text{ h}} = 40 \text{ mi/h}$$

The speed of a car may also be expressed in kilometers per hour (km/h). The SI unit for speed is meters per second (m/s).

FIGURE 1.6
Speed limit signs like this one warn drivers to reduce their speed on dangerous roads.

Instantaneous vs. Average Speed

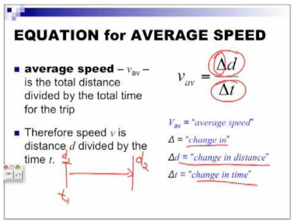
When you travel by car, you usually don't move at a constant speed. Instead you go faster or slower depending on speed limits, traffic, traffic lights, and many other factors. For example, you might travel 65 miles per hour on a highway but only 20 miles per hour on a city street (see **Figure** 1.7). You might come to a complete stop at traffic lights, slow down as you turn corners, and speed up to pass other cars. The speed of a moving car or other object at a given instant is called its instantaneous speed. It may vary from moment to moment, so it is hard to calculate.

FIGURE 1.7
Cars race by in a blur of motion on an open highway but crawl at a snail's pace when they hit city traffic.

It's easier to calculate the average speed of a moving object than the instantaneous speed. The average speed is the total distance traveled divided by the total time it took to travel that distance. To calculate the average speed, you can use the general formula for speed that was given above. Suppose, for example, that you took a 75-mile car trip with your family. Your instantaneous speed would vary throughout the trip. If the trip took a total of 1.5 hours, your average speed for the trip would be:

$$\text{average speed} = \frac{75 \text{ mi}}{1.5 \text{ h}} = 50 \text{ mi/h}$$

You can see a video about instantaneous and average speed and how to calculate them at this URL: http://www.youtube.com/watch?v=a8tIBrj84II (7:18).



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URL: http://www.ck12.org/flx/render/embeddedobject/5021

You Try It!

Problem: Terri rode her bike very slowly to the top of a big hill. Then she coasted back down the hill at a much faster speed. The distance from the bottom to the top of the hill is 3 kilometers. It took Terri 15 minutes to make the round trip. What was her average speed for the entire trip?

Distance-Time Graphs

The motion of an object can be represented by a distance-time graph like the one in **Figure** 1.8. A distance-time graph shows how the distance from the starting point changes over time. The graph in **Figure** 1.8 represents a bike trip. The trip began at 7:30 AM (A) and ended at 12:30 PM (F). The rider traveled from the starting point to a destination and then returned to the starting point again.

Slope Equals Speed

In a distance-time graph, the speed of the object is represented by the slope, or steepness, of the graph line. If the line is straight, like the line between A and B in **Figure** 1.8, then the speed is constant. The average speed can be calculated from the graph. The change in distance (represented by Δd) divided by the change in time (represented by Δt):

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}}$$

For example, the speed between A and B in **Figure** 1.8 is:

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}} = \frac{20 \text{ km} - 0 \text{ km}}{8{:}30 - 7{:}30 \text{ h}} = \frac{20 \text{ km}}{1 \text{ h}} = 20 \text{ km/h}$$

If the graph line is horizontal, as it is between B and C, then the slope and the speed are zero:

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}} = \frac{20 \text{ km} - 20 \text{ km}}{9{:}00 - 8{:}30 \text{ h}} = \frac{0 \text{ km}}{0.5 \text{ h}} = 0 \text{ km/h}$$

You Try It!

Problem: In **Figure** 1.8, calculate the speed of the rider between C and D.

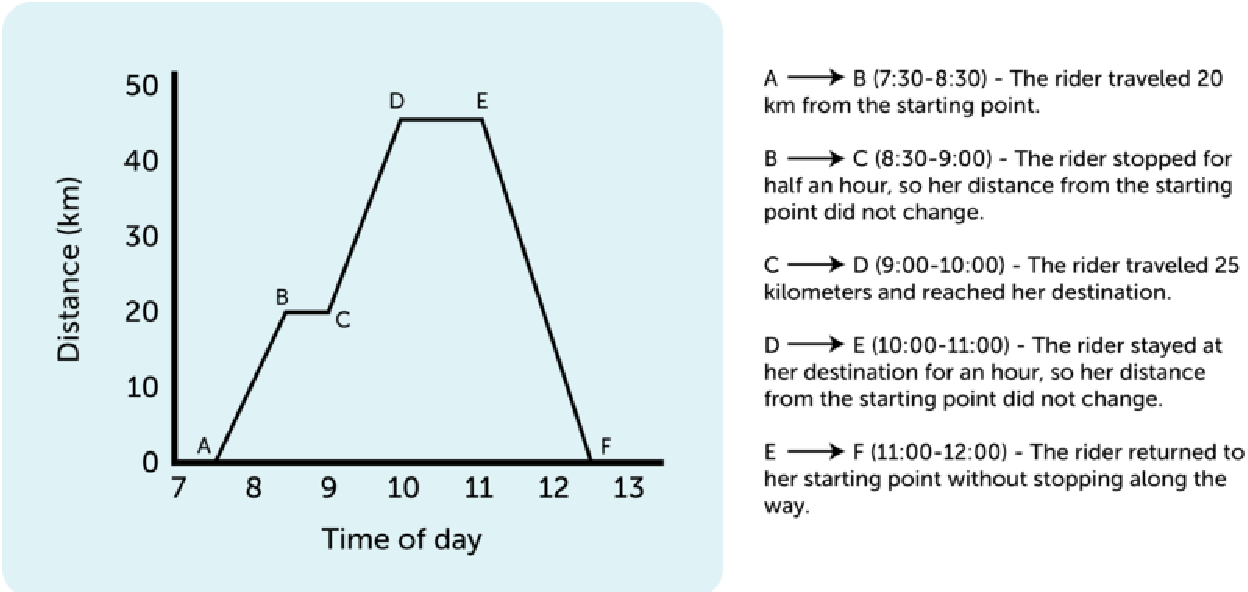

FIGURE 1.8
This graph shows how far a bike rider is from her starting point at 7:30 AM until she returned at 12:30 PM.

Calculating Distance from Speed and Time

If you know the speed of a moving object, you can also calculate the distance it will travel in a given amount of time. To do so, you would use this version of the general speed formula:

$$\text{distance} = \text{speed} \times \text{time}$$

For example, if a car travels at a speed of 60 km/h for 2 hours, then the distance traveled is:

$$\text{distance} = 60 \text{ km/h} \times 2 \text{ h} = 120 \text{ km}$$

You Try It!

Problem: If Maria runs at a speed of 2 m/s, how far will she run in 60 seconds?

Velocity

Speed tells you only how fast an object is moving. It doesn't tell you the direction the object is moving. The measure of both speed and direction is called **velocity**. Velocity is a vector that can be represented by an arrow. The length of the arrow represents speed, and the way the arrow points represents direction. The three arrows in **Figure** 1.9 represent the velocities of three different objects. Vectors A and B are the same length but point in different directions. They represent objects moving at the same speed but in different directions. Vector C is shorter than vector A or B but points in the same direction as vector A. It represents an object moving at a slower speed than A or B but in the same direction as A. If you're still not sure of the difference between speed and velocity, watch the cartoon at this URL: http://www.youtube.com/watch?v=mDcaeO0WxBI (2:10).

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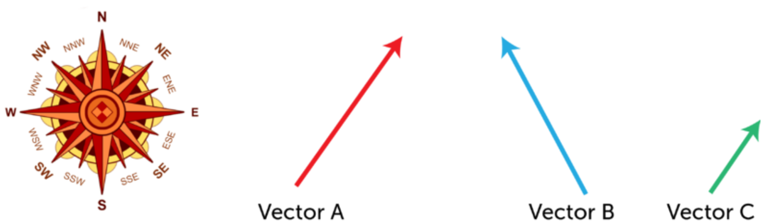

FIGURE 1.9

These vectors show both the speed and direction of motion.

In general, if two objects are moving at the same speed and in the same direction, they have the same velocity. If two objects are moving at the same speed but in different directions (like A and B in **Figure** 1.9), they have different velocities. If two objects are moving in the same direction but at a different speed (like A and C in **Figure** 1.9), they have different velocities. A moving object that changes direction also has a different velocity, even if its speed does not change.

Lesson Summary

- Speed is a measure of how fast or slow something moves. It depends on the distance traveled and how long it takes to travel that distance. The average speed of an object is calculated as the change in distance divided by the change in time.
- Velocity is a measure of both speed and direction. It is a vector that can be represented by an arrow. Velocity changes with a change in speed, a change in direction, or both.

Lesson Review Questions

Recall

1. What is speed? How is it calculated?
2. Define velocity.

Apply Concepts

3. Sam ran a 2000-meter race. He started at 9:00 AM and finished at 9:05 AM. He started out fast but slowed down toward the end. Calculate Sam's average speed during the race.
4. Create a distance-time graph to represent a typical trip from your home to school or some other route you travel often. You may estimate distances and times.

Think Critically

5. Explain how a distance-time graph represents speed.
6. Compare and contrast speed and velocity.
7. Is speed a vector? Why or why not?

Points to Consider

In this chapter, you read that the speed of a moving object equals the distance traveled divided by the time it takes to travel that distance. Speed may vary from moment to moment as an object speeds up or slows down. In the next lesson, "Acceleration," you will learn how to measure changes in speed over time.

- Do you know what a change in speed or direction is called?
- Why might measuring changes in speed or direction be important?

1.3 Acceleration

Lesson Objectives

- Define acceleration.
- Explain how to calculate acceleration.
- Describe velocity-time graphs.

Lesson Vocabulary

- acceleration

Introduction

Imagine the thrill of riding on a roller coaster like the one in **Figure** 1.10. The coaster crawls to the top of the track and then flies down the other side. It also zooms around twists and turns at breakneck speeds. These changes in speed and direction are what make a roller coaster ride so exciting. Changes in speed and/or direction are called **acceleration**.

FIGURE 1.10
Did you ever ride on a roller coaster like this one? It's called the "Blue Streak" for a reason. As it speeds around the track, it looks like a streak of blue.

Defining Acceleration

Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes. Acceleration may reflect a change in speed, a change in direction, or both. Because acceleration includes both a speed and direction, it is a vector.

People commonly think of acceleration as an increase in speed, but a decrease in speed is also acceleration. In this case, acceleration is negative. Negative acceleration may be called deceleration. A change in direction without a change in speed is acceleration as well. You can see several examples of acceleration in **Figure** 1.11.

FIGURE 1.11
How is velocity changing in each of these pictures?

If you are accelerating, you may be able to feel the change in velocity. This is true whether you change your speed or your direction. Think about what it feels like to ride in a car. As the car speeds up, you feel as though you are being pressed against the seat. The opposite occurs when the car slows down, especially if the change in speed is sudden. You feel yourself thrust forward. If the car turns right, you feel as though you are being pushed to the left. With a left turn, you feel a push to the right. The next time you ride in a car, notice how it feels as the car accelerates in each of these ways. For an interactive simulation about acceleration, go to this URL: http://phet.colorado.edu/en/simulation/moving-man .

Calculating Acceleration

Calculating acceleration is complicated if both speed and direction are changing. It's easier to calculate acceleration when only speed is changing. To calculate acceleration without a change in direction, you just divide the change in velocity (represented by Δv) by the change in time (represented by Δt). The formula for acceleration in this case is:

$$\text{Acceleration} = \frac{\Delta \text{v}}{\Delta \text{t}}$$

Consider this example. The cyclist in **Figure** 1.12 speeds up as he goes downhill on this straight trail. His velocity changes from 1 meter per second at the top of the hill to 6 meters per second at the bottom. If it takes 5 seconds for him to reach the bottom, what is his acceleration, on average, as he flies down the hill?

$$\text{Acceleration} = \frac{\Delta \text{v}}{\Delta \text{t}} = \frac{6 \text{ m/s} - 1 \text{ m/s}}{5 \text{ s}} = \frac{5 \text{ m/s}}{5 \text{ s}} = \frac{1 \text{ m/s}}{1 \text{ m}} = 1 \text{ m/s}^2$$

In words, this means that for each second the cyclist travels downhill, his velocity increases by 1 meter per second (on average). The answer to this problem is expressed in the SI unit for acceleration: m/s^2 ("meters per second squared").

FIGURE 1.12
Gravity helps this cyclist increase his downhill velocity.

You Try It!

Problem: Tranh slowed his skateboard as he approached the street. He went from 8 m/s to 2 m/s in a period of 3 seconds. What was his acceleration?

Velocity-Time Graphs

The acceleration of an object can be represented by a velocity–time graph like the one in **Figure** 1.13. A velocity-time graph shows how velocity changes over time. It is similar to a distance-time graph except the $y-$axis represents velocity instead of distance. The graph in **Figure** 1.13 represents the velocity of a sprinter on a straight track. The runner speeds up for the first 4 seconds of the race, then runs at a constant velocity for the next 3 seconds, and finally slows to a stop during the last 3 seconds of the race.

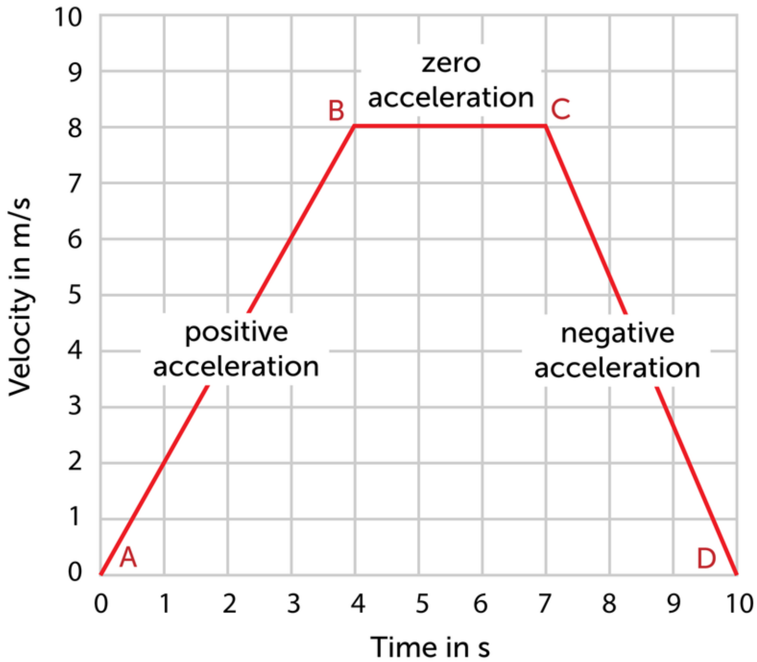

FIGURE 1.13
This graph shows how the velocity of a runner changes during a 10-second sprint.

In a velocity-time graph, acceleration is represented by the slope of the graph line. If the line slopes upward, like the line between A and B in **Figure** 1.13, velocity is increasing, so acceleration is positive. If the line is horizontal, as it is between B and C, velocity is not changing, so acceleration is zero. If the line slopes downward, like the line between C and D, velocity is decreasing, so acceleration is negative. You can review the concept of acceleration as well as other chapter concepts by watching the musical video at this URL: http://www.youtube.com/watch?v=4CWlNoNpXCc .

Lesson Summary

- Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes and whether the change is positive or negative. It may reflect a change in speed, a change in direction, or both.
- To calculate acceleration without a change in direction, divide the change in velocity by the change in time.
- The slope of a velocity-time graph represents acceleration.

Lesson Review Questions

Recall

1. What is acceleration?
2. How is acceleration calculated?
3. What does the slope of a velocity-time graph represent?

Apply Concepts

4. The velocity of a car on a straight road changes from 0 m/s to 6 m/s in 3 seconds. What is its acceleration?

Think Critically

5. Because of the pull of gravity, a falling object accelerates at 9.8 m/s^2. Create a velocity-time graph to represent this motion.

Points to Consider

Acceleration occurs when a force is applied to a moving object.

- What is force? What are some examples of forces?
- What forces might change the velocity of a moving object? (*Hint*: Read the caption to **Figure** 1.12.)

1.4 References

1. Train: John H. Gray; Cyclist: Flickr:DieselDemon; Inchworm: Clinton Charles Robertson; Hummingbird: Kevin Cole; Cartwheeler: Clemens v. Vogelsang (Flickr:vauvau); Meteor: Ed Sweeney (Flickr:Navicore). Train: http://www.flickr.com/photos/8391775@N05/3494460809/; Cyclist: http://www.flickr.com/photos/28096801@N05/3530472429/; Inchworm: http://www.flickr.com/photos/dad_and_clint/3571033947/; Hummingbird: http://www.flickr.com/photos/kevcole/2840250013/; Cartwheeler: http://www.flickr.com/photos/vauvau/8057026163/; Meteor: http://www.flickr.com/photos/edsweeney/4111291263/ . CC BY 2.0
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CHAPTER 2 Forces

Chapter Outline

Each of these basketball players is trying to push the ball. One player is trying to push it into the basket, and the other player is trying to push it away from the basket. If both players push the ball at the same time, where will it go? It depends on which player pushes the ball with greater force. Forces like this come into play in every sport, whether it's kicking a soccer ball, throwing a baseball, or spiking a volleyball. Forces are involved not only in sports such as these but in every motion in our daily lives. In this chapter, you'll see how forces affect the motion of everything from basketballs to planets.

2.1 What Is Force?

Lesson Objectives

- Define force, and give examples of forces.
- Describe how forces combine and affect motion.

Lesson Vocabulary

- force
- net force
- newton (N)

Introduction

Any time the motion of an object changes, a force has been applied. Force can cause a stationary object to start moving or a moving object to accelerate. The moving object may change its speed, its direction, or both. How much an object's motion changes when a force is applied depends on the strength of the force and the object's mass. You can explore the how force, mass, and acceleration are related by doing the activity at the URL http://www.harcourtschool.com/activity/newton/ . This will provide you with a good hands-on introduction to the concept of force in physics.

Defining Force

Force is defined as a push or a pull acting on an object. Examples of forces include friction and gravity. Both are covered in detail later in this chapter. Another example of force is applied force. It occurs when a person or thing applies force to an object, like the girl pushing the swing in **Figure** 2.1. The force of the push causes the swing to move.

Force as a Vector

Force is a vector because it has both size and direction. For example, the girl in **Figure** 2.1 is pushing the swing away from herself. That's the direction of the force. She can give the swing a strong push or a weak push. That's the size, or strength, of the force. Like other vectors, forces can be represented with arrows. **Figure** 2.2 shows some examples. The length of each arrow represents the strength of the force, and the way the arrow points represents the direction of the force. How could you use an arrow to represent the girl's push on the swing in **Figure** 2.1?

SI Unit of Force

The SI unit of force is the newton (N). One newton is the amount of force that causes a mass of 1 kilogram to accelerate at 1 m/s^2. Thus, the newton can also be expressed as $kg \cdot m/s^2$. The newton was named for the scientist Sir Isaac Newton, who is famous for his law of gravity. You'll learn more about Sir Isaac Newton later in the chapter.

FIGURE 2.1
When this girl pushes the swing away from her, it causes the swing to move in that direction.

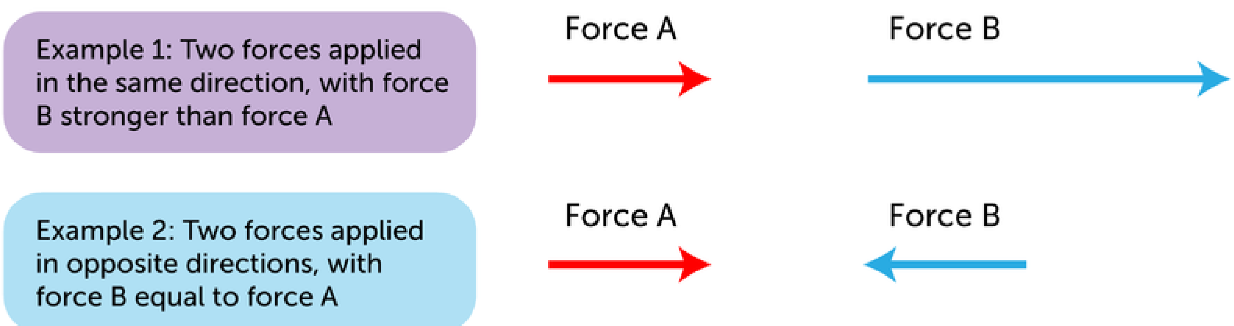


FIGURE 2.2
Forces can vary in both strength and direction.

Combining Forces

More than one force may act on an object at the same time. In fact, just about all objects on Earth have at least two forces acting on them at all times. One force is gravity, which pulls objects down toward the center of Earth. The other force is an upward force that may be provided by the ground or other surface.

Consider the example in **Figure** 2.3. A book is resting on a table. Gravity pulls the book downward with a force of 20 newtons. At the same time, the table pushes the book upward with a force of 20 newtons. The combined forces acting on the book — or any other object — are called the **net force**. This is the overall force acting on an object that takes into account all of the individual forces acting on the object. You can learn more about the concept of net force at this URL: http://www.mansfieldct.org/schools/mms/staff/hand/lawsunbalancedforce.htm .

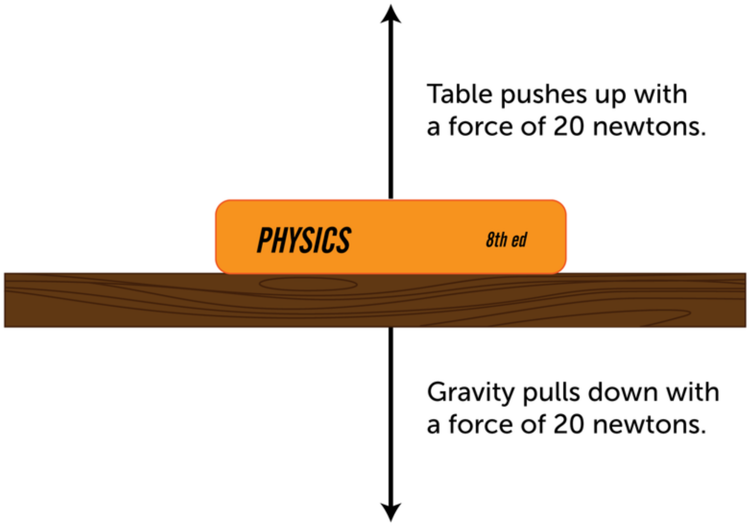


FIGURE 2.3
A book resting on a table is acted on by two opposing forces.

Forces Acting in Opposite Directions

When two forces act on an object in opposite directions, like the book on the table, the net force is equal to the difference between the two forces. In other words, one force is subtracted from the other to calculate the net force. If the opposing forces are equal in strength, the net force is zero. That's what happens with the book on the table. The upward force minus the downward force equals zero (20 N up - 20 N down = 0 N). Because the forces on the book are balanced, the book remains on the table and doesn't move.

In addition to these downward and upward forces, which generally cancel each other out, forces may push or pull an object in other directions. Look at the dogs playing tug-of-war in **Figure** 2.4. One dog is pulling on the rope with a force of 10 newtons to the left. The other dog is pulling on the rope with a force of 12 newtons to the right. These opposing forces are not equal in strength, so they are unbalanced. When opposing forces are unbalanced, the net force is greater than zero. The net force on the rope is 2 newtons to the right, so the rope will move to the right.

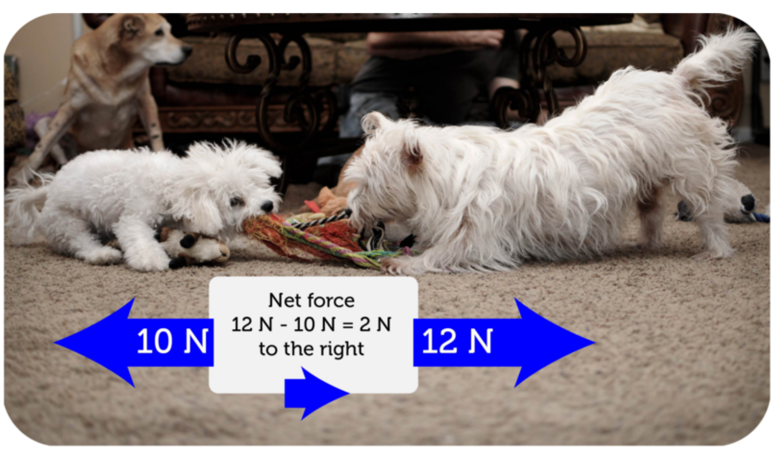


FIGURE 2.4
When unbalanced forces are applied to an object in opposite directions, the smaller force is subtracted from the larger force to yield the net force.

Forces Acting in the Same Direction

Two forces may act on an object in the same direction. You can see an example of this in **Figure** 2.5. After the man on the left lifts up the couch, he will push the couch to the right with a force of 25 newtons. At the same time, the man to the right is pulling the couch to the right with a force of 20 newtons. When two forces act in the same direction, the net force is equal to the sum of the forces. This always results in a stronger force than either of the individual forces alone. In this case, the net force on the couch is 45 newtons to the right, so the couch will move to the right.

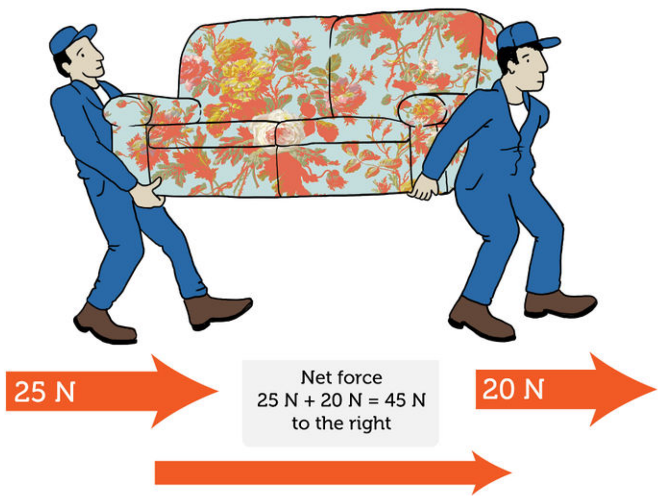
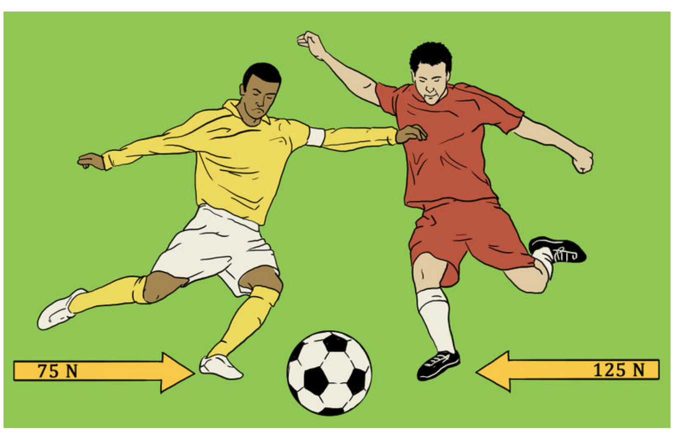


FIGURE 2.5
When two forces are applied to an object in the same direction, the two forces are added to yield the net force.

You Try It!



Problem: The boys in the drawing above are about to kick the soccer ball in opposite directions. What will be the net force on the ball? In which direction will the ball move?

If you need more practice calculating net force, go to this URL: http://www.physicsclassroom.com/class/newtlaws/U2L2d.cfm .

Lesson Summary

- Force is a push or a pull acting on an object. Examples of force include friction and gravity. Force is a vector because it has both size and direction. The SI unit of force is the newton (N).
- The combined forces acting on an object are called the net force. When forces act in opposite directions, they are subtracted to yield the net force. When they act in the same direction, they are added to yield the net force.

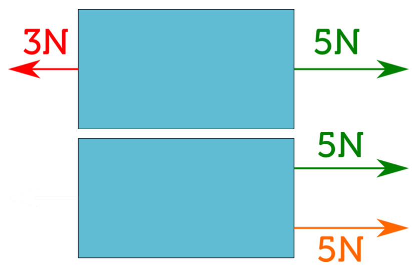
Lesson Review Questions

Recall

1. Define force. Give an example of a force.
2. What is a newton?
3. What is net force?
4. Describe an example of balanced forces and an example of unbalanced forces.

Apply Concepts

5. What is the net force acting on the block in each diagram below?



a.

b.

Think Critically

6. Explain how forces are related to motion.

Points to Consider

In the next lesson, "Friction," you will read about the force of friction. You experience this force every time you walk. It prevents your feet from slipping out from under you.

- How would you define friction?
- What do you think causes this force?

2.2 Friction

Lesson Objectives

- Describe friction and how it opposes motion.
- Identify types of friction.

Lesson Vocabulary

- fluid
- friction

Introduction

Did you ever rub your hands together to warm them up, like the girl in **Figure** 2.6? Why does this make your hands warmer? The answer is friction.

FIGURE 2.6
This girl is using friction to make her hands warmer.

What Is Friction?

Friction is a force that opposes motion between two surfaces that are touching. Friction can work for or against us. For example, putting sand on an icy sidewalk increases friction so you are less likely to slip. On the other hand, too much friction between moving parts in a car engine can cause the parts to wear out. Other examples of friction are illustrated in **Figure** 2.7. You can see an animation showing how friction opposes motion at this URL: http://www.darvill.clara.net/enforcemot/friction.htm .

FIGURE 2.7

Sometimes friction is useful. Sometimes it's not.

Why Friction Occurs

Friction is occurring all the time because no surface is perfectly smooth. Even surfaces that look smooth to the unaided eye appear rough or bumpy when viewed under a microscope. Look at the metal surfaces in **Figure** 2.8. The metal foil is so smooth that it is shiny. However, when highly magnified, the surface of metal appears to be very bumpy. All those mountains and valleys catch and grab the mountains and valleys of any other surface that contacts the metal. This creates friction.

Factors That Affect Friction

Rougher surfaces have more friction between them than smoother surfaces. That's why we put sand on icy sidewalks and roads. The blades of skates are much smoother than the soles of shoes. That's why you can't slide as far across ice with shoes as you can with skates (see **Figure** 2.9). The rougher surface of shoes causes more friction and slows you down. Heavier objects also have more friction because they press together with greater force. Did you ever try

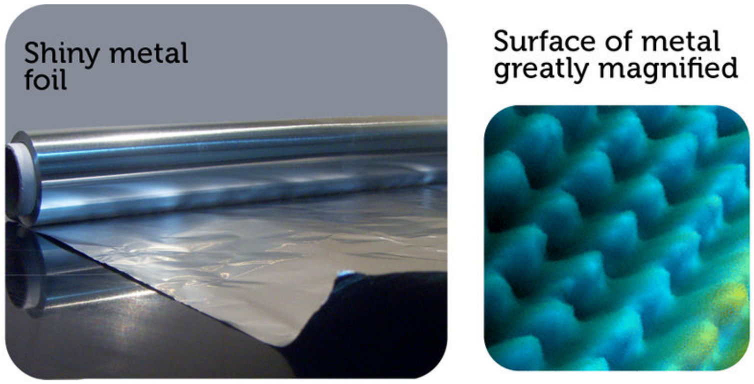


FIGURE 2.8
The surface of metal looks very smooth unless you look at it under a high-powered microscope.

to push boxes or furniture across the floor? It's harder to overcome friction between heavier objects and the floor than it is between lighter objects and the floor.

FIGURE 2.9
The knife-like blades of speed skates minimize friction with the ice.

Friction Produces Heat

You know that friction produces heat. That's why rubbing your hands together makes them warmer. But do you know why the rubbing produces heat? Friction causes the molecules on rubbing surfaces to move faster, so they have more heat energy. Heat from friction can be useful. It not only warms your hands. It also lets you light a match (see **Figure** 2.10). On the other hand, heat from friction can be a problem inside a car engine. It can cause the car to overheat. To reduce friction, oil is added to the engine. Oil coats the surfaces of moving parts and makes them slippery so there is less friction.

Types of Friction

There are different ways you could move heavy boxes. You could pick them up and carry them. You could slide them across the floor. Or you could put them on a dolly like the one in **Figure** 2.11 and roll them across the floor. This example illustrates three types of friction: static friction, sliding friction, and rolling friction. Another type

FIGURE 2.10
When you rub the surface of a match head across the rough striking surface on the matchbox, the friction produces enough heat to ignite the match.

of friction is fluid friction. All four types of friction are described below. In each type, friction works opposite the direction of the force applied to a move an object. You can see a video demonstration of the different types of friction at this URL: http://www.youtube.com/watch?v=0bXpYblzkR0 (1:07).

FIGURE 2.11
A dolly with wheels lets you easily roll boxes across the floor.

Static Friction

Static friction acts on objects when they are resting on a surface. For example, if you are walking on a sidewalk, there is static friction between your shoes and the concrete each time you put down your foot (see **Figure** 2.12). Without this static friction, your feet would slip out from under you, making it difficult to walk. Static friction also allows you to sit in a chair without sliding to the floor. Can you think of other examples of static friction?

FIGURE 2.12
Static friction between shoes and the sidewalk makes it possible to walk without slipping.

Sliding Friction

Sliding friction is friction that acts on objects when they are sliding over a surface. Sliding friction is weaker than static friction. That's why it's easier to slide a piece of furniture over the floor after you start it moving than it is to get it moving in the first place. Sliding friction can be useful. For example, you use sliding friction when you write with a pencil and when you put on your bike's brakes.

Rolling Friction

Rolling friction is friction that acts on objects when they are rolling over a surface. Rolling friction is much weaker than sliding friction or static friction. This explains why it is much easier to move boxes on a wheeled dolly than by carrying or sliding them. It also explains why most forms of ground transportation use wheels, including cars, 4-wheelers, bicycles, roller skates, and skateboards. Ball bearings are another use of rolling friction (see **Figure** 2.13). They allow parts of a wheel or other machine to roll rather than slide over one another.

Fluid Friction

Fluid friction is friction that acts on objects that are moving through a fluid. A **fluid** is a substance that can flow and take the shape of its container. Fluids include liquids and gases. If you've ever tried to push your open hand through the water in a tub or pool, then you've experienced fluid friction between your hand and the water. When a skydiver is falling toward Earth with a parachute, fluid friction between the parachute and the air slows the descent (see **Figure** 2.14). Fluid pressure with the air is called air resistance. The faster or larger a moving object is, the greater is the fluid friction resisting its motion. The very large surface area of a parachute, for example, has greater air resistance than a skydiver's body.

Lesson Summary

- Friction is a force that opposes motion between two surfaces that are touching. Friction occurs because no surface is perfectly smooth. Friction is greater when objects have rougher surfaces or are heavier so they press together with greater force.

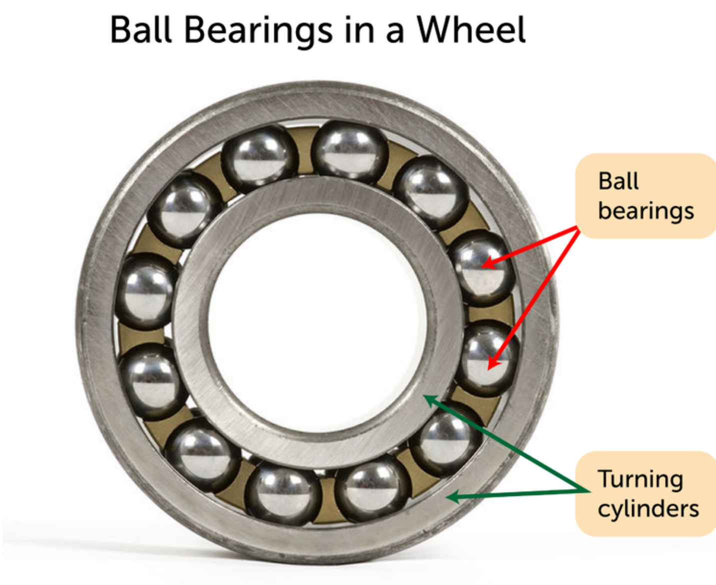


FIGURE 2.13
The ball bearings in this wheel reduce friction between the inner and outer cylinders when they turn.

- Types of friction include static friction, sliding friction, rolling friction, and fluid friction. Fluid friction with air is called air resistance.

Lesson Review Questions

Recall

1. What is friction?
2. List factors that affect friction.
3. How does friction produce heat?

Apply Concepts

4. Identify two forms of friction that oppose the motion of a moving car.

Think Critically

5. Explain why friction occurs.
6. Compare and contrast the four types of friction described in this lesson.

Points to Consider

A skydiver like the one in **Figure** 2.14 falls to the ground despite the fluid friction of his parachute with the air. Another force pulls him toward Earth. That force is gravity, which is the topic of the next lesson.

- What do you already know about gravity?
- What do you think causes gravity?

FIGURE 2.14
Fluid friction of the parachute with the air slows this skydiver as he falls.

2.3 Gravity

Lesson Objectives

- Define gravity.
- State Newton's law of universal gravitation.
- Explain how gravity affects the motion of objects.

Lesson Vocabulary

- gravity
- law of universal gravitation
- orbit
- projectile motion

Introduction

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system (see **Figure** 2.15). From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

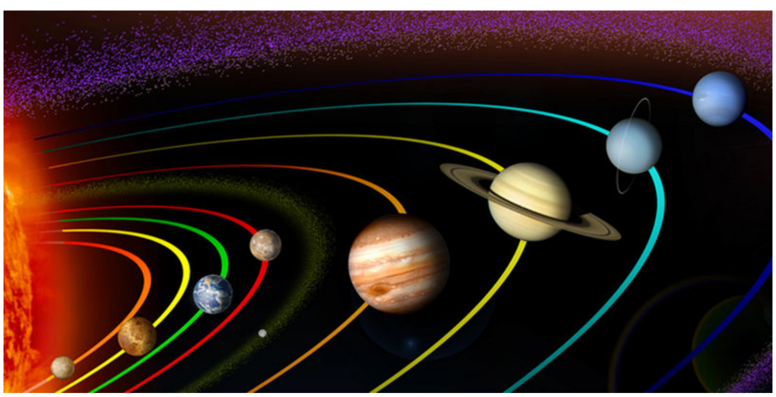


FIGURE 2.15
Gravity helped to form our solar system and all the other solar systems in the universe.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between two masses. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. The effect of gravity is that objects exert a pull on other objects. Unlike friction, which acts only between objects that are touching, gravity also acts between objects that are not touching. In fact, gravity can act over very long distances.

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from being flung out into space as the planet spins on its axis. It also pulls objects above the surface, from meteors to skydivers, down to the ground. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth moving around the sun.

Gravity and Weight

Weight measures the force of gravity pulling on an object. Because weight measures force, the SI unit for weight is the **newton (N)**. On Earth, a mass of 1 kilogram has a weight of about 10 newtons because of the pull of Earth's gravity On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale in **Figure** 2.16. The scale measures the force with which gravity pulls an object downward.

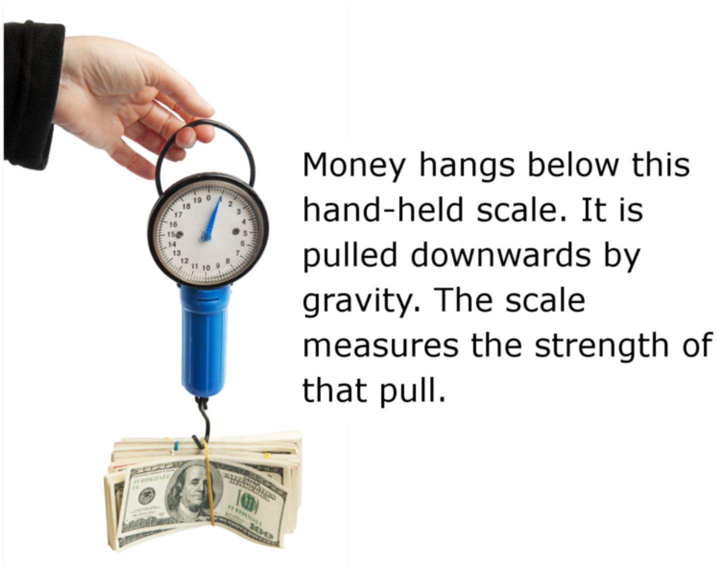


FIGURE 2.16
A scale measures the pull of gravity on an object.

Law of Gravity

People have known about gravity for thousands of years. After all, they constantly experienced gravity in their daily lives. They knew that things always fall toward the ground. However, it wasn't until Sir Isaac Newton developed his law of gravity in the late 1600s that people really began to understand gravity. Newton is pictured in **Figure** 2.17.

Newton's Law of Universal Gravitation

Newton was the first one to suggest that gravity is universal and affects all objects in the universe. That's why his law of gravity is called the **law of universal gravitation**. Universal gravitation means that the force that causes an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth. In fact, there is gravity between you and every mass around you — your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

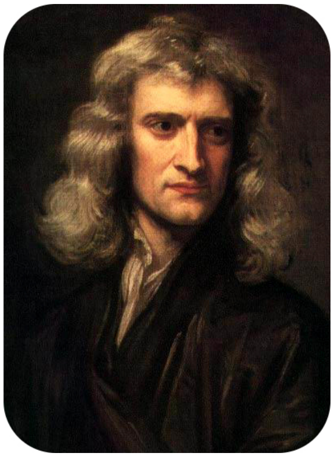


FIGURE 2.17
Sir Isaac Newton discovered that gravity is universal.

Newton's law had a huge impact on how people thought about the universe. It explains the motion of objects not only on Earth but in outer space as well.

Factors That Influence the Strength of Gravity

Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them.

- Objects with greater mass have a stronger force of gravity. For example, because Earth is so massive, it attracts you and your desk more strongly than you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another.
- Objects that are closer together have a stronger force of gravity. For example, the moon is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the moon and Earth than between the moon and the sun. That's why the moon circles around Earth rather than the sun. This is illustrated in **Figure** 2.18.

You can apply these relationships among mass, distance, and gravity by designing your own roller coaster at this URL: http://www.learner.org/interactives/parkphysics/coaster/ .

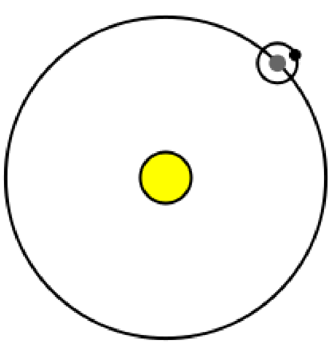


FIGURE 2.18
The moon keeps moving around Earth rather than the sun because it is much closer to Earth.

Einstein's Theory of Gravity

Newton's idea of gravity can predict the motion of most but not all objects. In the early 1900s, Albert Einstein came up with a theory of gravity that is better at predicting how all objects move. Einstein showed mathematically that gravity is not really a force in the sense that Newton thought. Instead, gravity is a result of the warping, or curving, of space and time. Imagine a bowling ball pressing down on a trampoline. The surface of the trampoline would curve downward instead of being flat. Einstein theorized that Earth and other very massive bodies affect space and time around them in a similar way. This idea is represented in **Figure** 2.19. According to Einstein, objects curve toward one another because of the curves in space and time, not because they are pulling on each other with a force of attraction as Newton thought. You can see an animation of Einstein's theory of gravity at this URL: http://einstein.stanford.edu/Media/Einsteins_Universe_Anima-Flash.html . To learn about recent research that supports Einstein's theory of gravity, go to this URL: http://www.universetoday.com/85401/gravity-probe-b-confirms-two-of-einsteins-space-time-theories/ .

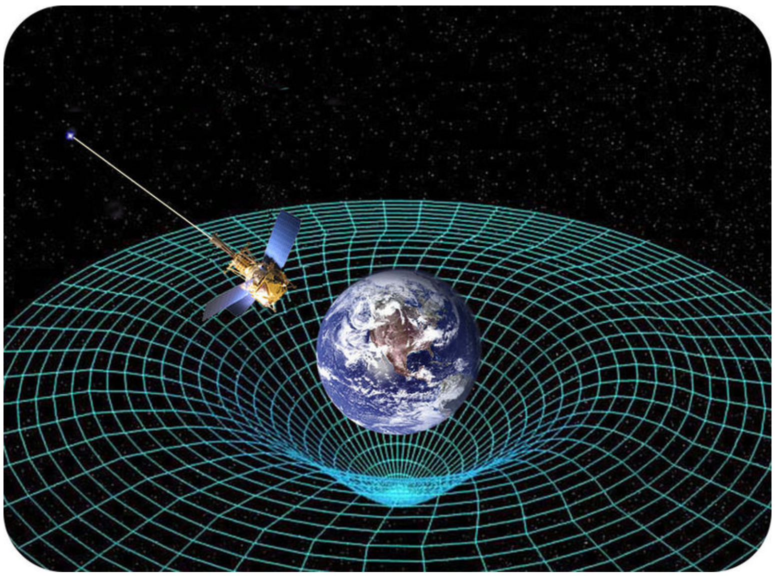


FIGURE 2.19
Einstein thought that gravity is the effect of curves in space and time around massive objects such as Earth. He proposed that the curves in space and time cause nearby objects to follow a curved path. How does this differ from Newton's idea of gravity?

Gravity and Motion

Regardless of what gravity is — a force between masses or the result of curves in space and time — the effects of gravity on motion are well known. You already know that gravity causes objects to fall down to the ground. Gravity affects the motion of objects in other ways as well.

Acceleration Due to Gravity

When gravity pulls objects toward the ground, it causes them to accelerate. Acceleration due to gravity equals 9.8 m/s^2. In other words, the velocity at which an object falls toward Earth increases each second by 9.8 m/s. Therefore, after 1 second, an object is falling at a velocity of 9.8 m/s. After 2 seconds, it is falling at a velocity of 19.6 m/s (9.8 m/s $\times$ 2), and so on. This is illustrated in **Figure** 2.20. You can compare the acceleration due to gravity on Earth, the moon, and Mars with the interactive animation called "Freefall" at this URL: http://jersey.uoregon.edu/vlab/ .

You might think that an object with greater mass would accelerate faster than an object with less mass. After all, its greater mass means that it is pulled by a stronger force of gravity. However, a more massive object accelerates at the

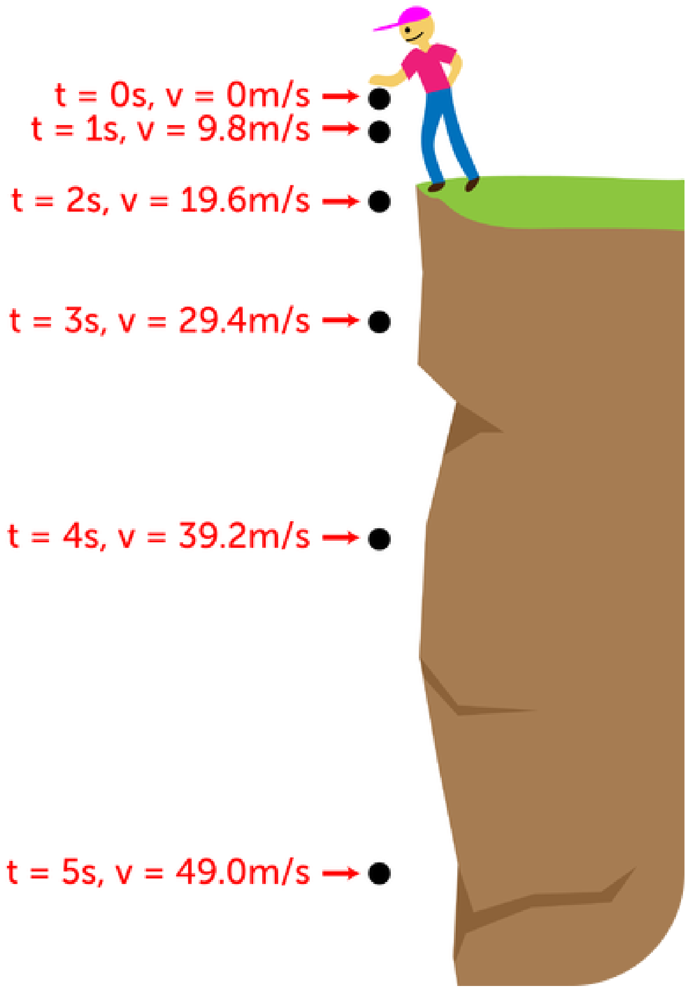


FIGURE 2.20

A boy drops an object at time t = 0 s. At time t = 1 s, the object is falling at a velocity of 9.8 m/s. What is its velocity by time t = 5 ?

same rate as a less massive object. The reason? The more massive object is harder to move because of its greater mass. As a result, it ends up moving at the same acceleration as the less massive object.

Consider a bowling ball and a basketball. The bowling ball has greater mass than the basketball. However, if you were to drop both balls at the same time from the same distance above the ground, they would reach the ground together. This is true of all falling objects, unless air resistance affects one object more than another. For example, a falling leaf is slowed down by air resistance more than a falling acorn because of the leaf's greater surface area. However, if the leaf and acorn were to fall in the absence of air (that is, in a vacuum), they would reach the ground at the same time.

Projectile Motion

Earth's gravity also affects the acceleration of objects that start out moving horizontally, or parallel to the ground. Look at **Figure** 2.21. A cannon shoots a cannon ball straight ahead, giving the ball horizontal motion. At the same time, gravity pulls the ball down toward the ground. Both forces acting together cause the ball to move in a curved path. This is called **projectile motion**.

Projectile motion also applies to other moving objects, such as arrows shot from a bow. To hit the bull's eye of a

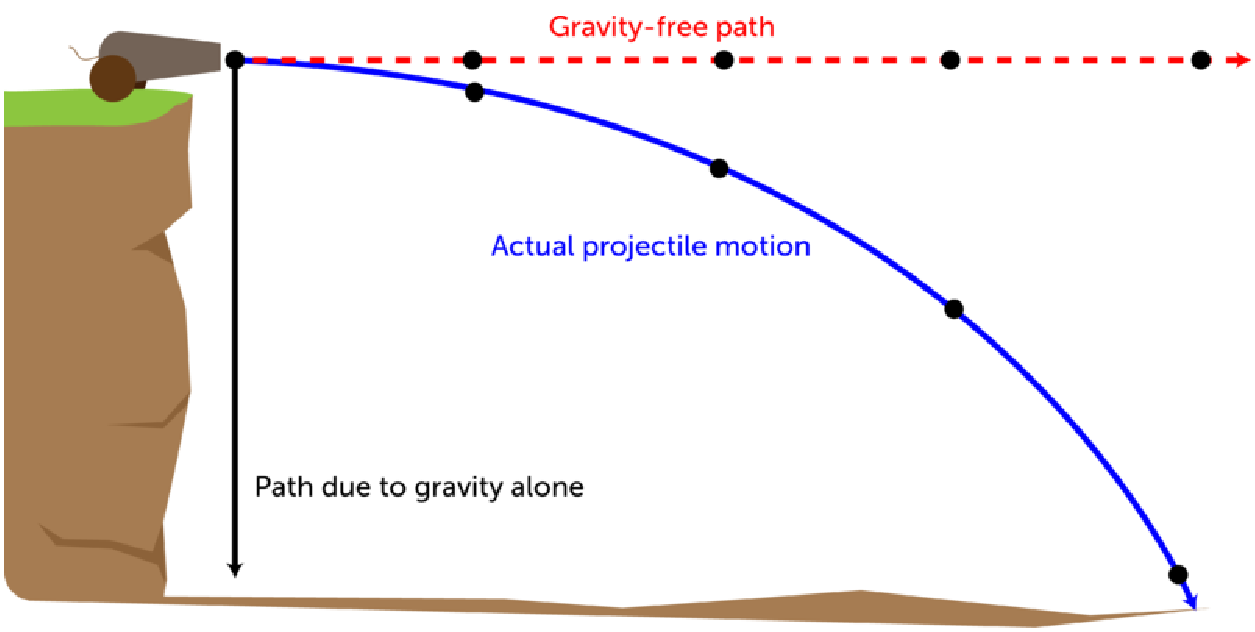


FIGURE 2.21
The cannon ball moves in a curved path because of the combined horizontal and downward forces.

target with an arrow, you actually have to aim for a spot above the bull's eye. That's because by the time the arrow reaches the target, it has started to curve downward toward the ground. **Figure** 2.22 shows what happens if you aim at the bull's eye instead of above it. You can access interactive animations of projectile motion at these URLs:

- http://phet.colorado.edu/en/simulation/projectile-motion
- http://jersey.uoregon.edu/vlab/ *(Select the applet entitled "Cannon.")*

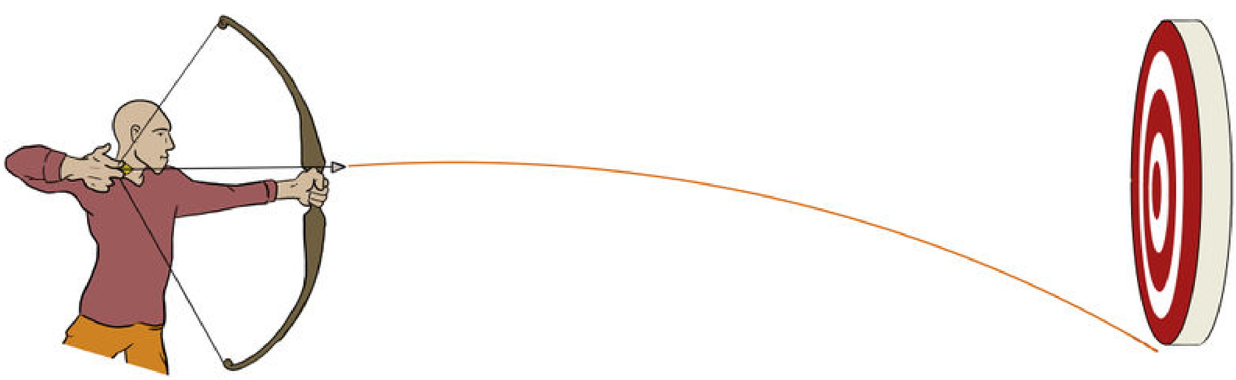


FIGURE 2.22
Aiming at the center of a target is likely to result in a hit below the bull's eye.

Orbital Motion

The moon moves around Earth in a circular path called an **orbit**. Why doesn't Earth's gravity pull the moon down to the ground instead? The moon has enough forward velocity to partly counter the force of Earth's gravity. It constantly falls toward Earth, but it stays far enough away from Earth so that it actually falls around the planet. As a result, the moon keeps orbiting Earth and never crashes into it. The diagram in **Figure** 2.23 shows how this happens. You can explore gravity and orbital motion in depth with the animation at this URL: http://phet.colorado.edu/en/simulation/gravity-and-orbits .

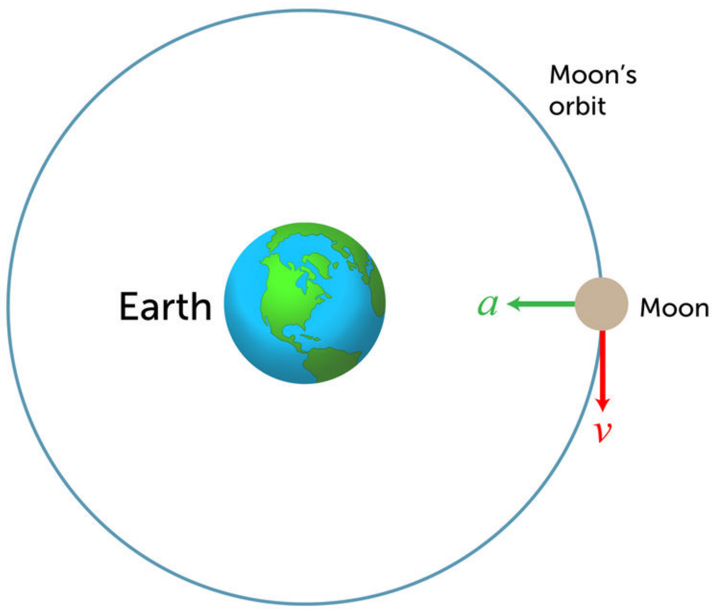


FIGURE 2.23
In this diagram, "v" represents the forward velocity of the moon, and "a" represents the acceleration due to gravity. The line encircling Earth shows the moon's actual orbit, which results from the combination of "v" and "a."

You can see an animated version of this diagram at: http://en.wikipedia.org/wiki/File:Orbital_motion.gif .

Lesson Summary

- Gravity is traditionally defined as a force of attraction between two masses. Weight measures the force of gravity and is expressed in newtons (N).
- According to Newton's law of universal gravitation, gravity is a force of attraction between all objects in the universe, and the strength of gravity depends on the masses of the objects and the distance between them. Einstein's theory of gravity states that gravity is an effect of curves in space and time around massive objects such as Earth.
- Gravity causes falling objects to accelerate at 9.8 m/s^2. Gravity also causes projectile motion and orbital motion.

Lesson Review Questions

Recall

1. What is the traditional definition of gravity?
2. How is weight related to gravity?
3. Summarize Newton's law of universal gravitation.

4. Describe Einstein's idea of gravity.

Apply Concepts

5. Create a poster to illustrate the concept of projectile motion.

Think Critically

6. In the absence of air, why does an object with greater mass fall toward Earth at the same acceleration as an object with less mass?
7. Explain why the moon keeps orbiting Earth.

Points to Consider

The scale you saw in **Figure** 2.16 contains a spring. When an object hangs from the scale, the spring exerts an upward force that partly counters the downward force of gravity. The type of force exerted by a spring is called elastic force, which is the topic of the next lesson.

- Besides springs, what other objects do you think might exert elastic force?
- What other ways might you use elastic force?

2.4 Elastic Force

Lesson Objectives

- Define elasticity and elastic force.
- Describe uses of elastic force.

Lesson Vocabulary

- elastic force
- elasticity

Introduction

The boy in **Figure** 2.24 has a newspaper route. Every morning, he rolls up newspapers for his customers and puts rubber bands around them. The rubber bands keep the newspapers tightly rolled up so it is easy to toss them onto porches and driveways as the boy rides by on his bike. Rubber bands are useful for this purpose because they are elastic.

FIGURE 2.24
A stretchy rubber band holds this newspaper in a tight roll.

Elasticity and Elastic Force

Something that is elastic can return to its original shape after being stretched or compressed. This property is called **elasticity**. As you stretch or compress an elastic material, it resists the change in shape. It exerts a counter force in the opposite direction. This force is called **elastic force**. Elastic force causes the material to spring back to its original shape as soon as the stretching or compressing force is released. You can watch a demonstration of elastic force at this URL: http://www.youtube.com/watch?v=fFtM9JznLh8 (3:57).

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5024

Using Elastic Force

Elastic force can be very useful. You probably use it yourself every day. A few common uses of elastic force are pictured in **Figure** 2.25. Did you ever use a resistance band like the one in the figure? When you pull on the band, it stretches but doesn't break. The resistance you feel when you pull on it is elastic force. The resistance of the band to stretching is what gives your muscles a workout. After you stop pulling on the band, it returns to its original shape, ready for the next workout.

Springs like the ones in **Figure** 2.26 also have elastic force when they are stretched or compressed. And like stretchy materials, they return to their original shape when the stretching or compressing force is released. Because of these properties, springs are used in scales to measure weight. They also cushion the ride in a car and provide springy support beneath a mattress. Can you think of other uses of springs?

Lesson Summary

- Elasticity is the ability of a material to return to its original shape after being stretched or compressed. Elastic force is the counter force that resists the stretching or compressing of an elastic material.
- Elastic force is very useful. It is used in rubber bands, bungee cords, and bed springs, to name just a few uses.

Lesson Review Questions

Recall

1. What is elasticity?
2. Describe elastic force.
3. Identify uses of elastic force.

FIGURE 2.25
All these items are useful because they can be stretched and then return to their original shape.

FIGURE 2.26
Springs are useful because they return to their original shape after being stretched or compressed.

Apply Concepts

4. Think of a way you could demonstrate elastic force to a younger student. Describe the procedure you would follow and the materials you would use.

Think Critically

5. Explain how springs are used in scales to measure weight.

Points to Consider

In this chapter, you read about Newton's law of universal gravitation. Newton developed several other laws as well. In the next chapter, "Newton's Laws of Motion," you'll read about his three laws of motion. Recall what you already know about motion.

- What is motion? What are examples of motion?
- What causes changes in motion? What are changes in motion called?

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CHAPTER 3 Newton's Laws of Motion

Chapter Outline

The sprinter in this photo is pushing off from the blocks at the start of a race. The blocks provide a counter force so she can take off in a hurry. With great effort, she will go from motionless to top speed in just a few seconds. She won't slow down until she crosses the finish line. By then, she will be going so fast that it will take her almost as much time to come to a full stop as it did to run the race.

No doubt you've experienced motions like these, even if you've never run a race. But do you know what explains these motions? For example, do you know why it's as hard to stop running as it is to start? These and other aspects of motion are explained by three laws of motion. The laws were developed by Sir Isaac Newton in the late 1600s. You'll learn about Newton's laws of motion in this chapter and how and why objects move as they do.

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3.1 Newton's First Law

Lesson Objectives

- State Newton's first law of motion.
- Define inertia, and explain its relationship to mass.

Lesson Vocabulary

- inertia
- Newton's first law of motion

Introduction

The amusement park ride pictured in **Figure** 3.1 keeps changing direction as it zooms back and forth. Each time it abruptly switches direction, the riders are forced to the opposite side of the car. What force causes this to happen? In this lesson, you'll find out.

FIGURE 3.1
Amusement park rides like this one are exciting because of the strong forces the riders feel.

Force and Motion

Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion and its velocity will remain the same. In other words, neither the direction nor the speed of the object will change as long as the net force acting on it is zero. You can watch a video about Newton's first law at this URL: http://videos.howstuffworks.com/discovery/29382-assignment-discovery-newtons-first-law-video.htm .

Look at the pool balls in **Figure** 3.2. When a pool player pushes the pool stick against the white ball, the white ball is set into motion. Once the white ball is rolling, it rolls all the way across the table and stops moving only after it crashes into the cluster of colored balls. Then, the force of the collision starts the colored balls moving. Some may roll until they bounce off the raised sides of the table. Some may fall down into the holes at the edges of the table. None of these motions will occur, however, unless that initial push of the pool stick is applied. As long as the net force on the balls is zero, they will remain at rest.

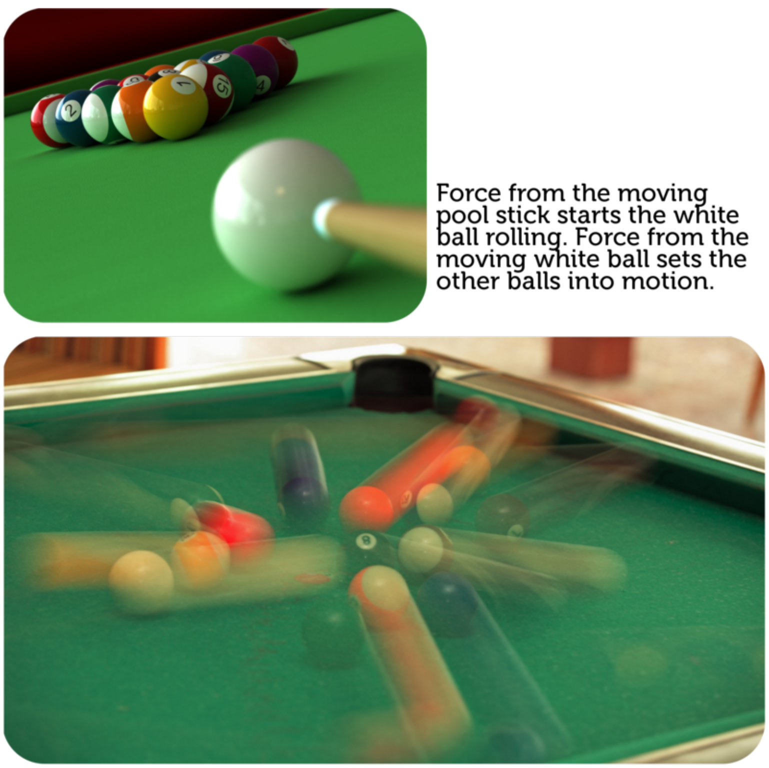

FIGURE 3.2
Pool balls remain at rest until an unbalanced force is applied to them. After they are in motion, they stay in motion until another force opposes their motion.

Inertia

Newton's first law of motion is also called the law of inertia. **Inertia** is the tendency of an object to resist a change in its motion. If an object is already at rest, inertia will keep it at rest. If the object is already moving, inertia will keep it moving.

Think about what happens when you are riding in a car that stops suddenly. Your body moves forward on the seat. Why? The brakes stop the car but not your body, so your body keeps moving forward because of inertia. That's why it's important to always wear a seat belt. Inertia also explains the amusement park ride in **Figure** 3.1. The car keeps changing direction, but the riders keep moving in the same direction as before. They slide to the opposite side of the car as a result. You can see an animation of inertia at this URL: http://www.physicsclassroom.com/mmedia/newtlaws/cci.cfm .

Inertia and Mass

The inertia of an object depends on its mass. Objects with greater mass also have greater inertia. Think how hard it would be to push a big box full of books, like the one in **Figure** 3.3. Then think how easy it would be to push the box if it was empty. The full box is harder to move because it has greater mass and therefore greater inertia.

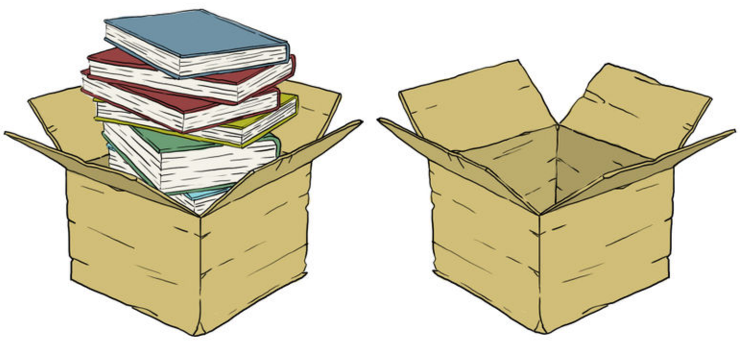

FIGURE 3.3
The tendency of an object to resist a change in its motion depends on its mass. Which box has greater inertia?

Overcoming Inertia

To change the motion of an object, inertia must be overcome by an unbalanced force acting on the object. Until the soccer player kicks the ball in **Figure** 3.4, the ball remains motionless on the ground. However, when the ball is kicked, the force on it is suddenly unbalanced. The ball starts moving across the field because its inertia has been overcome.

FIGURE 3.4
Force must be applied to overcome the inertia of a soccer ball at rest.

Once objects start moving, inertia keeps them moving without any additional force being applied. In fact, they won't stop moving unless another unbalanced force opposes their motion. What if the rolling soccer ball is not kicked by another player or stopped by a fence or other object? Will it just keep rolling forever? It would if another unbalanced force did not oppose its motion. Friction —in this case rolling friction with the ground —will oppose the motion of the rolling soccer ball. As a result, the ball will eventually come to rest. Friction opposes the motion of all moving objects, so, like the soccer ball, all moving objects eventually come to a stop even if no other forces oppose their motion.

Lesson Summary

- Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion.
- Inertia is the tendency of an object to resist a change in its motion. The inertia of an object depends on its mass. Objects with greater mass have greater inertia. To overcome inertia, an unbalanced force must be applied to an object.

Lesson Review Questions

Recall

1. State Newton's first law of motion.
2. Define inertia.
3. How does an object's mass affect its inertia?

Apply Concepts

4. Assume you are riding a skateboard and you run into a curb. Your skateboard suddenly stops its forward motion. Apply the concept of inertia to this scenario, and explain what happens next.

Think Critically

5. Why is Newton's first law of motion also called the law of inertia?

Points to Consider

In this lesson, you read that the mass of an object determines its inertia. You also learned that an unbalanced force must be applied to an object to overcome its inertia, whether it is moving or at rest. An unbalanced force causes an object to accelerate.

- Predict how the mass of an object affects its acceleration when an unbalanced force is applied to it.
- How do you think the acceleration of an object is related to the strength of the unbalanced force acting on it?

3.2 Newton's Second Law

Lesson Objectives

- State Newton's second law of motion.
- Identify the relationship between acceleration and weight.

Lesson Vocabulary

- Newton's second law of motion

Introduction

A car's gas pedal, like the one in **Figure** 3.5, is sometimes called the accelerator. That's because it controls the acceleration of the car. Pressing down on the gas pedal gives the car more gas and causes the car to speed up. Letting up on the gas pedal gives the car less gas and causes the car to slow down. Whenever an object speeds up, slows down, or changes direction, it accelerates. Acceleration is a measure of the change in velocity of a moving object. Acceleration occurs whenever an object is acted upon by an unbalanced force.

FIGURE 3.5
The car pedal on the right controls the amount of gas the engine gets. How does this affect the car's acceleration?

Acceleration, Force, and Mass

Newton determined that two factors affect the acceleration of an object: the net force acting on the object and the object's mass. The relationships between these two factors and motion make up **Newton's second law of motion**. This law states that the acceleration of an object equals the net force acting on the object divided by the object's mass. This can be represented by the equation:

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}, \text{ or}$$
$$a = \frac{F}{m}$$

You can watch a video about how Newton's second law of motion applies to football at this URL: http://science360.gov/obj/video/58e62534-e38d-430b-bfb1-c505e628a2d4 .

Direct and Inverse Relationships

Newton's second law shows that there is a direct relationship between force and acceleration. The greater the force that is applied to an object of a given mass, the more the object will accelerate. For example, doubling the force on the object doubles its acceleration. The relationship between mass and acceleration, on the other hand, is an inverse relationship. The greater the mass of an object, the less it will accelerate when a given force is applied. For example, doubling the mass of an object results in only half as much acceleration for the same amount of force.

Consider the example of a batter, like the boy in **Figure** 3.6. The harder he hits the ball, the greater will be its acceleration. It will travel faster and farther if he hits it with more force. What if the batter hits a baseball and a softball with the same amount of force? The softball will accelerate less than the baseball because the softball has greater mass. As a result, it won't travel as fast or as far as the baseball.

FIGURE 3.6

Hitting a baseball with greater force gives it greater acceleration. Hitting a softball with the same amount of force results in less acceleration. Can you explain why?

Calculating Acceleration

The equation for acceleration given above can be used to calculate the acceleration of an object that is acted on by an unbalanced force. For example, assume you are pushing a large wooden trunk, like the one shown in **Figure** 3.7. The trunk has a mass of 10 kilograms, and you are pushing it with a force of 20 newtons. To calculate the acceleration of the trunk, substitute these values in the equation for acceleration:

$$a = \frac{F}{m} = \frac{20 \text{ N}}{10 \text{ kg}} = \frac{2 \text{ N}}{\text{kg}}$$

Recall that one newton (1 N) is the force needed to cause a 1-kilogram mass to accelerate at 1 m/s^2. Therefore, force can also be expressed in the unit kg·m/s^2. This way of expressing force can be substituted for newtons in the solution to the problem:

$$a = \frac{2 \text{ N}}{\text{kg}} = \frac{2 \text{ kg} \cdot \text{m/s}^2}{\text{kg}} = 2 \text{ m/s}^2$$

Why are there no kilograms in the final answer to this problem? The kilogram units in the numerator and denominator of the fraction cancel out. As a result, the answer is expressed in the correct units for acceleration: m/s^2.

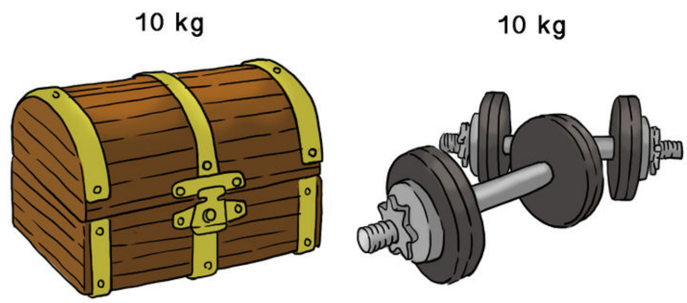

FIGURE 3.7
This empty trunk has a mass of 10 kilograms. The weights also have a mass of 10 kilograms. If the weights are placed in the trunk, what will be its mass? How will this affect its acceleration?

You Try It!

Problem: Assume that you add the weights to the trunk in **Figure** 3.7. If you push the trunk and weights with a force of 20 N, what will be the trunk's acceleration?

Need more practice? You can find additional problems at this URL: http://www.auburnschools.org/ajhs/lmcrowe/Week%2014/WorksheetPracticeProblemsforNewtons2law.pdf .

Acceleration and Weight

Newton's second law of motion explains the weight of objects. Weight is a measure of the force of gravity pulling on an object of a given mass. It's the force (F) in the acceleration equation that was introduced above:

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

This equation can also be written as:

$$F = m \times a$$

The acceleration due to gravity of an object equals $9.8\ m/s^2$, so if you know the mass of an object, you can calculate its weight as:

$$F = m \times 9.8\ \text{m/s}^2$$

As this equation shows, weight is directly related to mass. As an object's mass increases, so does its weight. For example, if mass doubles, weight doubles as well. You can learn more about weight and acceleration at this URL: http://www.nasa.gov/mov/192448main_018_force_equals_mass_time.mov .

Problem Solving

Problem: Daisy has a mass of 35 kilograms. How much does she weigh?

Solution: Use the formula: $F = m \times 9.8\ \text{m/s}^2$.

$F = 35 \text{ kg} \times 9.8 \text{ m/s}^2 = 343.0 \text{ kg} \cdot \text{m/s}^2 = 343.0 \text{ N}$

You Try It!

Problem: Daisy's dad has a mass is 70 kg, which is twice Daisy's mass. Predict how much Daisy's dad weighs. Then calculate his weight to see if your prediction is correct.

Helpful Hints

The equation for calculating weight ($F = m \times a$) works only when the correct units of measurement are used.

- Mass must be in kilograms (kg).
- Acceleration must be in m/s^2.
- Weight (F) is expressed in $\text{kg}\cdot\text{m/s}^2$ or in newtons (N).

Lesson Summary

- Newton's second law of motion states that the acceleration of an object equals the net force acting on the object divided by the object's mass.
- Weight is a measure of the force of gravity pulling on an object of a given mass. It equals the mass of the object (in kilograms) times the acceleration due to gravity (9.8 m/s^2).

Lesson Review Questions

Recall

1. State Newton's second law of motion.
2. Describe how the net force acting on an object is related to its acceleration.
3. If the mass of an object increases, how is its acceleration affected, assuming the net force acting on the object remains the same?
4. What is weight?

Apply Concepts

5. Tori applies a force of 20 newtons to move a bookcase with a mass of 40 kg. What is the acceleration of the bookcase?
6. Ollie has a mass of 45 kilograms. What is his weight in newtons?

Think Critically

7. If you know your weight in newtons, how could you calculate your mass in kilograms? What formula would you use?

Points to Consider

Assume that a 5-kilogram skateboard and a 50-kilogram go-cart start rolling down a hill. Both are moving at the same speed. You and a friend want to stop before they plunge into a pond at the bottom of the hill.

- Which will be harder to stop: the skateboard or the go-cart?
- Can you explain why?

3.3 Newton's Third Law

Lesson Objectives

- State Newton's third law of motion.
- Describe momentum and the conservation of momentum.

Lesson Vocabulary

- law of conservation of momentum
- momentum
- Newton's third law of motion

Introduction

Look at the skateboarders in **Figure** 3.8. When they push against each other, it causes them to move apart. The harder they push together, the farther apart they move. This is an example of Newton's third law of motion.

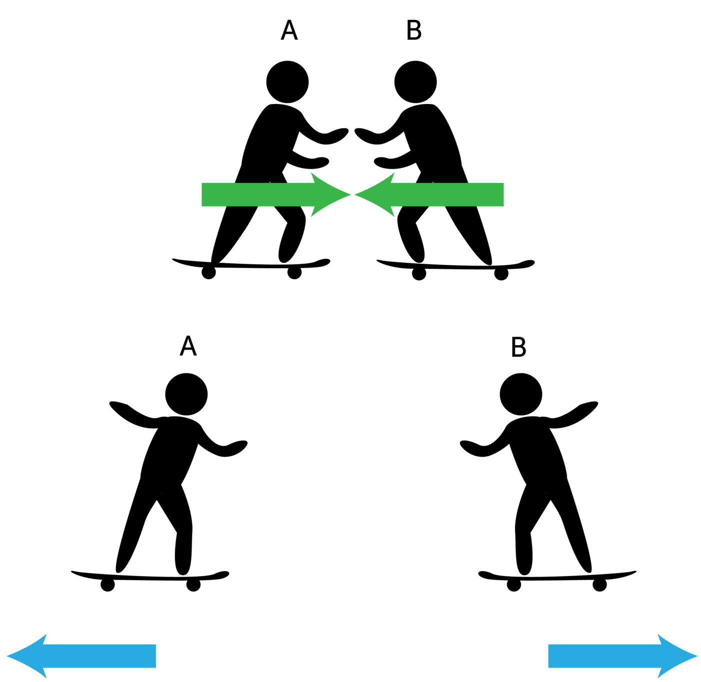

FIGURE 3.8
A and B move apart by first pushing together.

Action and Reaction

Newton's third law of motion states that every action has an equal and opposite reaction. This means that forces always act in pairs. First an action occurs, such as the skateboarders pushing together. Then a reaction occurs that is equal in strength to the action but in the opposite direction. In the case of the skateboarders, they move apart, and the distance they move depends on how hard they first pushed together. You can see other examples of actions and reactions in **Figure** 3.9. You can watch a video about actions and reactions at this URL: http://www.nasa.gov/mov/192449main_019_law_of_action.mov .

FIGURE 3.9
Each example shown here includes an action and reaction.

You might think that actions and reactions would cancel each other out like balanced forces do. Balanced forces, which are also equal and opposite, cancel each other out because they act on the same object. Action and reaction forces, in contrast, act on different objects, so they don't cancel each other out and, in fact, often result in motion. For example, in **Figure** 3.9, the kangaroo's action acts on the ground, but the ground's reaction acts on the kangaroo. As a result, the kangaroo jumps away from the ground. One of the action-reaction examples in the **Figure** 3.9 does not result in motion. Do you know which one it is?

Momentum

What if a friend asked you to play catch with a bowling ball, like the one pictured in **Figure** 3.10? Hopefully, you would refuse to play! A bowling ball would be too heavy to catch without risk of injury —assuming you could even throw it. That's because a bowling ball has a lot of mass. This gives it a great deal of momentum. **Momentum** is a property of a moving object that makes the object hard to stop. It equals the object's mass times its velocity. It can be represented by the equation:

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

This equation shows that momentum is directly related to both mass and velocity. An object has greater momentum if it has greater mass, greater velocity, or both. For example, a bowling ball has greater momentum than a softball when both are moving at the same velocity because the bowling ball has greater mass. However, a softball moving at a very high velocity —say, 100 miles an hour —would have greater momentum than a slow-rolling bowling ball. If an object isn't moving at all, it has no momentum. That's because its velocity is zero, and zero times anything is zero.

FIGURE 3.10
A bowling ball and a softball differ in mass. How does this affect their momentum?

Calculating Momentum

Momentum can be calculated by multiplying an object's mass in kilograms (kg) by its velocity in meters per second (m/s). For example, assume that a golf ball has a mass of 0.05 kg. If the ball is traveling at a velocity of 50 m/s, its momentum is:

$$\text{Momentum} = 0.05 \text{ kg} \times 50 \text{ m/s} = 2.5 \text{ kg} \cdot \text{m/s}$$

Note that the SI unit for momentum is kg·m/s.

Problem Solving

Problem: What is the momentum of a 40-kg child who is running straight ahead with a velocity of 2 m/s?

Solution: The child has momentum of: 40 kg × 2 m/s = 80 kg·m/s.

You Try It!

Problem: Which football player has greater momentum?

Player A: mass = 60 kg; velocity = 2.5 m/s

Player B: mass = 65 kg; velocity = 2.0 m/s

Conservation of Momentum

When an action and reaction occur, momentum is transferred from one object to the other. However, the combined momentum of the objects remains the same. In other words, momentum is conserved. This is the **law of conservation of momentum**.

Consider the example of a truck colliding with a car, which is illustrated in **Figure** 3.11. Both vehicles are moving in the same direction before and after the collision, but the truck is moving faster than the car before the collision occurs. During the collision, the truck transfers some of its momentum to the car. After the collision, the truck is moving slower and the car is moving faster than before the collision occurred. Nonetheless, their combined momentum is the same both before and after the collision. You can see an animation showing how momentum is conserved in a head-on collision at this URL: http://www.physicsclassroom.com/mmedia/momentum/cthoi.cfm .

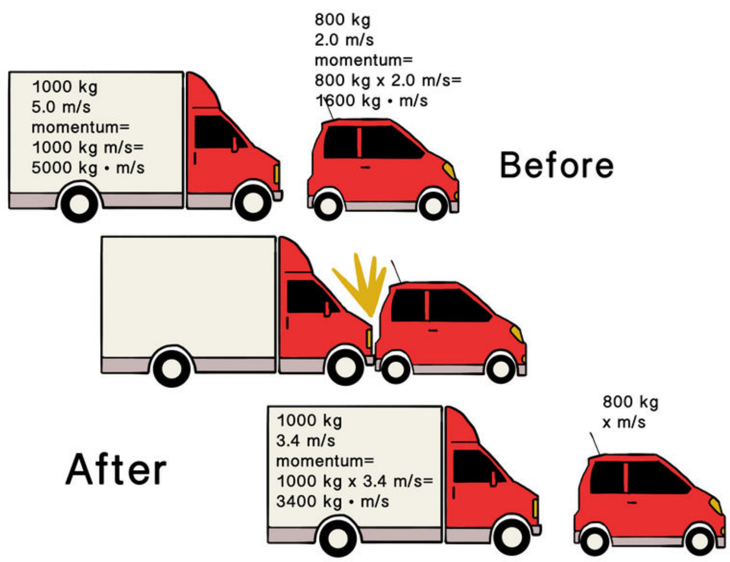

FIGURE 3.11
How can you tell momentum has been conserved in this collision?

KQED: Newton's Laws of Motion

Paul Doherty of the Exploratorium performs a "sit-down" lecture on one of Sir Issac Newton's most famous laws. For more information on Newton's laws of motion, see http://science.kqed.org/quest/video/quest-lab-newtons-laws-of-motion/ .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/129626

KQED: Out of the Park - The Physics of Baseball

At UC Berkeley, a team of undergrads is experimenting with velocity, force, and aerodynamics. But you won't find them in a lab – they work on a baseball diamond, throwing fast balls, sliders and curve balls. QUEST discovers how the principles of physics can make the difference between a strike and a home run. For more information on the physics of baseball, see http://science.kqed.org/quest/video/out-of-the-park-the-physics-of-baseball/ .

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/129624

Lesson Summary

- Newton's third law of motion states that every action has an equal and opposite reaction.
- Momentum is a property of a moving object that makes it hard to stop. It equals the object's mass times its velocity. When an action and reaction occur, momentum may be transferred from one object to another, but their combined momentum remains the same. This is the law of conservation of momentum.

Lesson Review Questions

Recall

1. State Newton's third law of motion.
2. Define momentum.
3. If you double the velocity of a moving object, how is its momentum affected?

Apply Concepts

4. A large rock has a mass of 50 kg and is rolling downhill at 3 m/s. What is its momentum?
5. Create a diagram to illustrate the transfer and conservation of momentum when a moving object collides with a stationary object.

Think Critically

6. The reaction to an action is an equal and opposite force. Why doesn't this yield a net force of zero?
7. Momentum is a property of an object, but it is different than a physical or chemical property, such as boiling point or flammability. How is momentum different?

Points to Consider

In this chapter, you learned about forces and motions of solid objects, such as balls and cars. In the next chapter, "Fluid Forces," you will learn about forces in fluids, which include liquids and gases.

- How do fluids differ from solids?
- What might be examples of forces in fluids? For example, what force allows some objects to float in water?

3.4 References

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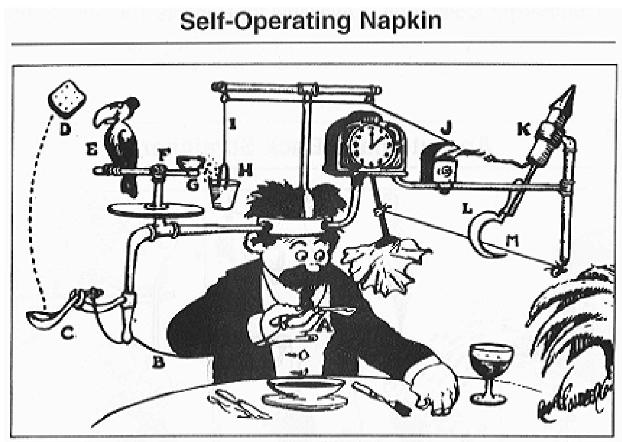
CHAPTER 4 Work and Machines

Chapter Outline



How the Self-Operating Napkin Works:

1. The man raises the soup spoon (A) to his mouth. This movement pulls the string (B), which jerks the ladle (C).
2. The ladle throws the cracker (D) past the parrot (E), which jumps for the cracker, causing the perch (F) to tilt.
3. When the perch tilts, it upsets the seeds (G) into the pail (H). The extra weight in the pail pulls the cord (I), which opens and lights the lighter (J).
4. The lighter sets off the skyrocket (K), which causes the sickle (L) to cut the string (M).
5. When the string is cut, it allows the pendulum with the attached napkin to swing back and forth, thereby wiping the man's chin.

A Rube Goldberg invention, like the "self-operating napkin" pictured here, is a needlessly complex machine that is used to complete a simple task. Rube Goldberg was an engineer and artist. He observed that people tend to find difficult ways to do simple things. He created silly cartoon machines, like the one above, to poke fun at this tendency. You can see some amazing Rube Goldberg-type machines in action by watching the videos at this URL: http://hhe.wikispaces.com/Rube+Goldberg+Machines .

In this chapter you'll learn about real machines, which —unlike Rube Goldberg inventions —actually make work easier. However, before learning about machines, you need to know what work means in physics. That's where this chapter begins.

Rube Goldberg. commons.wikimedia.org/wiki/File:Professor_Lucifer_Butts.gif. Public Domain.

4.1 Work

Lesson Objectives

- Define work, and state how to calculate it.
- Explain how power is related to work.

Lesson Vocabulary

- joule (J)
- power
- watt (W)
- work

Introduction

The teen playing tennis in **Figure** 4.1 is having fun. The other teen in the same figure is working hard studying for an exam. You can tell by their faces which teen is doing work — or can you? Would it surprise you to learn that the teen who is working is the one who is having fun playing tennis, while the teen who is studying isn't doing any work at all? The reason why has to do with how work is defined in physics.

FIGURE 4.1
Which teen is doing work and which teen isn't?

Defining and Calculating Work

Work is defined differently in physics than in everyday language. In physics, **work** means the use of force to move an object. The teen who is playing tennis in **Figure** 4.1 is using force to move her tennis racket, so she is doing work. The teen who is studying isn't moving anything, so she is not doing work.

Not all force that is used to move an object does work. For work to be done, the force must be applied in the same direction that the object moves. If a force is applied in a different direction than the object moves, no work is done. **Figure** 4.2 illustrates this point. The stick person applies an upward force on the box when raising it from the ground to chest height. Work is done because the force is applied in the same direction as the box is moving. However, as the stick person walks from left to right while holding the box at chest height, no more work is done by the person's arms holding the box up. That's because the force supporting the box acts in a different direction than the box is moving. A small amount of work in the horizontal direction is performed when the person is accelerating during the first step of the walk across the room. But other than that, there is no work, because there is no net force acting on the box horizontally.

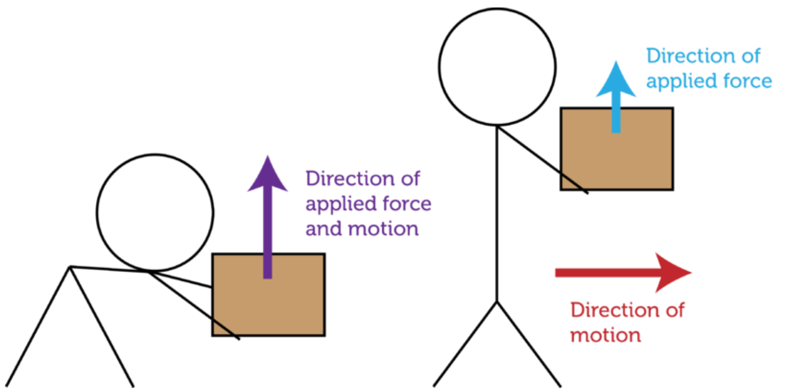


FIGURE 4.2
Carrying a box while walking does not result in work being done. Work is done only when the box is first lifted up from the ground. Can you explain why?

Work, Force, and Distance

Work is directly related to both the force applied to an object and the distance the object moves. It can be represented by the equation:

$$\text{Work} = \text{Force} \times \text{Distance}$$

This equation shows that the greater the force that is used to move an object or the farther the object is moved, the more work that is done. You can see a short video introduction to work as the product of force and distance at this link: http://www.schooltube.com/video/85de91bb7097c101fbda/Eureka-Episode-8-Work .

To see the effects of force and distance on work, compare the weight lifters in **Figure** 4.3. The two weight lifters on the left are lifting the same amount of weight, but the bottom weight lifter is lifting the weight a longer distance. Therefore, this weight lifter is doing more work. The two weight lifters on the bottom right are both lifting the weight the same distance, but the weight lifter on the left is lifting a heavier weight. Therefore, this weight lifter is doing more work.

Calculating Work

The equation for work given above can be used to calculate the amount of work that is done if force and distance are known. For example, assume that one of the weight lifters in **Figure** 4.2 lifts a weight of 400 newtons over his head to a height of 2.2 meters off the ground. The amount of work he does is:

$$\text{Work} = 400 \text{ N} \times 2.2 \text{ m} = 880 \text{ N} \cdot \text{m}$$

Notice that the unit for work is the newton $\cdot$meter. This is the SI unit for work, also called the **joule (J)**. One joule equals the amount of work that is done when 1 newton of force moves an object over a distance of 1 meter.

Problem Solving

Problem: Todd pushed a 500 N box 4 meters across the floor. How much work did he do?

Solution: Use the equation $\text{Work} = \text{Force} \times \text{Distance}$.

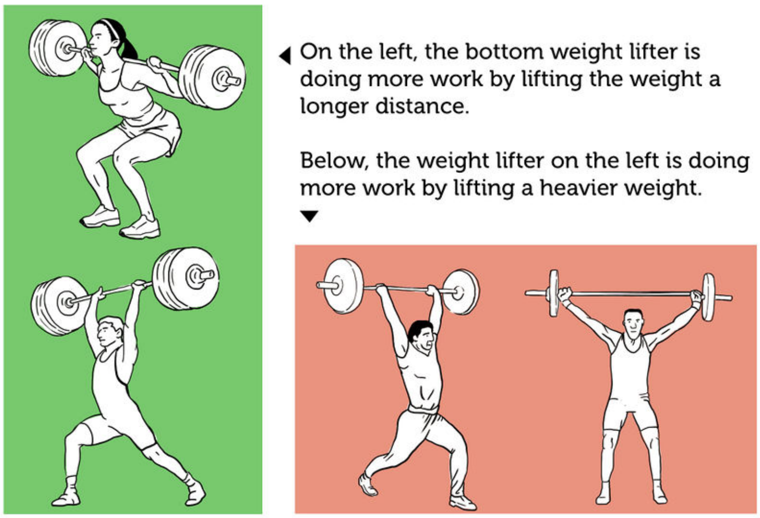


FIGURE 4.3
Weight lifters do more work when they move weights a longer distance or move heavier weights.

$$\text{Work} = 500\text{ N} \times 4\text{ m} = 2000\text{ N}\cdot\text{m, or } 2000\text{ J}$$

You Try It!

Problem: Lara lifted a 100 N box 1.5 meters above the floor. How much work did she do?

Work and Power

Did you ever rake leaves, like the woman in **Figure** 4.4? It can take a long time to do all that work. But if you use an electric leaf blower, like the man in the figure, the job gets done much sooner. Both the leaf blower and the rake do the work of removing leaves from the yard, but the leaf blower has more power. That's why it can do the same amount of work in less time.

FIGURE 4.4
Which way of removing leaves would take less effort on your part?

What Is Power?

Power is a measure of the amount of work that can be done in a given amount of time. Power can be represented by the equation:

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

In this equation, work is measured in joules and time is measured in seconds, so power is expressed in joules per second (J/s). This is the SI unit for work, also known as the **watt (W)**. A watt equals 1 joule of work per second. The watt is named for James Watt, a Scottish inventor you will read about below.

You may already be familiar with watts. That's because light bulbs and small appliances such as hair dryers are labeled with the watts of power they provide. For example, the hair dryer in **Figure** 4.5 is labeled "2000 watts." This amount of power could also be expressed kilowatts. A kilowatt equals 1000 watts, so the 2000-watt hair dryer produces 2 kilowatts of power.

FIGURE 4.5
Hair dryers vary in power. How do you think this affects drying time?

Compared with a less powerful device, a more powerful device can either do more work in the same time or do the same work in less time. For example, compared with a low-power microwave, a high-power microwave can cook more food in the same time or the same amount of food in less time.

Calculating Power or Work

Power can be calculated using the formula above, if the amount of work and time are known. For example, assume that a small engine does 3000 joules of work in 2 seconds. Then the power of the motor is:

$$\text{Power} = \frac{3000 \text{ J}}{2 \text{ s}} = 1500 \text{ J/s, or } 1500 \text{ W}$$

You can also calculate work if you know power and time by rewriting the power equation above as:

$$\text{Work} = \text{Power} \times \text{Time}$$

For example, if you use a 2000-watt hair dryer for 30 seconds, how much work is done? First express 2000 watts in J/s and then substitute this value for power in the work equation:

$$\text{Work} = 2000 \text{ J/s} \times 30 \text{ s} = 60,000 \text{ J}$$

For a video presentation on calculating power and work, go to this link: http://www.brightstorm.com/science/physics/energy-and-momentum/power/ .

Problem Solving

Problem: An electric mixer does 2500 joules of work in 5 seconds. What is its power?

Solution: Use the equation: $\text{Power} = \frac{\text{Work}}{\text{Time}}$.

$$\text{Power} = \frac{2500 \text{ J}}{5 \text{ s}} = 500 \text{ J/s, or } 500 \text{ W}$$

You Try It!

Problem: How much work can be done in 30 seconds by a 1000-watt microwave?

Horsepower

Sometimes power is measured in a unit called the horsepower. One horsepower is the amount of work a horse can do in 1 minute. It equals 745 watts of power. The horsepower was introduced by James Watt, who invented the first powerful steam engine in the 1770s. Watt's steam engine led to a revolution in industry and agriculture because of its power. Watt wanted to impress people with the power of his steam engine, so he compared it with something familiar to people of his time: the power of workhorses, like those pictured in **Figure** 4.6. Watt said his steam engine could produce the power of 20 horses, or 20 horsepower. The most powerful engines today may produce more than 100,000 horsepower! How many watts of power is that?

FIGURE 4.6
The horses and the tractor are both pulling a plow. The horses provide less horsepower than the tractor. Which do you think will get the job done faster?

Lesson Summary

- Work is the use of force to move an object. It can be calculated as the product of force and distance. The SI unit for work is the joule (J).
- Power is a measure of the amount of work that can be done in a given amount of time. The SI unit for power is the watt (W).

Lesson Review Questions

Recall

1. How is work defined in physics?
2. What does power measure?
3. Identify the SI units for work and power.

Apply Concepts

4. Jana lifted a 200-newton weight over her head to a distance of 2 meters above the ground. How much work did she do?
5. Pieter picked up a 20-newton book from the floor. Then he passed it to Ahmad, who carried it for 20 meters. How much work did Ahmad do?
6. If an electric mixer does 10,000 joules of work in 10 seconds, what is its power?

Think Critically

7. Explain how power is related to work.

Points to Consider

Machines such as the tractor and leaf blower you read about in this lesson help people do work.

- What are other examples of machines?
- What do all these machines have in common?

4.2 Machines

Lesson Objectives

- Explain how machines help us do work.
- Define efficiency, and state how it is calculated.
- Define mechanical advantage, and state how it is calculated.

Lesson Vocabulary

- efficiency
- machine
- mechanical advantage

Introduction

When you hear the word "machine," do you think of large appliances, power tools, factory machines, or construction equipment, like the examples pictured in **Figure** 4.7? While all of these examples are machines, you might be surprised to learn that devices as simple as hammers and screws are also machines. Why are these simple tools considered machines? Read on to find out.

FIGURE 4.7
Do you know what type of work each of these machines does?

How Machines Help Us Do Work

A **machine** is any device that makes work easier by changing a force. When you use a machine, you apply force to the machine. This force is called the input force. The machine, in turn, applies force to an object. This force is called the output force. Recall that work equals force multiplied by distance:

$$\text{Work} = \text{Force} \times \text{Distance}$$

The force you apply to a machine is applied over a given distance, called the input distance. The force applied by the machine to the object is also applied over a distance, called the output distance. The output distance may or may not be the same as the input distance.

Machines make work easier by increasing the amount of force that is applied, increasing the distance over which the force is applied, or changing the direction in which the force is applied. Contrary to popular belief, machines do not increase the amount of work that is done. They just change how the work is done. So if a machine increases the force applied, it must apply the force over a shorter distance. Similarly, if a machine increases the distance over which the force is applied, it must apply less force.

Increasing Force

Examples of machines that increase force are doorknobs and nutcrackers. **Figure** 4.8 explains how these machines work. In each case, the force applied by the user is less than the force applied by the machine, but the machine applies the force over a shorter distance.

FIGURE 4.8
Both of these machines increase the force applied by the user, while reducing the distance over which the force is applied.

Increasing Distance

Examples of machines that increase the distance over which force is applied are paddles and hammers. **Figure** 4.9 explains how these machines work. In each case, the machine increases the distance over which the force is applied, but it reduces the strength of the applied force.

Changing the Direction of Force

Some machines change the direction of the force applied by the user. They may or may not also change the strength of the force or the distance over which it is applied. Two examples of machines that work in this way are claw hammers and the rope systems (pulleys) that raise or lower flags on flagpoles. **Figure** 4.10 explains how these

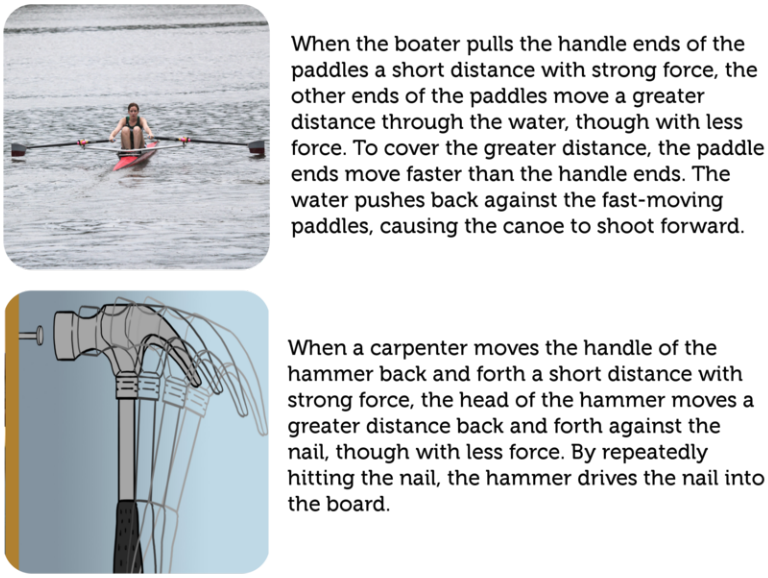


FIGURE 4.9
Both of these machines increase the distance over which force applied, while reducing the strength of the force.

machines work. In each case, the direction of the force applied by the user is reversed by the machine. How does this make it easier to do the job?

FIGURE 4.10
Both of these machines change the direction over which force is applied. The claw hammer also increases the strength of the force.

KQED: Exoskeletons Walk Forward

An exoskeleton suit may seem like science fiction, turning ordinary humans into super heroes. But wearable robots are moving forward into reality. And for paraplegics, the ability to stand and walk that these machines provide is a super power. QUEST meets Austin Whitney and Tamara Mena, two "Exoskeleton Test Pilots" who are now putting this new technology through its paces. For more information on exoskeleton suits, see http://science.kqed.org/ques t/video/exoskeletons-walk-forward/ .

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/129627

Efficiency of Machines

You read above that machines do not increase the work done on an object. In other words, you can't get more work out of a machine than you put into it. In fact, machines always do less work on the object than the user does on the machine. That's because all machines must use some of the work put into them to overcome friction. How much work? It depends on the efficiency of the machine. **Efficiency** is the percent of input work that becomes output work. It is a measure of how well a machine reduces friction.

An Example: Efficiency of a Ramp

Consider the ramp in **Figure** 4.11. It's easier to push the heavy piece of furniture up the ramp to the truck than to lift it straight up off the ground. However, pushing the furniture over the surface of the ramp creates a lot of friction. Some of the force applied to moving the furniture must be used to overcome the friction. It would be more efficient to use a dolly on wheels to roll the furniture up the ramp. That's because rolling friction is much less than sliding friction. As a result, the efficiency of the ramp would be greater with a dolly.

FIGURE 4.11

A ramp is a machine because it makes work easier by changing a force. How does it change force?

Calculating Efficiency

Efficiency can be calculated with the equation:

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100\%$$

Consider a machine that puts out 6000 joules of work. To produce that much work from the machine requires the user to put in 8000 joules of work. To find the efficiency of the machine, substitute these values into the equation for efficiency:

$$\text{Efficiency} = \frac{6000 \text{ J}}{8000 \text{ J}} \times 100\% = 75\%$$

You Try It!

Problem: Rani puts 10,000 joules of work into a car jack. The car jack, in turn, puts out 7000 joules of work to raise up the car. What is the efficiency of the jack?

Mechanical Advantage of Machines

Another measure of the effectiveness of a machine is its mechanical advantage. **Mechanical advantage** is the number of times a machine multiplies the input force. It can be calculated with the equation:

$$\text{Mechanical Advantage} = \frac{\text{Output force}}{\text{Input force}}$$

This equation computes the actual mechanical advantage of a machine. It takes into account the reduction in output force that is due to friction. It shows how much a machine actually multiplies force when it used in the real world.

Ideal Mechanical Advantage

It can be difficult to measure the input and output forces needed to calculate actual mechanical advantage. It's usually much easier to measure the input and output distances. These measurements can then be used to calculate the ideal mechanical advantage. The ideal mechanical advantage represents the multiplication of input force that would be achieved in the absence of friction. Therefore, it is greater than the actual mechanical advantage because all machines use up some work in overcoming friction. Ideal mechanical advantage is calculated with the equation:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Input distance}}{\text{Output distance}}$$

Compare this equation with the equation above for actual mechanical advantage. Notice how the input and output values are switched. This makes sense when you recall that when a machine increases force, it decreases distance — and vice versa.

Consider the simple ramp in **Figure** 4.12. A ramp can be used to raise an object up off the ground. The input distance is the length of the sloped surface of the ramp. The output distance is the height of the ramp, or the vertical distance the object is raised. Therefore, the ideal mechanical advantage of the ramp is:

$$\text{Ideal Mechanical Advantage} = \frac{6\text{ m}}{2\text{ m}} = 3$$

An ideal mechanical advantage of 3 means that the ramp ideally (in the absence of friction) multiplies the output force by a factor of 3.

FIGURE 4.12

The input force is applied along the length of the sloping ramp surface. The output force is applied along the height of the ramp. The input distance is greater than the output distance. This means that the input force is less than the output force.

Mechanical Advantage and Type of Machine

As you read above, some machines increase the force put into the machine, while other machines increase the distance over which the force is applied. Still other machines change only the direction of the force. Which way a machine works affects its mechanical advantage.

- For machines that increase force — including ramps, doorknobs, and nutcrackers — the output force is greater than the input force. Therefore, the mechanical advantage is greater than 1.
- For machines that increase the distance over which force is applied, such as paddles and hammers, the output force is less than the input force. Therefore, the mechanical advantage is less than 1.
- For machines that change only the direction of the force, such as the rope systems on flagpoles, the output force is the same as the input force. Therefore, the mechanical advantage is equal to 1.

Lesson Summary

- A machine is any device that makes work easier by changing a force. A machine may increase force, increase the distance over which force is applied, or change the direction of force.
- The efficiency of a machine is a measure of how well it reduces friction. It is calculated as the percent of input work that becomes output work.
- The mechanical advantage of a machine is the number of times it multiplies the input force. The ideal mechanical advantage is the multiplication of force that would be achieved in the absence of friction. It is calculated as the input distance divided by the output distance.

Lesson Review Questions

Recall

1. What is a machine?
2. Identify three different ways that machines may change force.
3. What does efficiency measure?
4. Define actual mechanical advantage.

5. How does ideal mechanical advantage differ from actual mechanical advantage? How is ideal mechanical advantage calculated?

Apply Concepts

6. In the picture below, a screwdriver is being used to pry the lid off a paint can. The tip of the screwdriver is resting on the top edge of the can. When the handle of the screwdriver is pushed down, the tip of the screwdriver pushes up on the edge of the lid. Draw a simple labeled sketch to show the input and output distances involved in this work. How does the input distance compare with the output distance? Is the ideal mechanical advantage of the screwdriver greater than, less than, or equal to 1?

7. Assume that a machine puts out 8000 joules of work when the user puts in 10,000 joules of work. What is the efficiency of the machine?

Think Critically

8. The mechanical advantage of a machine is related to how it changes force. Explain this relationship.

Points to Consider

The canoe paddles, nutcracker, and hammer that you read about in this lesson have something in common. All three are examples of a type of simple machine called a lever.

- Based on these three examples, how would you describe a lever?
- How do you think a lever changes the force applied to it?

4.3 Simple Machines

Lesson Objectives

- Explain how an inclined plane changes force.
- List common examples of wedges and screws.
- Compare and contrast the three classes of levers.
- Describe two ways that a wheel and axle can be used.
- Identify three types of pulleys.

Lesson Vocabulary

- inclined plane
- lever
- pulley
- screw
- wedge
- wheel and axle

Introduction

Look at the axe head and the foot of the "doorstop man" in **Figure** 4.13. Do you see anything similar about them? What do you think they have in common? The answer is that both devices are a type of simple machine called a wedge. A wedge is just one of six types of simple machines. The others are the inclined plane, screw, lever, wheel and axle, and pulley. These six types of simple machines are the basis of all machines. More complex machines consist of two or more simple machines. In this lesson you'll learn how all six types of simple machines make work easier. You can explore animations of all six types at this link: http://www.cosi.org/files/Flash/simpMach/sm1.swf .

FIGURE 4.13
The axe head and the doorstop are both examples of a wedge, a type of simple machine.

Inclined Plane

The man in **Figure** 4.14 is using a ramp to move a heavy dryer up to the back of a truck. The highway in the figure switches back and forth so it climbs up the steep hillside. Both the ramp and the highway are examples of inclined planes. An **inclined plane** is a simple machine consisting of a sloping surface that connects lower and higher elevations.

FIGURE 4.14
An inclined plane makes it easier to move objects to a higher elevation.

The sloping surface of the inclined plane supports part of the weight of the object as it moves up the slope. As a result, it takes less force to move the object uphill. The trade-off is that the object must be moved over a greater distance than if it were moved straight up to the higher elevation. On the other hand, the output force is greater than the input force because it is applied over a shorter distance. Like other simple machines, the ideal mechanical advantage of an inclined plane is given by:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Input distance}}{\text{Output distance}}$$

For an inclined plane, the input distance is the length of the sloping surface, and the output distance is the maximum height of the inclined plane. This was illustrated in **Figure** 4.12. Because the sloping surface is always greater than the height of the inclined plane, the ideal mechanical advantage of an inclined plane is always greater than 1. An inclined plane with a longer sloping surface relative to its height has a gentler slope. An inclined plane with a gentler slope has a greater mechanical advantage and requires less input force to move an object to a higher elevation.

Wedge and Screw

Two simple machines that are based on the inclined plane are the wedge and the screw. Both increase the force used to move an object because the input force is applied over a greater distance than the output force.

Wedge

Imagine trying to slice a tomato with a fork or spoon instead of a knife, like the one in **Figure** 4.15. The knife makes the job a lot easier because of the wedge shape of the blade. A **wedge** is a simple machine that consists of two inclined planes. But unlike one inclined plane, a wedge works only when it moves. It has a thin end and thick end, and the thin end is forced into an object to cut or split it. The chisel in **Figure** 4.15 is another example of a wedge.

The input force is applied to the thick end of a wedge, and it acts over the length of the wedge. The output force pushes against the object on both sides of the wedge, so the output distance is the thickness of the wedge. Therefore, the ideal mechanical advantage of a wedge can be calculated as:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Length of wedge}}{\text{Maximum thickness of wedge}}$$

The length of a wedge is always greater than its maximum thickness. As a result, the ideal mechanical advantage of a wedge is always greater than 1.

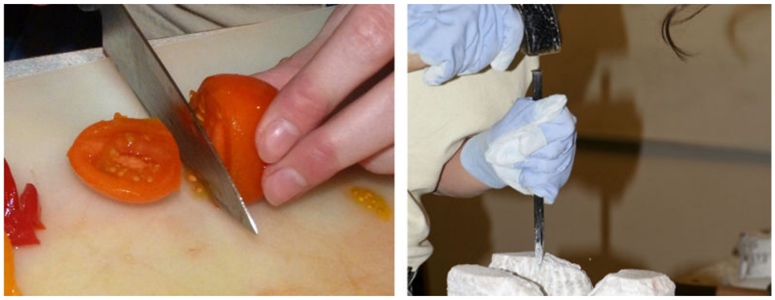


FIGURE 4.15

The thin edge of a knife or chisel enters an object and forces it apart.

Screw

The spiral staircase in **Figure** 4.16 also contains an inclined plane. Do you see it? The stairs that wrap around the inside of the walls make up the inclined plane. The spiral staircase is an example of a screw. A **screw** is a simple machine that consists of an inclined plane wrapped around a cylinder or cone. No doubt you are familiar with screws like the wood screw in **Figure** 4.16. The screw top of the container in the figure is another example. Screws move objects to a higher elevation (or greater depth) by increasing the force applied.

When you use a wood screw, you apply force to turn the inclined plane. The output force pushes the screw into the wood. It acts along the length of the cylinder around which the inclined plane is wrapped. Therefore, the ideal mechanical advantage of a screw is calculated as:

$$\text{Ideal Mechanical Advantage} = \frac{\text{Length of inclined plane}}{\text{Length of screw}}$$

The length of the inclined plane is always greater than the length of the screw. As a result, the mechanical advantage of a screw is always greater than 1.

Look at the collection of screws and bolts in **Figure** 4.17. In some of them, the turns (or threads) of the inclined plane are closer together. The closer together the threads are, the longer the inclined plane is relative to the length of the screw or bolt, so the greater its mechanical advantage is. Therefore, if the threads are closer together, you need to apply less force to penetrate the wood or other object. The trade-off is that more turns of the screw or bolt are needed to do the job because the distance over which the input force must be applied is greater.

Lever

Did you ever use a hammer to pull a nail out of a board? If not, you can see how it's done in **Figure** 4.18. When you pull down on the handle of the hammer, the claw end pulls up on the nail. A hammer is an example of a lever. **A lever** is a simple machine consisting of a bar that rotates around a fixed point called the fulcrum. For a video introduction to levers using skateboards as examples, go to this link: http://www.youtube.com/watch?v=72ZNEactb-k (1:35).

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Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5029

FIGURE 4.16
All of these examples are screws. Can you identify the inclined plane in each example?

FIGURE 4.17
The threads of a screw or bolt may be closer together or farther apart. How does this affect its ideal mechanical advantage?

FIGURE 4.18

Using a hammer to remove a nail changes both the direction and strength of the applied force. Where is the fulcrum of the hammer when it is used in this way?

A lever may or may not increase the force applied, and it may or may not change the direction of the force. It all depends on the location of the input and output forces relative to the fulcrum. In this regard, there are three basic types of levers, called first-class, second-class, and third-class levers. **Figure** 4.19 describes the three classes.

Comparing Classes of Levers

All three classes of levers make work easier, but they do so in different ways.

- When the input and output forces are on opposite sides of the fulcrum, the lever changes the direction of the applied force. This occurs only with a first-class lever.
- When both the input and output forces are on the same side of the fulcrum, the direction of the applied force does not change. This occurs with both second- and third-class levers.
- When the input force is applied farther from the fulcrum, the input distance is greater than the output distance, so the ideal mechanical advantage is greater than 1. This always occurs with second-class levers and may occur with first-class levers.
- When the input force is applied closer to the fulcrum, the input distance is less than the output distance, so the ideal mechanical advantage is less than 1. This always occurs with third-class levers and may occur with first-class levers.
- When both forces are the same distance from the fulcrum, the input distance equals the output distance, so the ideal mechanical advantage equals 1. This occurs only with first class-levers.

Advantage of Third-Class Levers

You may be wondering why you would use a third-class lever when it doesn't change the direction or strength of the applied force. The advantage of a third-class lever is that the output force is applied over a greater distance than the input force. This means that the output end of the lever must move faster than the input end. Why would this be useful when you are moving a hockey stick or baseball bat, both of which are third-class levers?

Wheel and Axle

Did you ever ride on a Ferris wheel, like the one pictured in **Figure** 4.20? If you did, then you know how thrilling the ride can be. A Ferris wheel is an example of a wheel and axle. A **wheel and axle** is a simple machine that consists of two connected rings or cylinders, one inside the other, which both turn in the same direction around a single center point. The smaller, inner ring or cylinder is called the axle. The bigger, outer ring or cylinder is called the wheel. The car steering wheel in **Figure** 4.20 is another example of a wheel and axle.

In a wheel and axle, force may be applied either to the wheel or to the axle. In both cases, the direction of the force does not change, but the force is either increased or applied over a greater distance.

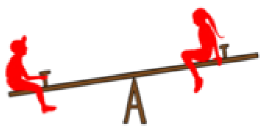
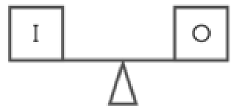
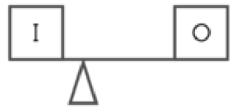
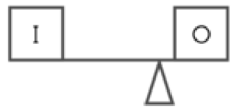
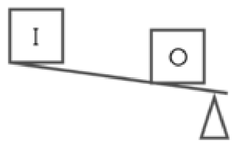
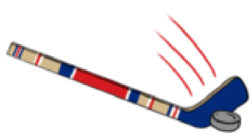
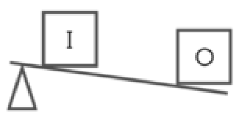
Class of Lever	Example	Location of Input & Output Forces & Fulcrum	Ideal Mechanical Advantage	Change in Direction of Force?
First class	Seesaw 		IMA = 1	yes
			IMA < 1	yes
			IMA > 1	yes
Second class	Wheelbarrow 		IMA > 1	no
Third class	Hockey stick 		IMA < 1	no

FIGURE 4.19

Which class of lever would you use to carry a heavy load, sweep a floor, or pry open a can of paint?

- When the input force is applied to the axle, as it is with a Ferris wheel, the wheel turns with less force, so the ideal mechanical advantage is less than 1. However, the wheel turns over a greater distance, so it turns faster than the axle. The speed of the wheel is one reason that the Ferris wheel ride is so exciting.
- When the input force is applied to the wheel, as it is with a steering wheel, the axle turns over a shorter distance but with greater force, so the ideal mechanical advantage is greater than 1. This allows you to turn the steering wheel with relatively little effort, while the axle of the steering wheel applies enough force to turn the car.

FIGURE 4.20
Both a Ferris wheel and a car steering wheel have an outer wheel and an inner axle.

Pulley

Another simple machine that uses a wheel is the pulley. A **pulley** is a simple machine that consists of a rope and grooved wheel. The rope fits into the groove in the wheel, and pulling on the rope turns the wheel. **Figure** 4.21 shows two common uses of pulleys.

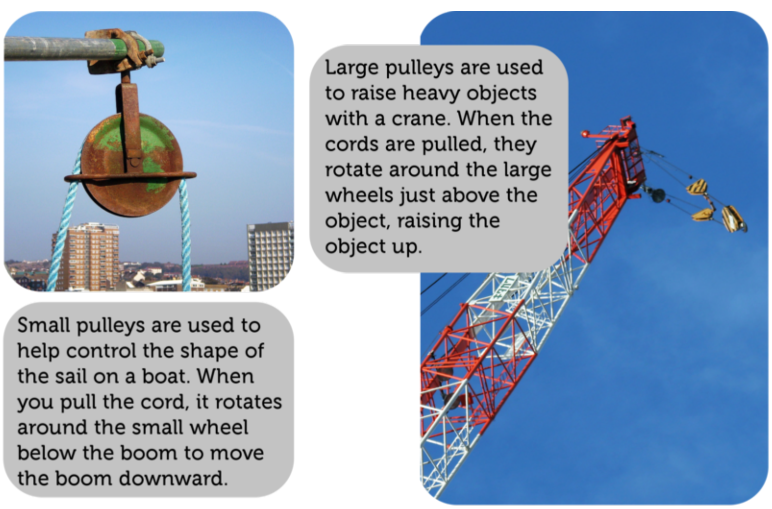


FIGURE 4.21
In both of these examples, pulling the rope turns the wheel of the pulley.

Some pulleys are attached to a beam or other secure surface and remain fixed in place. They are called fixed pulleys. Other pulleys are attached to the object being moved and are moveable themselves. They are called moveable pulleys. Sometimes, fixed and moveable pulleys are used together. They make up a compound pulley. The three types of pulleys are compared in **Figure** 4.22. In all three types, the ideal mechanical advantage is equal to the number of rope segments pulling up on the object. The more rope segments that are helping to do the lifting work, the less force that is needed for the job. You can experiment with an interactive animation of compound pulleys with various numbers of pulleys at this link: http://www.walter-fendt.de/ph14e/pulleysystem.htm .

- In a single fixed pulley, only one rope segment lifts the object, so the ideal mechanical advantage is 1. This type of pulley doesn't increase the force, but it does change the direction of the force. This allows you to use your weight to pull on one end of the rope and more easily raise the object attached to the other end.

- In a single moveable pulley, two rope segments lift the object, so the ideal mechanical advantage is 2. This type of pulley doesn't change the direction of the force, but it does increase the force.
- In a compound pulley, two or more rope segments lift the object, so the ideal mechanical advantage is equal to or greater than 2. This type of pulley may or may not change the direction of the force, depending on the number and arrangement of pulleys. When several pulleys are combined, the increase in force may be very great.

Lesson Summary

- An inclined plane is a simple machine consisting of a sloping surface that connects lower and higher elevations. The ideal mechanical advantage of an inclined plane is always greater than 1.
- A wedge is a simple machine that consists of two inclined planes. A screw is a simple machine that consists of an inclined plane wrapped around a cylinder or cone. The ideal mechanical advantage of wedges and screws is always greater than 1.
- A lever is a simple machine that consists of a bar that rotates around a fixed point called the fulcrum. There are three classes of levers. Depending on its class, a lever may have an ideal mechanical advantage that is less than, equal to, or greater than 1. First-class levers also change the direction of the input force.
- A wheel and axle is a simple machine that consists of two connected rings or cylinders, one inside the other, which both turn in the same direction around a single center point. When force is applied to the inner axle, the ideal mechanical advantage is less than 1. When force is applied to the outer wheel, the ideal mechanical advantage is greater than 1.
- A pulley is a simple machine that consists of a rope and grooved wheel. Single pulleys may be fixed or moveable. Single and moveable pulleys may be combined in a compound pulley. The ideal mechanical advantage of a pulley or compound pulley is always equal to or greater than 1. Fixed pulleys and some compound pulleys also change the direction of the input force.

Lesson Review Questions

Recall

1. What is an inclined plane?
2. Give an example of a wedge. What work does it do?
3. How does force change when it is applied to the axle of a wheel and axle?
4. What determines the ideal mechanical advantage of a pulley?

Apply Concepts

5. A leaf rake is a type of lever. Where is the fulcrum and where are the input and output forces applied? Which class of lever is a rake? Explain your answer.

Think Critically

6. Explain why inclined planes, wedges, and screws always have an ideal mechanical advantage greater than 1.
7. Compare and contrast the three classes of levers.

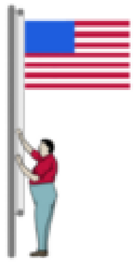
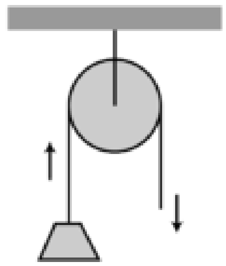
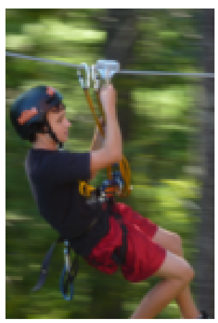
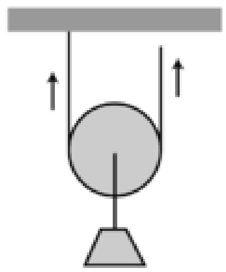
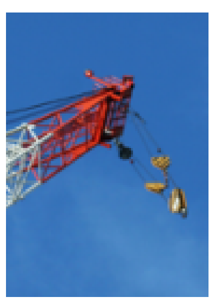
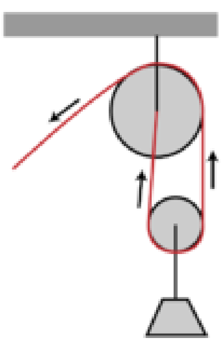
Type of Pulley	Example	How it Works	No. of Rope Segments Pulling up	Ideal Mechanical Advantage	Change in Direction of Force?
Single fixed pulley	Flagpole pulley 		1	1	yes yes yes
Single movable pulley	Zip-line pulley 		2	2	no
Compound pulley (fixed & movable pulleys)	Crane pulley 		≥ 2	≥ 2	no

FIGURE 4.22
Single pulleys may be fixed or moveable. Compound pulleys consist of two or more pulleys.

Points to Consider

In this lesson, you read that a compound pulley consists of two or more single pulleys. Many other machines also consist of two or more simple machines.

- Can you think of additional examples of machines that consist of more than one simple machine? Which simple machines do they contain?

- How might combining simple machines into a more complex machine affect efficiency and mechanical advantage?

4.4 Compound Machines

Lesson Objectives

- Give examples of compound machines.
- Describe the efficiency and mechanical advantage of compound machines.

Lesson Vocabulary

- compound machine

Introduction

Did you ever look closely at the moving parts of a bicycle, like the mountain bike gears in **Figure** 4.23? If you did, then you observed several simple machines, including wheels and axles, pulleys, and levers. A bicycle is an example of a compound machine.

FIGURE 4.23
What simple machines do you see in this photo of bicycle gears?

What Is a Compound Machine?

A **compound machine** is a machine that consists of more than one simple machine. Some compound machines consist of just two simple machines. For example, a wheelbarrow consists of a lever, as you read earlier in the lesson

"Simple Machines," and also a wheel and axle. Other compound machines, such as cars, consist of hundreds or even thousands of simple machines. Two common examples of compound machines are scissors and fishing rods with reels. To view a young student's compound machine invention that includes several simple machines, watch the video at this link: http://www.youtube.com/watch?v=e4LUaAwuh_U . To see if you can identify the simple machines in a lawn mower, go to the URL below and click on "Find the Simple Machines."

http://www.cosi.org/files/Flash/simpMach/sm2.html

Scissors

Look at the scissors in **Figure** 4.24. As you can see from the figure, scissors consist of two levers and two wedges. You apply force to the handle ends of the levers, and the output force is exerted by the blade ends of the levers. The fulcrum of both levers is where they are joined together. Notice that the fulcrum lies between the input and output points, so the levers are first-class levers. They change the direction of force. They may or may not also increase force, depending on the relative lengths of the handles and blades. The blades themselves are wedges, with a sharp cutting edge and a thicker dull edge.

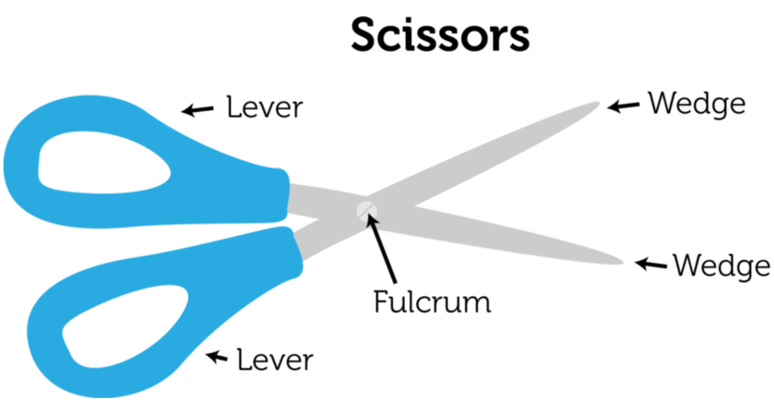


FIGURE 4.24
A pair of scissors is a compound machine consisting of levers and wedges.

Fishing Rod with Reel

The fishing rod with reel shown in **Figure** 4.25 is another compound machine. The rod is a third-class lever, with the fulcrum on one end of the rod, the input force close to the fulcrum, and the output force at the other end of the rod. The output distance is greater than the input distance, so the angler can fling the fishing line far out into the water with just a flick of the wrist. The reel is a wheel and axle that works as a pulley. The fishing line is wrapped around the wheel. Using the handle to turn the axle of the wheel winds or unwinds the line.

KQED: The Science of Riding a Bicycle

Riding a bicycle might be easy. But the forces that allow humans to balance atop a bicycle are complex. QUEST visits Davis – a city that loves its bicycles – to take a ride on a research bicycle and explore a collection of antique bicycles. Scientists say studying the complicated physics of bicycling can lead to the design of safer, and more efficient bikes. For more information on the science of riding a bicycle, see http://www.kqed.org/quest/television/cool-critters-dwarf-cuttlefish .

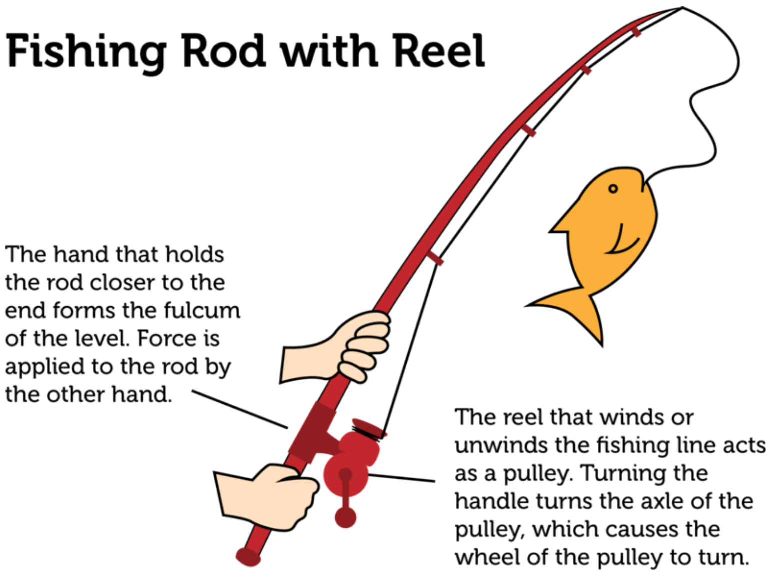


FIGURE 4.25
As a third-class lever, how does a fishing rod change the force applied to the rod? How does the reel help land the fish?

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/129628

Efficiency and Mechanical Advantage of Compound Machines

Because compound machines have more moving parts than simple machines, they generally have more friction to overcome. As a result, compound machines tend to have lower efficiency than simple machines. When a compound machine consists of a large number of simple machines, friction may become a serious problem, and it may produce a lot of heat. Lubricants such as oil or grease may be used to coat the moving parts so they slide over each other more easily. This is how a car's friction is reduced.

Compound machines have a greater mechanical advantage than simple machines. That's because the mechanical advantage of a compound machine equals the product of the mechanical advantages of all its component simple machines. The greater the number of simple machines it contains, the greater is its mechanical advantage.

Lesson Summary

- A compound machine consists of two or more simple machines. Examples of compound machines include bicycles, cars, scissors, and fishing rods with reels.
- Compound machines generally have lower efficiency but greater mechanical advantage than simple machines.

Lesson Review Questions

Recall

1. What is a compound machine?
2. Give two examples of compound machines.
3. How is the mechanical advantage of a compound machine calculated?

Apply Concepts

4. The can opener in the picture below is a compound machine. Identify two simple machines it contains.

Think Critically

5. Explain why the efficiency of compound machines is generally less than the efficiency of simple machines.

Points to Consider

Some of the machines you read about in this chapter require electricity in order to work. Electricity is a form of energy.

- What is energy?
- Besides electricity, what might be other forms of energy?

4.5 References

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12. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
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15. Knife: Flickr:normanack; Chisel: Andrew Magill. Knife: http://www.flickr.com/photos/29278394@N00/7200149818/; Chisel: http://www.flickr.com/photos/amagill/290331276/ . CC BY 2.0
16. Spiral staircase: Karel Jakubec (Wikimedia: Karelj); Screws: Pascal (Flickr:pasukaru76); Jar: Dwight Burdette. Stairs: http://commons.wikimedia.org/wiki/File:Spiral_staircase_in_the_Vatican_Museums_2011_04.jpg; Srews: http://www.flickr.com/photos/pasukaru76/3629604891/; Jar: http://commons.wikimedia.org/wiki/Category:Mason_jars .
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19. Christopher Auyeung and Laura Guerin. photo . CC BY-NC 3.0
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21. Pulley: Les Chatfield (Flickr: Elsie esq.); Crane: Flick:OiMax. Pulley: http://www.flickr.com/photos/elsie/2893140066; Crane: http://www.flickr.com/photos/oimax/273930741/ . CC BY 2.0
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Zip line: http://www.flickr.com/photos/tourismnewbrunswick/6088556853/; Crane: http://www.flickr.com/photos/oimax/273930741/ . Flag: CC BY-NC 3.0; Zip line: CC BY 2.0; Crane: CC BY 2.0
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