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# 8th Grade Integrated Science 2020-21

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# CHAPTER 1 Unit 1: Colossal Collisions

## Chapter Outline

1.1 FOSSILS
1.2 MASS EXTINCTION
1.3 KINETIC ENERGY
1.4 NEWTON'S FIRST LAW
1.5 NEWTON'S SECOND LAW
1.6 NEWTON'S THIRD LAW
1.7 COLLISION THEORY
1.8 MASS VS WEIGHT
1.9 GRAVITY
1.10 GRAVITY IN THE SOLAR SYSTEM
1.11 REFERENCES

# 1.1 Fossils

## Learning Objectives

- Define fossil.
- Describe how fossils help us understand the past.

### Would this be evidence of evolution?

Fossils, like this dinosaur fossil, provide evidence of species that lived in the past and have since gone extinct. In other words, these fossils are evidence of evolution.

## Fossil Evidence

In his book *On the Origin of Species*, Darwin included evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

**Fossils** are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in the **Figure** 3.8. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

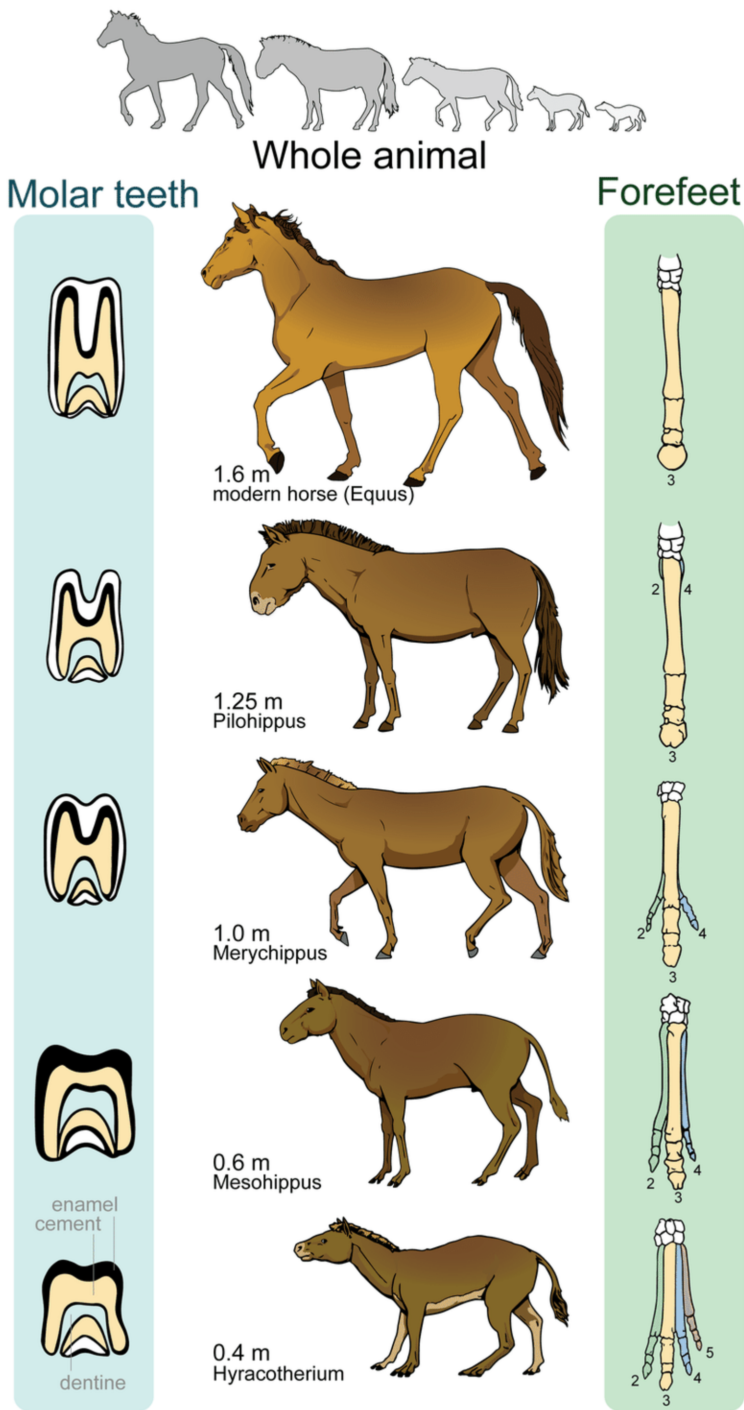
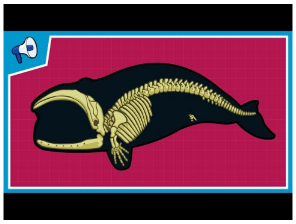



FIGURE 1.1

Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process. Notice the 57 million year evolution of the horse leg bones and teeth. Especially obvious is the transformation of the leg bones from having four distinct digits to that of today's horse.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea.



MEDIA
Click image to the left or use the URL below.

**Science Friday: Millions of Fossils Can't Be Wrong**

What's in a tar pit? In this video by Science Friday, Dr. John Harris describes how the La Brea Tar Pit has come to accumulate so many fossils.

MEDIA
Click image to the left or use the URL below.

## Summary

- Fossils provide a window into the past. They are evidence for evolution.
- Scientists who find and study fossils are called paleontologists.

## Review

1. What is a fossil?
2. How do paleontologists learn about evolution?
3. Describe what fossils reveal about the evolution of the horse.

# 1.2 Mass Extinction

## Learning Objectives

- Define mass extinction.
- Give examples of mass extinctions.
- Describe the importance of the mass extinction dated at 65.5 million years ago.

**What happened to the dinosaurs?**

Most of the dinosaurs disappeared from Earth about 65 million years ago. This is probably the most famous example of a mass extinction. So how do you define a mass extinction?

## Mass Extinctions

An organism goes extinct when all of the members of a species die out and no more members remain. **Extinctions** are part of natural selection. Species often go extinct when their environment changes, and they do not have the traits they need to survive. Only those individuals with the traits needed to live in a changed environment survive (Survival of the Fittest) (**Figure** 1.2).

**Mass extinctions**, such as the extinction of dinosaurs and many marine mammals, happened after major catastrophes such as volcanic eruptions and earthquakes (**Figure** 1.3).

Since life began on Earth, there have been several major mass extinctions. If you look closely at the geological time scale, you will find that at least five major mass extinctions have occurred in the past 540 million years. In each mass extinction, over 50% of animal species died. Though species go extinct frequently, a mass extinction in which such

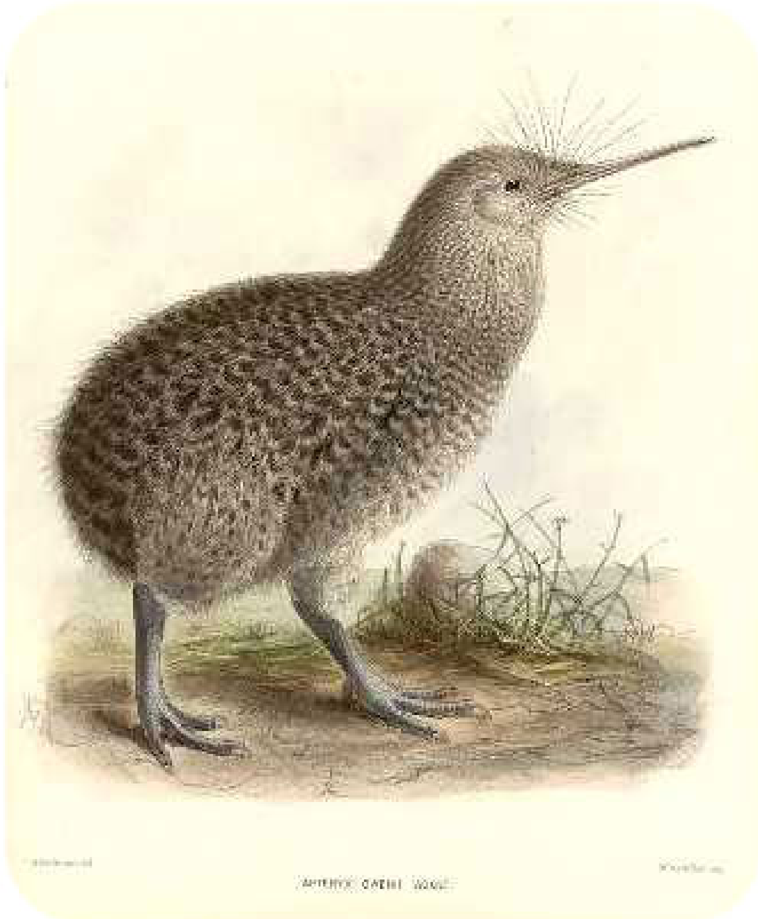


FIGURE 1.2
Humans have caused many extinctions by introducing species to new places. For example, many of New Zealand's birds have adapted to nesting on the ground. This was possible because there were no land mammals in New Zealand. Then Europeans arrived and brought cats, foxes, and other predators with them. Several of New Zealand's ground nesting birds, such as this flightless kiwi, are now extinct or threatened because of these predators.

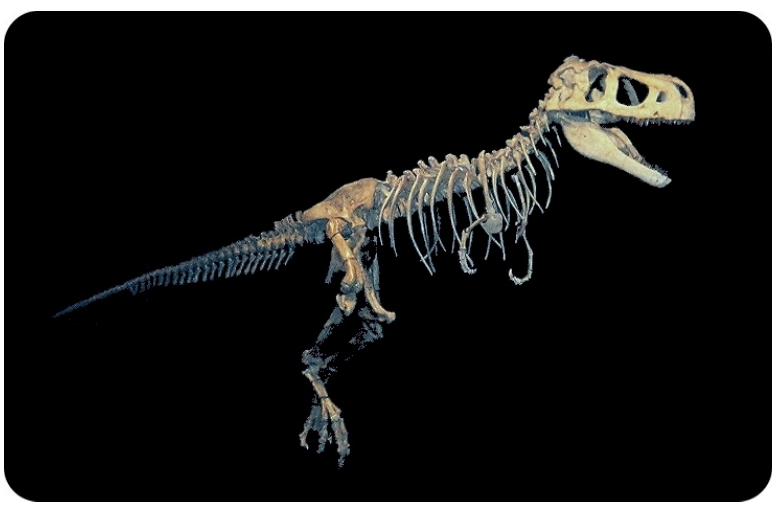


FIGURE 1.3
The fossil of Tarbosaurus, one of the land dinosaurs that went extinct during one of the mass extinctions.

a high percentage of species go extinct is rare. The total number of mass extinctions could be as high as 20. It is probable that we are currently in the midst of another mass extinction.

Two of the largest extinctions are described below:

- At the end of the Permian Period, it is estimated that about 99.5% of individual organisms went extinct! Up to 95% of marine species perished, compared to "only" 70% of land species. Some scientists theorize that the extinction was caused by the formation of **Pangaea,** or one large continent made out of many smaller ones. One large continent has a smaller shoreline than many small ones, so reducing the shoreline space may have caused much of the marine life to go extinct (**Figure** 1.4).

FIGURE 1.4
The supercontinent Pangaea encompassed all of today's continents in a single land mass. This configuration limited shallow coastal areas which harbor marine species. This may have contributed to the dramatic event which ended the Permian—the most massive extinction ever recorded.

- At the end of the Cretaceous Period, or 65 million years ago, all dinosaurs (except those which led to birds) went extinct. Some scientists believe a possible cause is a collision between the Earth and a comet or asteroid. The collision could have caused tidal waves, changed the climate, increased atmospheric dust and clouds, and reduced sunlight by 10-20%. A decrease in photosynthesis would have resulted in less plant food, leading to the extinction of the dinosaurs.

Evidence for the extinction of dinosaurs by asteroid includes an iridium-rich layer in the Earth, dated at 65.5 million years ago. Iridium is rare in the Earth's crust but common in comets and asteroids. Maybe the asteroid that hit the Earth left the iridium behind.

After each mass extinction, new species evolve to fill the habitats where old species lived. This is well documented in the fossil record.

### Further Reading

Human Causes of Extinction

### Summary

- Extinctions, when a species entirely dies out, can happen when the environment changes, and the organisms do not have the traits they need to survive.
- Since life began on Earth, there have been at least five major massive extinctions.

### Review

1. Why do species sometimes go extinct?
2. What is a mass extinction?
3. What may have caused the mass extinction that killed the dinosaurs, and what is the evidence?

87.11

# 1.3 Kinetic Energy

## Learning Objectives

- Define kinetic energy.
- Show how to calculate the kinetic energy of a moving object.


What could these four photos possibly have in common? Can you guess what it is? All of them show things that have kinetic energy.

## Defining Kinetic Energy

**Kinetic energy** is the energy of moving matter. Anything that is moving has kinetic energy—from atoms in matter to stars in outer space. Things with kinetic energy can do work. For example, the spinning saw blade in the photo above is doing the work of cutting through a piece of metal.

## Calculating Kinetic Energy

The amount of kinetic energy in a moving object depends directly on its mass and velocity. An object with greater mass or greater velocity has more kinetic energy. You can calculate the kinetic energy of a moving object with this equation:

$\text{Kinetic Energy (KE)} = \frac{1}{2}\text{mass} \times \text{velocity}^2$

This equation shows that an increase in velocity increases kinetic energy more than an increase in mass. If mass doubles, kinetic energy doubles as well, but if velocity doubles, kinetic energy increases by a factor of four. That's because velocity is squared in the equation.

Let's consider an example. The **Figure** 1.5 shows Juan running on the beach with his dad. Juan has a mass of 40 kg and is running at a velocity of 1 m/s. How much kinetic energy does he have? Substitute these values for mass and velocity into the equation for kinetic energy:

$KE = \frac{1}{2} \times 40\text{ kg} \times (1\frac{\text{m}}{\text{s}})^2 = 20\text{ kg} \times \frac{\text{m}^2}{\text{s}^2} = 20\text{ N} \cdot \text{m, or } 20\text{ J}$

Notice that the answer is given in joules (J), or N • m, which is the SI unit for energy. One joule is the amount of energy needed to apply a force of 1 Newton over a distance of 1 meter.

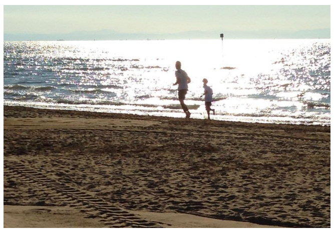


FIGURE 1.5

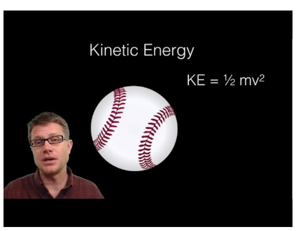
What about Juan's dad? His mass is 80 kg, and he's running at the same velocity as Juan (1 m/s). Because his mass is twice as great as Juan's, his kinetic energy is twice as great:

$KE = \frac{1}{2} \times 80\text{ kg} \times (1\frac{\text{m}}{\text{s}})^2 = 40\text{ kg} \times \frac{\text{m}^2}{\text{s}^2} = 40\text{ N} \cdot \text{m, or } 40\text{ J}$

**Q:** What is Juan's kinetic energy if he speeds up to 2 m/s from 1 m/s?

**A:** By doubling his velocity, Juan increases his kinetic energy by a factor of four:

$KE = \frac{1}{2} \times 40\text{ kg} \times (2\frac{\text{m}}{\text{s}})^2 = 80\text{ kg} \times \frac{\text{m}^2}{\text{s}^2} = 80\text{ N} \cdot \text{m, or } 80\text{ J}$

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## Summary

- Kinetic energy (KE) is the energy of moving matter. Anything that is moving has kinetic energy.
- The amount of kinetic energy in a moving object depends directly on its mass and velocity. It can be calculated with the equation: $KE = \frac{1}{2}\text{mass} \times \text{velocity}^2$.

## Review

1. What is kinetic energy?
2. The kinetic energy of a moving object depends on its mass and its
   a. volume.
   b. velocity.

c. distance.
d. acceleration.

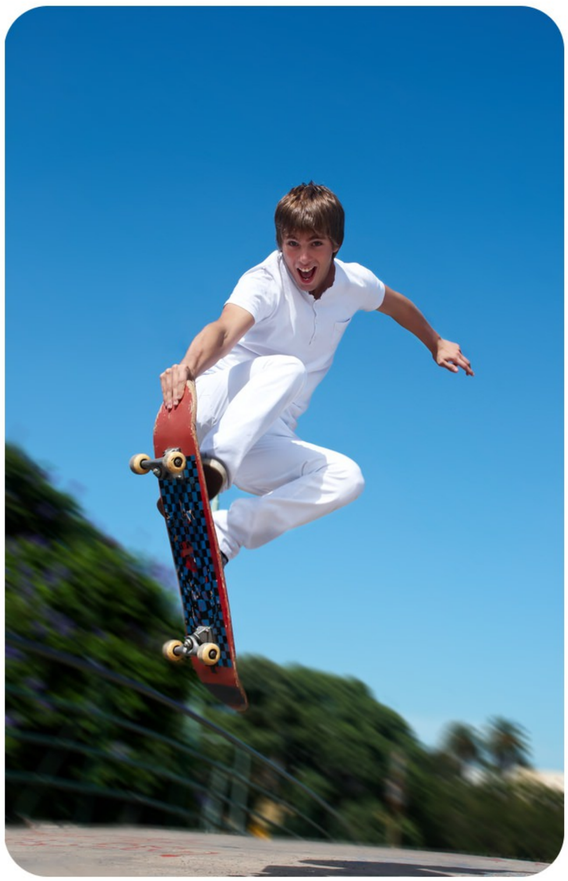
3. The bowling ball in the **Figure** 1.6 is whizzing down the bowling lane at 4.0 m/s. If the mass of the bowling ball is 7.0 kg, what is its kinetic energy?

FIGURE 1.6

# 1.4 Newton's First Law

## Learning Objectives

- Use skateboarding to explain Newton's first law of motion.



There's no doubt from Corey's face that he loves skateboarding! Corey and his friends visit Newton's Skate Park every chance they get. They may not know it, but while they're having fun on their skateboards, they're actually applying science concepts such as forces and motion.

## Starting and Stopping

Did you ever ride a skateboard? Even if you didn't, you probably know that to start a skateboard rolling over a level surface, you need to push off with one foot against the ground. That's what Corey's friend Nina is doing in this picture 1.7.

Do you know how to stop a skateboard once it starts rolling? Look how Nina's friend Laura does it in the **Figure** 1.8. She steps down on the back of the skateboard so it scrapes on the pavement. This creates friction, which stops the skateboard.

FIGURE 1.7

FIGURE 1.8

Even if Laura didn't try to stop the skateboard, it would stop sooner or later. That's because there's also friction between the wheels and the pavement. Friction is a force that counters all kinds of motion. It occurs whenever two surfaces come into contact.

MEDIA

Click image to the left or use the URL below.

### Laws of the Park: Newton's First Law

If you understand how a skateboard starts and stops, then you already know something about **Newton's first law of motion**. This law was developed by English scientist Isaac Newton around 1700. Newton was one of the greatest scientists of all time. He developed three laws of motion and the law of gravity, among many other contributions.

**Newton's first law of motion** states that an object at rest will remain at rest and an object in motion will stay in motion unless it is acted on by an unbalanced force. Without an unbalanced force, a moving object will not only keep moving, but its speed and direction will also remain the same. Newton's first law of motion is often called the law of inertia because 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 an object is already in motion, inertia will keep it moving.

### Do You Get It?

**Q**: How does Nina use Newton's first law to start her skateboard rolling?

**A**: The skateboard won't move unless Nina pushes off from the pavement with one foot. The force she applies when she pushes off is stronger than the force of friction that opposes the skateboard's motion. As a result, the force on the skateboard is unbalanced, and the skateboard moves forward.

**Q**: How does Nina use Newton's first law to stop her skateboard?

**A**: Once the skateboard starts moving, it would keep moving at the same speed and in the same direction if not for another unbalanced force. That force is friction between the skateboard and the pavement. The force of friction is unbalanced because Nina is no longer pushing with her foot to keep the skateboard moving. That's why the skateboard stops.

## Changing Direction

FIGURE 1.9

Corey's friend Jerod likes to skate on the flat banks at Newton's Skate Park. That's Jerod in the **Figure** 1.9. As he reaches the top of a bank, he turns his skateboard to go back down. To change direction, he presses down with his heels on one edge of the skateboard. This causes the skateboard to turn in the opposite direction.

### Do You Get It?

**Q**: How does Jerod use Newton's first law of motion to change the direction of his skateboard?

**A**: Pressing down on just one side of a skateboard creates an unbalanced force. The unbalanced force causes the skateboard to turn toward the other side. In the picture, Jerod is pressing down with his heels, so the skateboard turns toward his toes.

## Summary

- Newton's first law of motion states that an object at rest will remain at rest and an object in motion will remain in motion unless it is acted on by an unbalanced force.
- Using unbalanced forces to control the motion of a skateboard demonstrates Newton's first law of motion.

## Review

1. State Newton's first law of motion.
2. You don't need to push off with a foot against the ground to start a skateboard rolling down a bank. Does this violate Newton's first law of motion? Why or why not?

FIGURE 1.10

3. Nina ran into a rough patch of pavement, but she thought she could ride right over it. Instead, the skateboard stopped suddenly and Nina ended up on the ground (see **Figure** 1.10). Explain what happened.
4. Now that you know about Newton's first law of motion, how might you use it to ride a skateboard more safely?

# 1.5 Newton's Second Law

## Learning Objectives

- State Newton's second law of motion.
- Compare and contrast the effects of force and mass on acceleration.

These boys are racing around the track at Newton's Skate Park. The boy who can increase his speed the most will win the race. Tony, who is closest to the camera in this picture, is bigger and stronger than the other two boys, so he can apply greater force to his skates.

**Q**: Does this mean that Tony will win the race?

**A**: Not necessarily, because force isn't the only factor that affects acceleration.

## Force, Mass, and Acceleration

Whenever an object speeds up, slows down, or changes direction, it accelerates. Acceleration occurs whenever an unbalanced force acts on an object. Two factors affect the acceleration of an object: the net force acting on the object and the object's mass. **Newton's second law of motion** describes how force and mass affect acceleration. The 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:

$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}$

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

**Q**: While Tony races along on his rollerblades, what net force is acting on the skates?

**A**: Tony exerts a backward force against the ground, as you can see in the **Figure** 1.11, first with one skate and then with the other. This force pushes him forward. Although friction partly counters the forward motion of the skates, it is weaker than the force Tony exerts. Therefore, there is a net forward force on the skates.

FIGURE 1.11

Watch the video below to learn more about Newton's second law and the relationship between force, mass, and acceleration: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Click image to the left or use the URL below.

## 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 is different. It is an inverse relationship. In an inverse relationship, when one variable increases, the other variable decreases. 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.

**Q**: Tony has greater mass than the other two boys he is racing (pictured in the opening image). How will this affect his acceleration around the track?

**A**: Tony's greater mass will result in less acceleration for the same amount of force.

## Summary

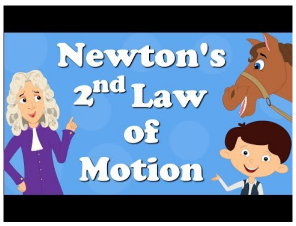
- Newton's second law of motion states that the acceleration of an object equals the net force acting on the object divided by the object's mass.
- According to the second law, there is a direct relationship between force and acceleration and an inverse relationship between mass and acceleration.

### Review

1. State Newton's second law of motion.
2. How can Newton's second law of motion be represented with an equation?
3. If the net force acting on an object doubles, how will the object's acceleration be affected?
4. Tony has a mass of 50 kg, and his friend Sam has a mass of 45 kg. Assume that both friends push off on their rollerblades with the same force. Explain which boy will have greater acceleration.

### Explore More

Use this resource to answer the questions that follow:

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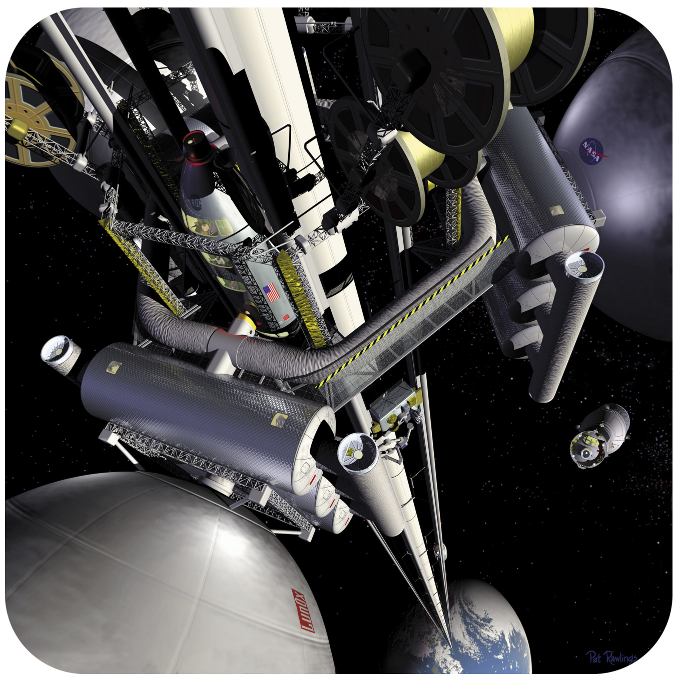
Click image to the left or use the URL below.

1. How is force proportional to acceleration?
2. How is force proportional to mass?

# 1.6 Newton's Third Law

## Learning Objectives

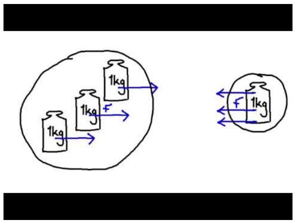
- Explain Newton's Third Law of Motion
- Understand the theory of equal and opposite forces



The image above is a NASA artist's conceptual illustration of a space elevator. It was imagined as a geo-stationary transfer station for passengers and cargo between Earth and space. This idea was not pursued beyond the initial discussion and evaluation stage, but the scientists involved believe the concept will become truly possible with the expected technological advances of the late $21^{st}$ century.

## Newton's Third Law of Motion

Where do forces come from? Observations suggest that a force applied to an object is always applied by another object. A hammer strikes a nail, a car pulls a trailer, and a person pushes a grocery cart. Newton realized that forces are not so one-sided. When the hammer exerts a force on the nail, the nail also exerts a force on the hammer—after all, the hammer comes to rest after the interaction. This led to **Newton's Third Law of Motion**, which states that whenever one object exerts a force on a second object, the second object also exerts a force on the first object, equal in magnitude and opposite in direction.



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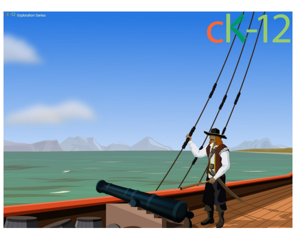
This law is sometimes paraphrased as: "For every action, there is an equal and opposite reaction." A very important point to remember is that the two forces are on different objects—never on the same object. It is frequently the case that one of the objects moves as a result of the force applied but the motion of the other object in the opposite direction is not apparent.

Consider the situation where an ice skater is standing at the edge of the skating rink holding on to the side rail. If the skater exerts a force on the rail, the rail is held in place with tremendous friction and therefore, will not move in any noticeable way. The skater, on the other hand, had little friction with the ice, and therefore will be accelerated in the direction opposite of her original push. This is the process people use to jump up into the air. The person's feet exert force on the ground and the ground exerts an equal and opposite force on the person's feet. The force on the feet is sufficient to raise the person off the ground. The force on the ground has little effect because the Earth is so large. One of the accelerations is visible but the other is not visible.

A case where the reaction motion due to the reaction force is visible is the case of a person throwing a heavy object out of a small boat, such as a kayak. The object is accelerated in one direction and the boat is accelerated in the opposite direction. In this case, both the motion of the object is visible and the motion of the boat in the opposite direction is also visible. Explore the resulting motion of two interacting objects as a result of Newton's Third Law in this Pirate Ship simulation below:



SIMULATION

Click image to the left or use the URL below.

URL: https://romer.ck12.org/physics/newtons-third-law/simulationint/Pirate-Ship

Rockets also work in this manner. It is a misconception that the rocket moves forward because the escaping gas pushes on the ground or the surrounding air to make the rocket go forward. Rockets work in outer space where there is no ground or surrounding air. The rocket exerts a force on the gases causing them to be expelled and the gases exert a force on the rocket causing it to be accelerated forward.

The applications of Newton's Third Law can also be explored in the classic example if a horse pulling a cart. How does the horse-cart system move if the cart pulls on the horse with the same exact force and in the opposite direction as the horse pulls on the cart? (Beware, there are many misconceptions related to this example! Always remember that Newton's Third Law applies to the same ***type*** of force acting on different objects).

SIMULATION

Learn about Newtonś Third Law force calculations in two dimensions and the interaction of multiple objects in the context of a horse pulling a cart.

URL: https://romer.ck12.org/physics/free-body-diagrams/simulationint/Horse-And-Cart

## Summary

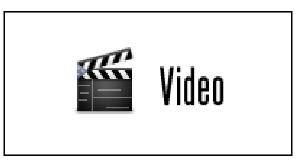
- A force applied to an object is always applied by another object.
- Newton's Third Law of Motion states, "Whenever one object exerts a force on a second object, the second object also exerts a force on the first object, equal in magnitude and opposite in direction."

## Review

1. What is wrong with the following statement: When you exert a force on a baseball, the equal and opposite force on the ball balances the original force and therefore, the ball will not accelerate in any direction.
2. When a bat strikes a ball, the force exerted can send the ball deep into the outfield. Where is the equal and opposite force in this case?
3. Suppose you wish to jump horizontally and in order for you to jump a distance of 4 feet horizontally, you must exert a force of 200 N. When you are standing on the ground, you have no trouble jumping 4 feet horizontally. If you are standing in a canoe, however, and you need to jump 4 feet to reach the pier, you will surely fall into the lake. Why is it that you cannot jump 4 feet out of a canoe when you can easily do this when on land?

## Explore More

Use the resource below to answer the questions that follow.




MEDIA

Click image to the left or use the URL below.

1. What does the bottle rocket have to do with Newton's Third Law of Motion?

## Vocabulary

- **Newton's Third Law of Motion:** Whenever one object exerts a force on a second object, the second object also exerts a force on the first object, equal in magnitude and opposite in direction.

# 1.7 Collision Theory

## Learning Objectives

- Define collision theory.

### Oops!

Car damage can be very expensive, especially if the person hitting your car does not have insurance. Many people have had the experience of backing up while parallel parking and hearing that "bump". Fortunately, there is often no damage because the cars were not going fast enough. But every once in a while there is a rearrangement of the body parts of a car when it is hit with sufficient speed. Then things need to be fixed.

## Collision Theory

The behavior of the atoms, molecules, or ions that comprise the reactants is responsible for the rates of a given chemical reaction. **Collision theory** is a set of principles that states that the reacting particles can form products when they collide with one another provided those collisions have enough kinetic energy and the correct orientation. Particles that lack the necessary kinetic energy may collide, but the particles will simply bounce off one another unchanged. The figure below illustrates the difference. In the first collision, the particles bounce off one another and no rearrangement of atoms has occurred. The second collision occurs with greater kinetic energy, and so the bond between the two red atoms breaks. One red atom bonds with the other molecule as one product, while the single red atom is the other product. The first collision is called an **ineffective collision**, while the second collision is called an **effective collision**.

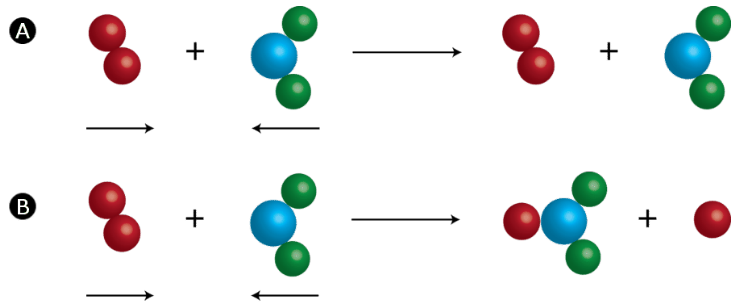
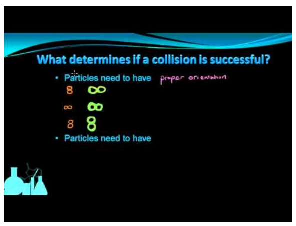



FIGURE 1.12
An ineffective collision (A) is one that does not result in product formation. An effective collision (B) is one in which chemical bonds are broken and a product is formed.




MEDIA
Click image to the left or use the URL below.

## Summary

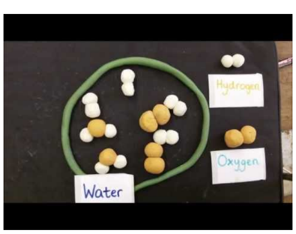
- Collision theory explains how materials can collide and become new materials.

## Review

1. How does a chemical reaction occur?
2. What are two requirements for collision to form a product?
3. Two molecules collide and then bounce off of one another. What kind of collision is that?

## Explore More

Use the resource below to answer the questions that follow.

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Click image to the left or use the URL below.

1. What were the reactants?
2. What was the product?
3. What did the match do?

## Vocabulary

- **collision theory:** A set of principles that states that the reacting particles can form products when they collide with one another, provided those collisions have enough kinetic energy and the correct orientation.
- **effective collision:** Bonds break between atoms.
- **ineffective collision:** No rearrangement of atoms occurs.

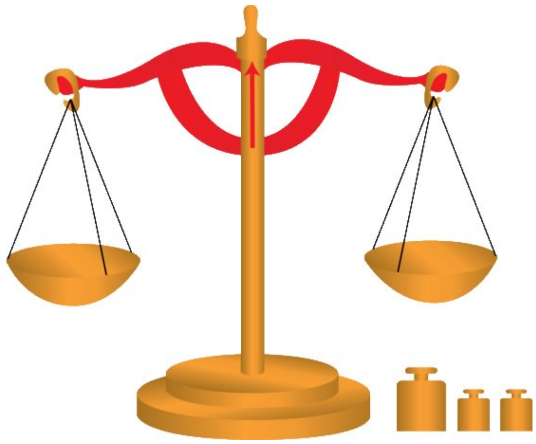
# 1.8 Mass vs Weight

- Distinguish between mass and weight.
- Given the acceleration due to gravity and either the mass or the weight of an object, calculate the other one.

Astronauts in training often fly in the KC-135 training aircraft to experience near-weightlessness. Three Japan Aerospace Exploration Agency astronauts—Akihiko Hoshide, Satoshi Furukawa, and Naoko Yamazaki—are shown here during such an exercise. Though they experience near-weightlessness, we can see that their mass has not changed. What is the relationship between mass and weight?

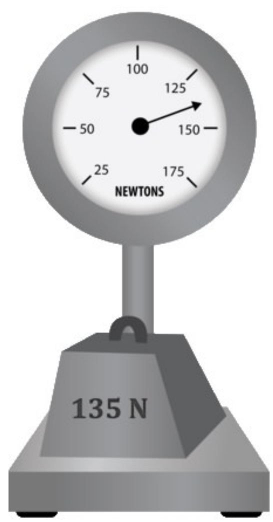
## Mass and Weight

The **mass** of an object is defined as the amount of matter in the object. The amount of mass an object has does not change; a moon rock that has been returned to Earth has the same mass on the Earth's surface as it had on the moon. The amount of mass in an object is measured by comparing the object to known masses on an instrument called a balance.



Using the balance shown here, the object would be placed in one pan and known masses would be placed in the other pan until the pans were exactly balanced. When balanced, the mass of the object would be equal to the sum of the known masses in the other pan. A balance will work in any location; whether on the moon or on Earth, the moon rock mentioned earlier will have the same mass.

The **weight** of an object is the force pulling the object downward. On Earth, this would be the gravitational force of the Earth on the object. On the moon, this would be the gravitational force of the moon on the object. The gravitational force of the moon is one-sixth the magnitude of the gravitational force of the Earth; the weight of the moon rock on the moon will be one-sixth the weight of the moon rock on the Earth's surface. Weight is measured in force units—newtons—by a calibrated spring scale as shown here.




The force of gravity is given by Newton's Second Law, $F = ma$, where $F$ is the force of gravity in newtons, $m$ is the mass of the object in kilograms, and $a$ is the acceleration due to gravity, 9.81 m/s$^2$. When the formula is used specifically for finding weight from mass or vice versa, it may appear as $W = mg$.

**Example Problem:** What is the weight of an object sitting on the Earth's surface if the mass of the object is 43.7 kg?

**Solution:** $W = mg = (43.7 \text{ kg})(9.81 \text{ m/s}^2) = 429 \text{ N}$

**Example Problem:** What is the mass of an object whose weight sitting on the Earth is 2570 N?

$m = \frac{W}{a} = \frac{2570 \text{ N}}{9.81 \text{ m/s}^2} = 262 \text{ kg}$

### Summary

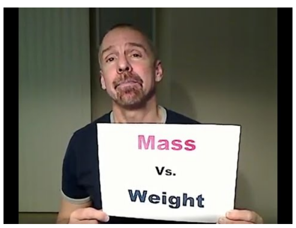
- The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- Mass is determined by comparing an object to known masses on a balance.
- The weight of an object on the Earth is defined as the force acting on the object by the Earth's gravity.
- Weight is measured by a calibrated spring scale.
- The formula relating mass and weight is $W = mg$.

### Practice

*Questions*

A song about the difference between mass and weight sung by Mr. Edmunds to the tune of Sweet Caroline. Remember to make allowances for the fact that he is a teacher, not a professional singer. Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=1whMAIGNq7E




MEDIA

Click image to the left or use the URL below.

1. What is used to measure mass?
2. What is used to measure weight?
3. What units are used to measure mass?
4. What units are used to measure weight?

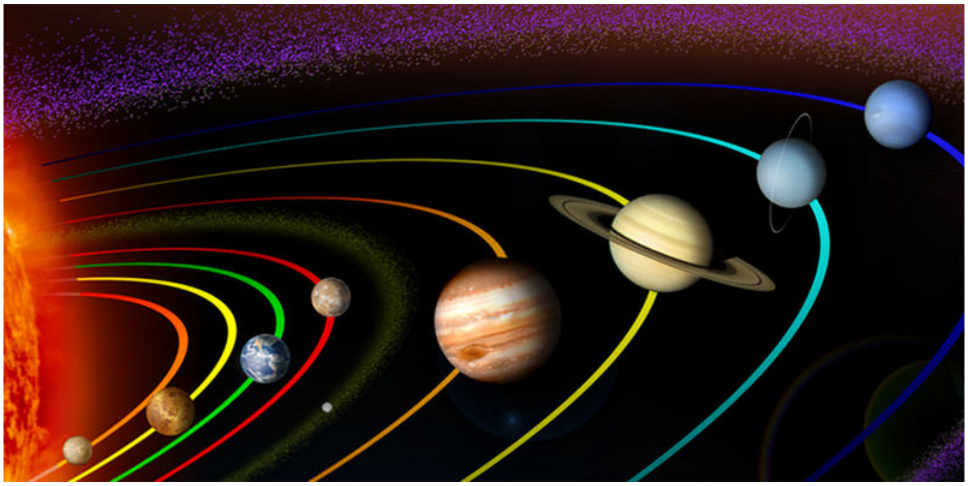
### Review

*Questions*

1. The mass of an object on the Earth is 100. kg.
   a. What is the weight of the object on the Earth?
   b. What is the mass of the object on the moon?
   c. Assuming the acceleration due to gravity on the moon is exactly one-sixth of the acceleration due to gravity on Earth, what is the weight of the object on the moon?
2. A man standing on the Earth can exert the same force with his legs as when he is standing on the moon. We know that the mass of the man is the same on the Earth and the moon. We also know that $F = ma$ is true on both the Earth and the moon. Will the man be able to jump higher on the moon than the Earth? Why or why not?

- **mass:** The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- **weight:** The weight of an object on the earth is defined as the force acting on the object by the earth's gravity.

# 1.9 Gravity



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. 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.

### Defining Gravity

**Gravity** has traditionally been defined as a force of attraction between things that have mass. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. Gravity can act between objects that are not even touching. In fact, gravity can act over very long distances. However, the farther two objects are from each other, the weaker is the force of gravity between them. Less massive objects also have less gravity than more massive objects.

### 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 that are 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 and the other planets moving around the much more massive sun.

**Q**: There is a force of gravity between Earth and you and also between you and all the objects around you. When you drop a paper clip, why doesn't it fall toward you instead of toward Earth?

**A**: Earth is so much more massive than you that its gravitational pull on the paper clip is immensely greater.

### Gravity and Weight

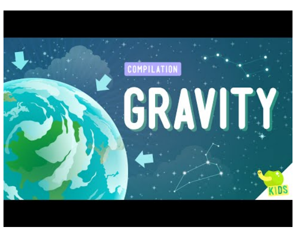
Weight measures the force of gravity pulling downward on an object. The SI unit for weight, like other forces, is the Newton (N). On Earth, a mass of 1 kilogram has a weight of about 10 Newtons because of the pull of Earth's gravity.

Money hangs below this hand-held scale. It is pulled downwards by gravity. The scale measures the strength of that pull.

FIGURE 1.13

On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale shown in the **Figure** 2.14. The scale measures the force with which gravity pulls an object downward.

Watch the video below to learn more about gravity and factors that influence the strength of gravity between two objects:




MEDIA

Click image to the left or use the URL below.

## Summary

- Gravity has traditionally been defined as a force of attraction between things that have mass. The strength of gravity between two objects depends on their mass and their distance apart.
- Earth's gravity constantly pulls matter toward the center of the planet. It also keeps moons and satellites orbiting Earth and Earth orbiting the sun.
- Weight measures the force of gravity pulling on an object. The SI unit for weight is the Newton (N).

## Vocabulary

1. What is the traditional definition of gravity?
2. Identify factors that influence the strength of gravity between two objects.
3. Define weight. What is the SI unit for weight?
4. Explain why an astronaut would weigh less on the moon than on Earth.

### Vocabulary

**Gravity** is a force of attraction between things that have mass.

# 1.10 Gravity in the Solar System

## Learning Objectives

- Define gravity.
- Explain how mass and distance influence the gravitational attraction between two objects.

### Did you ever hear the old adage, "What goes up must come down"?

Every moment of every day is a field trip to gravity. Gravity is everywhere! You have a gravitational attraction to your dog. You have one to your pencil. You even have one to your school principal! These gravitational attractions are very small compared with the most important one you have. This is your gravitational attraction to Earth. It's what keeps you from floating off into space. Gravity holds our planet together. Gravity keeps Earth orbiting the Sun. We wouldn't be here without gravity.

## The Role of Gravity

All objects in the universe have an attraction to each other. This attraction is known as **gravity** (**Figure** 1.14). The strength of the force of gravity depends on two things. One is the mass of the objects. The other is the distance between the objects. As an object's mass increases, the attraction increases. As the distance between the objects increases, the attraction decreases.

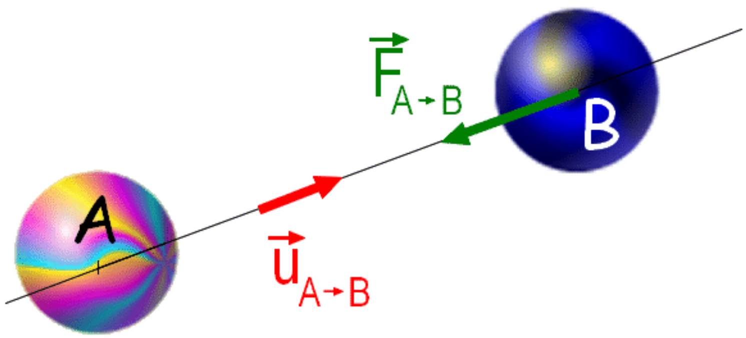



FIGURE 1.14
The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (*u*) between them.

Isaac Newton first described gravity as the force that causes objects to fall to the ground. Gravity is also the force that keeps the Moon circling Earth. Gravity keeps Earth circling the Sun. Without gravity, these objects would fly off into space (**Figure** 1.15).

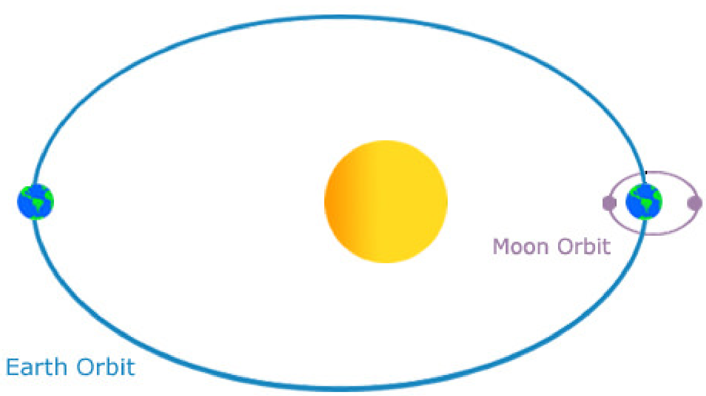



FIGURE 1.15
The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

Gravity pulls any object on or near Earth toward the planet's center.

## Summary

- All objects have a gravitational attraction to each other. This is called gravity.
- The attraction is proportional to the mass of the objects. The attraction is inversely proportional to the distance between the objects.
- Gravity keeps the Moon orbiting Earth. Gravity keeps the planets orbiting the Sun.

## Review

1. For which object is the force of gravity greatest: Earth, Moon, or Sun? Why?
2. Imagine that the Moon and the Sun are the same distance from Earth. Which one would Earth be gravitationally attracted to?
3. What is gravity?

## Explore More

Use the resource below to answer the questions that follow.


MEDIA

Click image to the left or use the URL below.

1. Who was Isaac Newton?
2. What did Newton discover?
3. How did Newton make his discovery?

# 1.11 References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# CHAPTER 2 Unit 2: Traveling Through Space

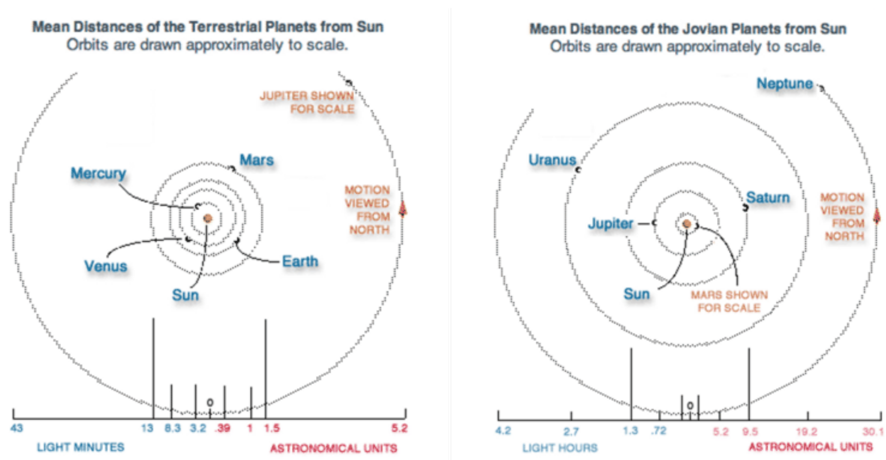
## Chapter Outline


2.1 PLANETS OF THE SOLAR SYSTEM
2.2 THE SUN-EARTH-MOON SYSTEM
2.3 LUNAR ECLIPSES
2.4 SOLAR ECLIPSES
2.5 MASS VS WEIGHT
2.6 EARTH AS A MAGNET
2.7 WHY EARTH IS A MAGNET
2.8 GRAVITY
2.9 REFERENCES

# 2.1 Planets of the Solar System

## Learning Objectives

- Define astronomical unit.
- Describe the solar system's eight planets.




### Can humans take a field trip through the solar system?

A field trip through the solar system would take a long time. It took 12 years for the Voyager spacecraft to get from Earth to Neptune. If a human was on board, he or she would probably want to come back! Fortunately, unmanned spacecrafts can send back images of far distant places in the solar system.

## Solar System Objects

Astronomers now recognize eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects (**Figure** 2.1). These objects move in regular and predictable paths around the Sun.

### Planet Sizes

The Sun is just an average star compared to other stars. But it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Listed below is data on the sizes of the Sun and planets relative to Earth (**Table** 2.1).

TABLE 2.1: Sizes of Solar System Objects Relative to Earth

| Object | Mass (relative to Earth) | Diameter (relative to Earth) |
|---|---|---|
| Sun | 333,000 | 109.2 |
| Mercury | 0.06 | 0.39 |
| Venus | 0.82 | 0.95 |

**TABLE 2.1:** (continued)

| Object | Mass (relative to Earth) | Diameter (relative to Earth) |
|---|---|---|
| Earth | 1.00 | 1.00 |
| Mars | 0.11 | 0.53 |
| Jupiter | 317.8 | 11.21 |
| Saturn | 95.2 | 9.41 |
| Uranus | 14.6 | 3.98 |
| Neptune | 17.2 | 3.81 |

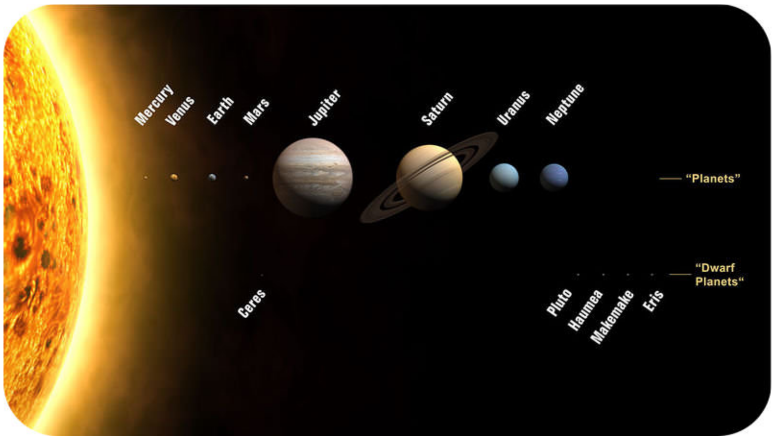



FIGURE 2.1
Relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are to scale. The relative distances are not to scale.

### Distances in the Solar System

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km (93 million miles). Listed below is the distance from the Sun to each planet in AU (**Table** 2.2). The table shows how long it takes each planet to spin once on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

TABLE 2.2: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

| Planet | Average Distance from Sun (AU) | Length of Day (in Earth days) | Length of Year (in Earth years) |
|---|---|---|---|
| Mercury | 0.39 | 56.84 | 0.24 |
| Venus | 0.72 | 243.02 | 0.62 |
| Earth | 1.00 | 1.00 | 1.00 |
| Mars | 1.52 | 1.03 | 1.88 |
| Jupiter | 5.20 | 0.41 | 11.86 |
| Saturn | 9.54 | 0.43 | 29.46 |
| Uranus | 19.22 | 0.72 | 84.01 |
| Neptune | 30.06 | 0.67 | 164.8 |

### The Size and Shape of Orbits

**Figure** 2.2 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical (**Figure** 2.2).

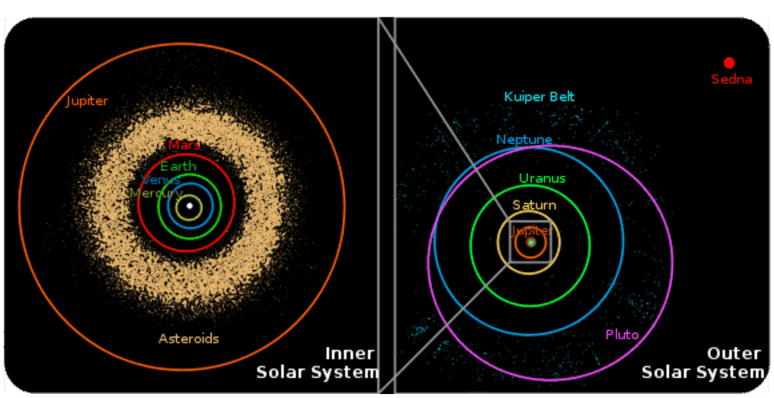


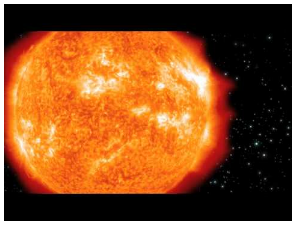

FIGURE 2.2
The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

## Review

1. What are the names of the planets and dwarf planets?
2. Where are the most massive planets? Where are the least massive planets?
3. What is an astronomical unit? Why is this unit used to measure distances in the solar system?

## Explore More

Use the resource below to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

1. What did early astronomers believe about planet Earth?
2. How many planets did early astronomers know about?
3. What did Kepler discover?
4. How did our solar system form?
5. How many planets are in the solar system?
6. What is the Kuiper belt?
7. What is the Oort cloud?
8. What is found in the Oort cloud?
9. What is the outer boundary of the solar system?
10. Why are scientists interested in the other planets?

# 2.2 The Sun-Earth-Moon System

## Lesson Objectives

- Explain solar and lunar eclipses. (Advanced Topic)
- Describe the phases of the Moon and explain why they occur.

## Lesson Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- solar eclipse
- umbra

## Introduction

One pattern in the sky is well known to us. Every morning, the Sun rises above the eastern horizon. Throughout the day, the Sun moves across the sky from East to West. Every night the Sun sets, or goes down, in the Western sky.

Every month, you can see the Moon change. This is due to where it is relative to the Sun and Earth. This change occurs gradually through the month. The Moon is sometimes very bright and full. A week later, only part of it can be seen. Two weeks after the full Moon, the Moon cannot be seen at all. Over the course of the next two weeks, the Moon becomes more visible. This continues until it is full again. Are there some other differences you have noticed?

## Day and Night Cycle

Every morning you are greeted by the Sun's rise above the horizon. Unless it is cloudy, the Sun is visible throughout the day. In the evening, the Sun disappears over the horizon. How is this like the Moon? Is the Moon always out at night? Can it be seen every night, just like the Sun is present every day?

Unlike the Sun, the Moon's presence in the sky is not as simple. The Moon travels once around the Earth every month. Depending on its position, it can be seen all night long, part of the night, or not at all. It can sometimes even be seen during the daylight hours. How can you predict when the Moon is visible? When the Moon is visible and how it looks in the night sky are related.

## The Phases of the Moon

Unlike the Sun, the Moon does not produce any light of its own. It only reflects light from the Sun. Only the side of the Moon facing the Sun is lit. As the Moon moves around the Earth, we see different parts of the Moon being lit up by the Sun. This is what causes the phases of the Moon. As the Moon revolves around Earth, it changes from fully lit to completely dark and back again. If you were out in space, you would see that half of the Moon is always in sunlight. Half the Moon is always in darkness, just like our Earth. When we see the Moon's different phases, you are actually looking at the Moon's day and night.

When the Moon moves between Earth and the Sun, the side facing Earth is completely dark. Only the side of the Moon facing away from Earth is lit. This is called the **new Moon** phase. So why can we sometimes see the whole Moon in the daytime sky? At times, you can just barely make out the outline of the new Moon in the sky. This is because some sunlight reflects off the Earth and back to the Moon. This is how you can see the Moon during the daylight hours.

About one week later, the Moon enters the quarter-Moon phase. Like always, one side of the Moon is completely lit by the Sun. What has changed is the Moon's position with respect to Earth. We are only able to see half of that half lit portion. Scientists call this lunar phase the quarter-Moon phase. As a result, we see the Moon as a half-circle. The Moon is now one-quarter of its way through its Earth's orbit.

After the passing of another week, a full Moon occurs as the whole side facing Earth is lit. This happens when Earth is between the Moon and the Sun. If you were able to travel out into space, you could see that the half of the Moon facing away from Earth is not being lit. The entire side facing Earth is being lit by the Sun.

With the passing of another week, the Moon is now 3/4 of the way around its orbit. Just like after the full Moon, we can see only half of the half lit portion of the Moon.

Finally, in one more week, the Moon is back to its new Moon phase and cannot be seen in the nighttime sky.

Before and after the quarter-Moon phases are the gibbous and crescent phases. During the **crescent** Moon phase, the Moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** Moon phase, the Moon is more than half lit. It is not full. The Moon undergoes a complete cycle of phases about every 29.5 days.

In **Figure** 2.3, assume the Sun is toward the top of the picture. The bottom of the image is away from the Sun.

FIGURE 2.3
The Moon's phases are a result of the Moon's orbit around Earth.

### Solar Eclipses (Advanced Topic)

When a new Moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** 2.9). Eclipses do not always happen when this occurs. It only happens when the positions are just right. At those times, the Moon casts a shadow on the Earth. When this happens, it blocks our view of the Sun. This happens only when all three are lined up and in the same plane. This plane, or path, is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun. Solar eclipses only happen on rare occurrences.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.

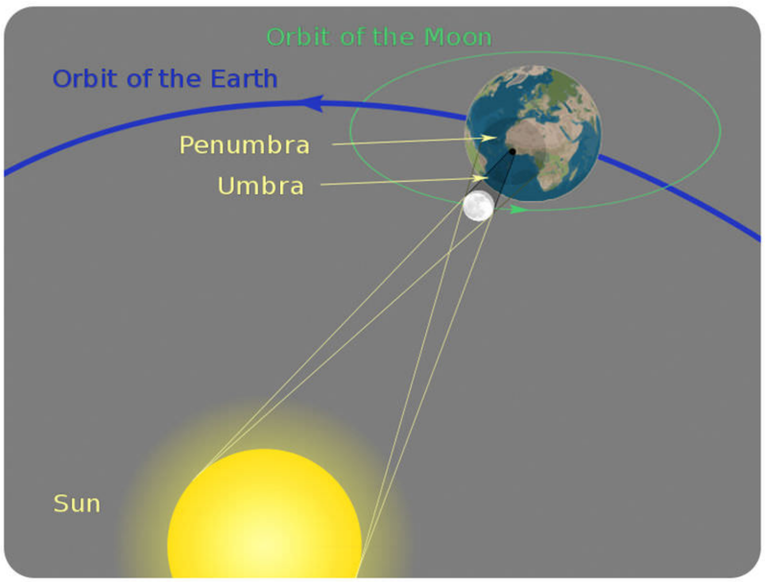



FIGURE 2.4
During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** 2.5). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth. It is also because the Earth is turning very rapidly and the shadow passes quickly.

Solar eclipses are amazing to experience. Imagine it gets dark right in the middle of the day. Birds may even start to sing as they do at dusk. Stars become visible in the sky. It will even feel cooler. Unlike at night, the Sun is out. So during a solar eclipse, you can see the very outer part of the Sun called the corona.

### A Lunar Eclipse (Advanced Topic)

Sometimes a full Moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** 2.8). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours. Anyone with a view of the Moon can see a lunar eclipse. So unlike a solar eclipse, it doesn't get dark on Earth. Instead it gets dark on the Moon.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse.

FIGURE 2.5
A photo of a total solar eclipse.

FIGURE 2.6
A lunar eclipse is shown in a series of pictures.

### Lesson Summary

- The appearance of the Moon from Earth has distinct phases.
- A full Moon is completely lit; a new Moon is completely dark.
- A gibbous Moon is more than half lit; a crescent Moon is less than half lit.
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.
- When the new Moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced. (Advanced)
- When the Earth comes between the full Moon and the Sun along the ecliptic, a lunar eclipse occurs. (Advanced)
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.

## Lesson Review Questions

1. Describe how the Sun, Moon, and Earth are aligned during a full Moon.
2. Describe how the Sun, Moon, and Earth are aligned during a new Moon.
3. Draw and label pictures of the Moon in its phases.

### Apply Concepts

4. Why do lunar eclipses happen more often and last longer than solar eclipses?
5. The same side of the Moon always faces Earth. What would Earth be like if its same side always faced the Sun?

### Think Critically

6. Why is it a different time in San Francisco and in Denver? Why is the time different in Denver and Chicago? What would things be like if the entire United States decided to have all places be the same time always?
7. People think that Earth's season are caused by its elliptical orbit around the Sun. Explain why this is not so.

## Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

## External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://eclipse.gsfc.nasa.gov/solar.html

http://www.youtube.com/watch?v=nXseTWTZlks

# 2.3 Lunar Eclipses

## Learning Objectives

- Describe lunar eclipses.

### Can you see a lunar eclipse?

Again, of course! Anyone with a view of the Moon can see a lunar eclipse. The next four total lunar eclipses predicted for North America will be on January 20, 2019, May 26, 2021, May 15, 2022, and November 8, 2022.

## Lunar Eclipses

Sometimes a full moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** 2.7). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse (**Figure** 2.8).

Check out the video below for more information about the super blue moon which occurred on January 31, 2018 which had an added bonus of a lunar eclipse.

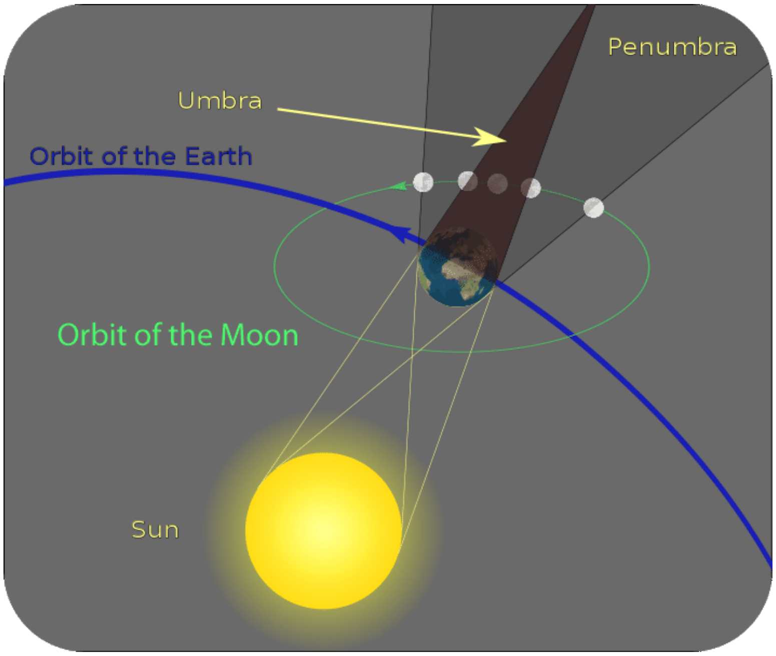
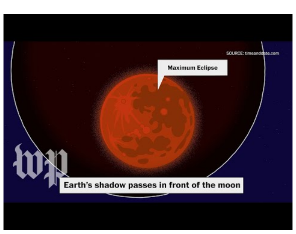



FIGURE 2.7
A lunar eclipse.

FIGURE 2.8
A lunar eclipse is shown in a series of pictures.




MEDIA
Click image to the left or use the URL below.

## Summary

- During a lunar eclipse, the full moon moves through Earth's shadow.
- Earth's shadow is large so lunar eclipses last longer than solar eclipses. They cover more area too.

- The umbra is the part of the shadow in which light is completely blocked.
- The penumbra is the part of the shadow that is partially lit.

## Review

1. What causes a lunar eclipse?
2. Why are you more likely to see a lunar eclipse than a solar eclipse?
3. When does a lunar eclipse occur?

# 2.4 Solar Eclipses

## Learning Objectives

- Describe solar eclipses.

### Can you see a solar eclipse?

Of course! This photo of a partial solar eclipse was taken on May 20, 2012 in Gilbert, Arizona. The maximum was 82% at that location. Further north people experienced totality. Much of the United States experienced a total solar eclipse on January 31, 2017. The next total solar eclipse in North America is April 8, 2024 and will be visible in the US from Texas to Maine. If you try to view an eclipse, be sure to use eye protection!

### Solar Eclipses

When a new moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** 2.9). The Moon casts a shadow on the Earth and blocks our view of the Sun. This only happens if all three are lined up and in the same plane. This plane is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.

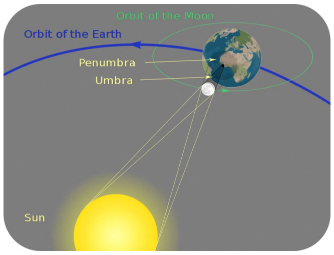



FIGURE 2.9
During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** 2.10). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth, and Earth is turning very rapidly.

Solar eclipses are amazing to experience. The light disappears so that it's like night, only strange. Birds may sing as they do at dusk. Stars become visible in the sky. It gets colder outside. Unlike at night, though, the Sun is out. So during a solar eclipse, it's easy to see the Sun's corona and solar prominences.

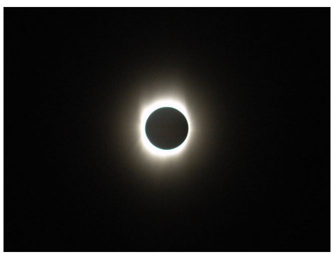


FIGURE 2.10
A photo of a total solar eclipse.

## Summary

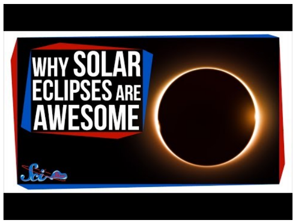
- During a solar eclipse, the new moon passes between Earth and Sun.
- The umbra is the part of the shadow in which light is completely blocked.
- The penumbra is the part of the shadow that is partially lit.

## Review

1. What is a solar eclipse?
2. What causes a solar eclipse?
3. What is the relationship of the umbra and the penumbra?

## Explore More

Use this resource to answer the questions that follow.




MEDIA

Click image to the left or use the URL below.

1. What happens during a solar eclipse? What happens during a total solar eclipse?
2. What can scientists learn during total solar eclipses that they can't otherwise learn?
3. How do we know that the corona is hotter than the Sun's surface?
4. How did a total eclipse prove Einstein's general theory of relativity?
5. What do you need to do to see a total eclipse? How long does it last?
6. What safety precautions do you need to follow before you view an eclipse?
7. When is the next total solar eclipse in North America?

## Review

1. What is a solar eclipse?
2. What causes a solar eclipse?
3. What is the relationship of the umbra and the penumbra?

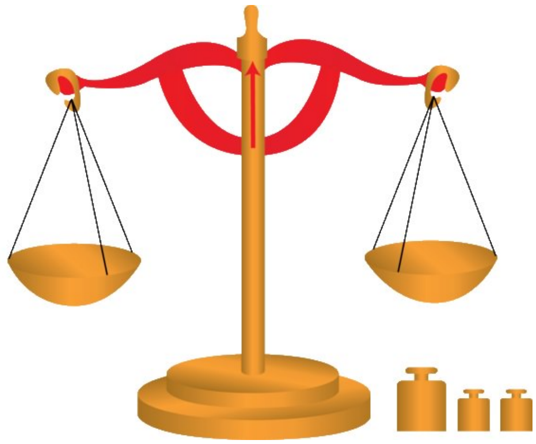
# 2.5 Mass vs Weight

- Distinguish between mass and weight.
- Given the acceleration due to gravity and either the mass or the weight of an object, calculate the other one.

Astronauts in training often fly in the KC-135 training aircraft to experience near-weightlessness. Three Japan Aerospace Exploration Agency astronauts—Akihiko Hoshide, Satoshi Furukawa, and Naoko Yamazaki—are shown here during such an exercise. Though they experience near-weightlessness, we can see that their mass has not changed. What is the relationship between mass and weight?

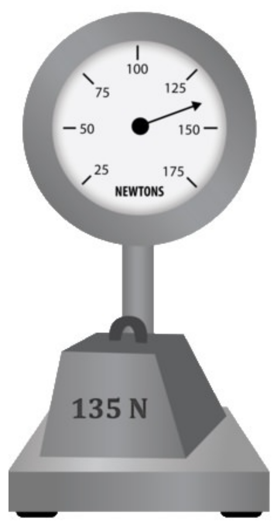
## Mass and Weight

The **mass** of an object is defined as the amount of matter in the object. The amount of mass an object has does not change; a moon rock that has been returned to Earth has the same mass on the Earth's surface as it had on the moon. The amount of mass in an object is measured by comparing the object to known masses on an instrument called a balance.



Using the balance shown here, the object would be placed in one pan and known masses would be placed in the other pan until the pans were exactly balanced. When balanced, the mass of the object would be equal to the sum of the known masses in the other pan. A balance will work in any location; whether on the moon or on Earth, the moon rock mentioned earlier will have the same mass.

The **weight** of an object is the force pulling the object downward. On Earth, this would be the gravitational force of the Earth on the object. On the moon, this would be the gravitational force of the moon on the object. The gravitational force of the moon is one-sixth the magnitude of the gravitational force of the Earth; the weight of the moon rock on the moon will be one-sixth the weight of the moon rock on the Earth's surface. Weight is measured in force units—newtons—by a calibrated spring scale as shown here.




The force of gravity is given by Newton's Second Law, $F = ma$, where $F$ is the force of gravity in newtons, $m$ is the mass of the object in kilograms, and $a$ is the acceleration due to gravity, 9.81 m/s$^2$. When the formula is used specifically for finding weight from mass or vice versa, it may appear as $W = mg$.

**Example Problem:** What is the weight of an object sitting on the Earth's surface if the mass of the object is 43.7 kg?

**Solution:** $W = mg = (43.7 \text{ kg})(9.81 \text{ m/s}^2) = 429 \text{ N}$

**Example Problem:** What is the mass of an object whose weight sitting on the Earth is 2570 N?

$m = \frac{W}{a} = \frac{2570 \text{ N}}{9.81 \text{ m/s}^2} = 262 \text{ kg}$

## Summary

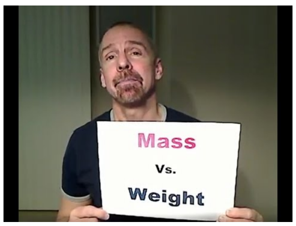
- The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- Mass is determined by comparing an object to known masses on a balance.
- The weight of an object on the Earth is defined as the force acting on the object by the Earth's gravity.
- Weight is measured by a calibrated spring scale.
- The formula relating mass and weight is $W = mg$.

## Practice

*Questions*

A song about the difference between mass and weight sung by Mr. Edmunds to the tune of Sweet Caroline. Remember to make allowances for the fact that he is a teacher, not a professional singer. Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=1whMAIGNq7E




MEDIA
Click image to the left or use the URL below.

1. What is used to measure mass?
2. What is used to measure weight?
3. What units are used to measure mass?
4. What units are used to measure weight?

## Review

*Questions*

1. The mass of an object on the Earth is 100. kg.
   a. What is the weight of the object on the Earth?
   b. What is the mass of the object on the moon?
   c. Assuming the acceleration due to gravity on the moon is exactly one-sixth of the acceleration due to gravity on Earth, what is the weight of the object on the moon?
2. A man standing on the Earth can exert the same force with his legs as when he is standing on the moon. We know that the mass of the man is the same on the Earth and the moon. We also know that $F = ma$ is true on both the Earth and the moon. Will the man be able to jump higher on the moon than the Earth? Why or why not?

- **mass:** The mass of an object is measured in kilograms and is defined as the amount of matter in an object.
- **weight:** The weight of an object on the earth is defined as the force acting on the object by the earth's gravity.

# 2.6 Earth as a Magnet

## Learning Objectives

- Describe how Earth is a magnet.
- Distinguish between Earth's geographic and magnetic poles.
- Describe the magnetosphere.


Did you ever use a compass like the one in this picture? Even if you've never used a compass, you probably know that the needle of a compass always points north. That's because a compass needle is magnetized, so it is attracted by a magnet.

**Q:** What magnet attracts a compass needle?

**A:** A compass needle is attracted by magnet Earth. It always points north because Earth acts as a giant magnet.

## Earth's Magnetic Poles

Imagine a huge bar magnet passing through Earth's axis, as in the **Figure** 2.11. This is a good representation of Earth as a magnet. Like a bar magnet, Earth has north and south magnetic poles. A **magnetic pole** is the north or south end of a magnet, where the magnet exerts the most force.

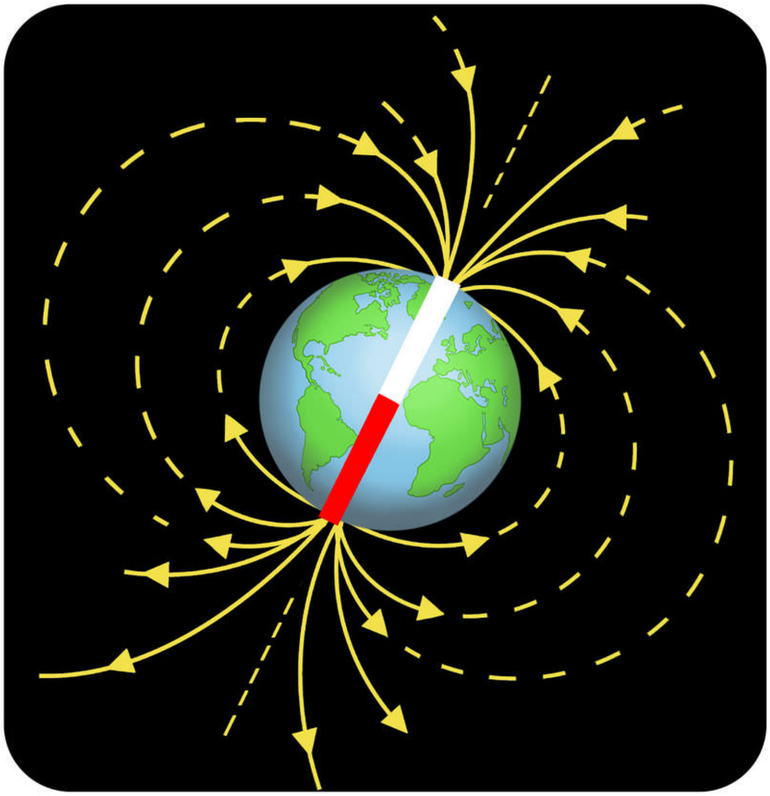


FIGURE 2.11

### Two North Poles

Although the needle of a compass always points north, it doesn't point to Earth's north geographic pole. Find the north geographic pole in the **Figure** 2.12. As you can see, it is located at 90° north latitude. Where does a compass needle point instead? It points to Earth's north magnetic pole, which is located at about 80° north latitude. Earth also has two south poles: a south geographic pole and a south magnetic pole.

**Q:** The north end of a compass needle points toward Earth's north magnetic pole. The like poles of two magnets repel each other, and the opposite poles attract. So why doesn't the north end of a compass needle point to Earth's south magnetic pole instead?

**A:** The answer may surprise you. The compass needle actually does point to the south pole of magnet Earth. However, it is called the north magnetic pole because it is close to the north geographic pole. This naming convention was adopted a long time ago to avoid confusion.

### Earth's Magnetic Field

Like all magnets, Earth has a magnetic field. Earth's magnetic field is called the **magnetosphere**. You can see a model of the magnetosphere in the **Figure ??**. It is a huge region that extends outward from Earth in all directions. Earth exerts magnetic force over the entire field, but the force is strongest at the poles, where lines of force converge.

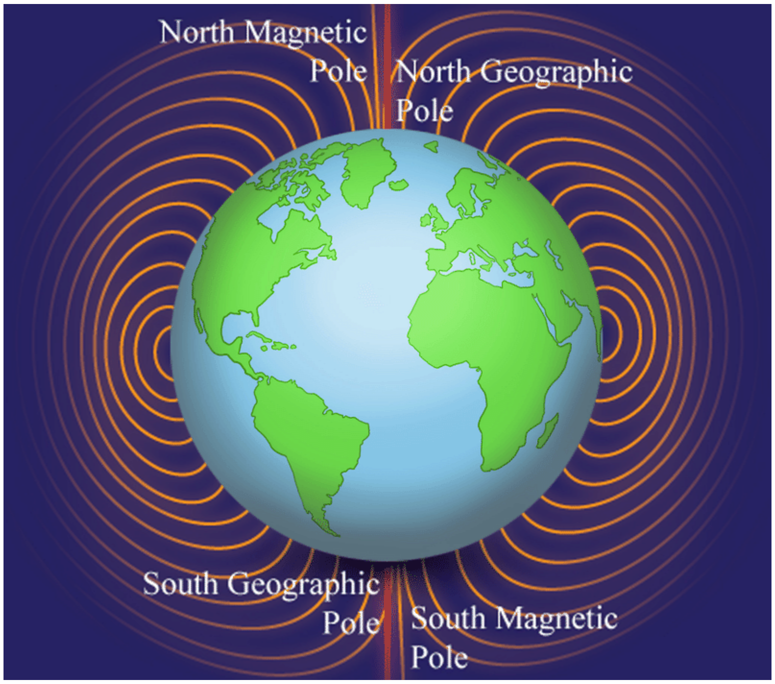
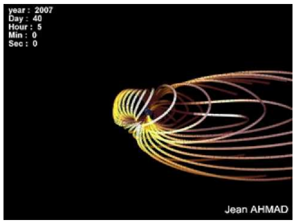



FIGURE 2.12




MEDIA

Click image to the left or use the URL below.

Launch the PLIX Interactive below to learn more about how a compass utilizes the Earth's magnetic field and observe what happens to a compass as you change positions on Earth:


PLIX

Click image to the left or use the URL below.

URL: https://romer.ck12.org/earth-science/earths-magnetic-field/plix/Earths-Magnetic-Field-Compass-Poles-5a43e5809616aa082fbcf6d6

## Summary

- Earth acts as a giant magnet with magnetic poles and a magnetic field over which it exerts magnetic force.
- Earth has north and south magnetic poles like a bar magnet. Earth's magnetic poles are not the same as the geographic poles.
- Earth's magnetic field is called the magnetosphere. It is strongest at the poles.

### Review

1. How does Earth act as a bar magnet?
2. The compass in a car shows that the car is moving north. Does this mean that the car is moving toward 90° north latitude? Why or why not?
3. Describe the magnetosphere.

### Vocabulary

- **Magnetic Poles:** Earth has north and south magnetic poles like a bar magnet. Earth's magnetic poles are not the same as the geographic poles.
- **Magnetosphere:** the Earth's magnetic field; it is strongest at the poles.

# 2.7 Why Earth Is A Magnet

## Learning Objectives

- Describe how Gilbert discovered that Earth is a magnet.
- Relate Earth's inner structure to its magnetic field.

Did you ever see a globe like this one? Magnets in the globe and its stand repel each other, allowing the globe to hover in midair. The globe is a good model for Earth the magnet.

## Earth the Magnet

Like the real Earth, the globe pictured above is a magnet. A **magnet** is an object that has north and south magnetic poles and a magnetic field. The magnetic globe is a modern device, but the idea that Earth is a magnet is far from new. It was first proposed in 1600 by a British physician named William Gilbert. He used a spherical magnet to represent Earth. With a compass, he demonstrated that it the spherical magnet causes a compass needle to behave the same way that Earth causes a compass needle to behave. This showed that a spherical magnet is a good model for Earth and therefore that Earth is a magnet.

**Q:** Can you describe Earth's magnetic poles and magnetic field?

**A:** Earth has north and south magnetic poles. The North Pole is located at about 80 degrees north latitude. The magnetic field is an area around Earth that is affected by its magnetic field. The field is strongest at the poles, and lines of magnetic force move from the north to the south magnetic pole.

## Spinning Like a Top

Although the idea that Earth is a magnet is centuries old, the discovery of why Earth is a magnet is a relatively new. In the early 1900s, scientists started using seismographic data to learn about Earth's inner structure. A seismograph detects and measure earthquake waves. Evidence from earthquakes showed that Earth has a solid inner core and a liquid outer core (see the **Figure** 2.13). The outer core consists of molten metals, mainly iron and nickel. Scientists think that Earth's magnetic field is generated by the movement of charged particles through these molten metals in the outer core. The particles move as Earth spins on its axis.

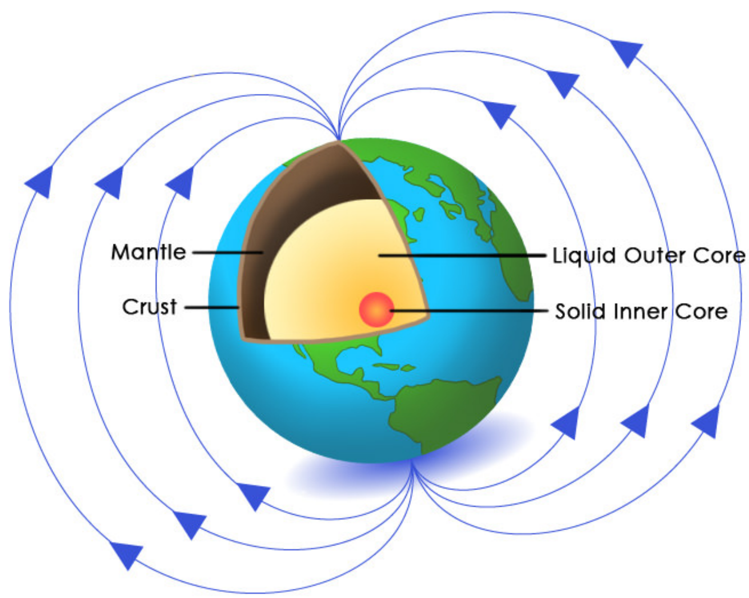
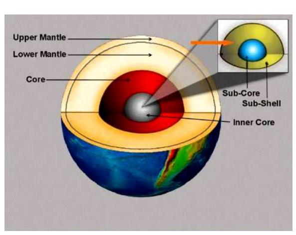



FIGURE 2.13

Watch the video below to learn more about the origin of Earth's magnetic field:




MEDIA

Click image to the left or use the URL below.

Launch the Field Lines simulation below to help you visualize the invisible magnetic field that surrounds the Earth. You can also travel to different planets in the solar system and measure the properties of their magnetic fields. Can you determine which planet has the largest magnetic field? Which planet has no field? Then, try to develop a hypothesis about why this might be.


MEDIA
Click image to the left or use the URL below.

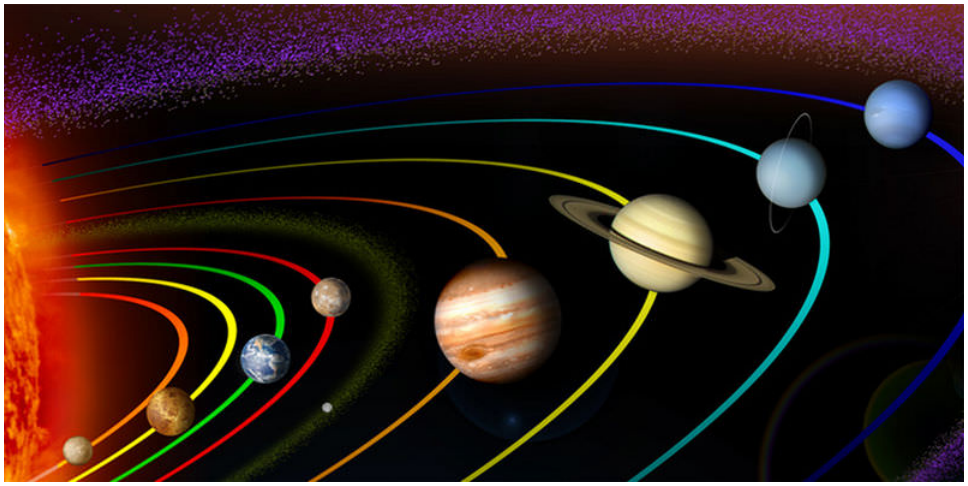
## Summary

- In the 1600s, William Gilbert demonstrated that Earth is basically a spherical magnet, with north and south poles and a magnetic field.
- In the 1900s, scientists used earthquake data to determine that Earth has a solid inner core and molten outer core. Scientists think that Earth is a magnet because of charged particles moving through the molten outer core as Earth spins on its axis.

## Review

1. How did Gilbert show that Earth is a magnet?
2. Which would be a better model of Earth's inner structure: a peach or an orange? Explain your answer?
3. Explain why Earth generates a magnetic field.

# 2.8 Gravity



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. 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.

## Defining Gravity

**Gravity** has traditionally been defined as a force of attraction between things that have mass. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. Gravity can act between objects that are not even touching. In fact, gravity can act over very long distances. However, the farther two objects are from each other, the weaker is the force of gravity between them. Less massive objects also have less gravity than more massive objects.

## 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 that are 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 and the other planets moving around the much more massive sun.

**Q**: There is a force of gravity between Earth and you and also between you and all the objects around you. When you drop a paper clip, why doesn't it fall toward you instead of toward Earth?

**A**: Earth is so much more massive than you that its gravitational pull on the paper clip is immensely greater.

## Gravity and Weight

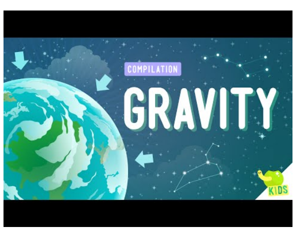
Weight measures the force of gravity pulling downward on an object. The SI unit for weight, like other forces, is the Newton (N). On Earth, a mass of 1 kilogram has a weight of about 10 Newtons because of the pull of Earth's gravity.

Money hangs below this hand-held scale. It is pulled downwards by gravity. The scale measures the strength of that pull.

FIGURE 2.14

On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale shown in the **Figure** 2.14. The scale measures the force with which gravity pulls an object downward.

Watch the video below to learn more about gravity and factors that influence the strength of gravity between two objects:




MEDIA

Click image to the left or use the URL below.

## Summary

- Gravity has traditionally been defined as a force of attraction between things that have mass. The strength of gravity between two objects depends on their mass and their distance apart.
- Earth's gravity constantly pulls matter toward the center of the planet. It also keeps moons and satellites orbiting Earth and Earth orbiting the sun.
- Weight measures the force of gravity pulling on an object. The SI unit for weight is the Newton (N).

## Vocabulary

1. What is the traditional definition of gravity?
2. Identify factors that influence the strength of gravity between two objects.
3. Define weight. What is the SI unit for weight?
4. Explain why an astronaut would weigh less on the moon than on Earth.

### Vocabulary

**Gravity** is a force of attraction between things that have mass.

# 2.9 References


1. User:Holek/Wikimedia Commons, NASA/JPL-Caltech/R. Hurt;Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Oort_cloud_Sedna_orbit.svg;http://sohowww.nascom.nasa.gov/classroom/classroom.html . Public Domain
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7. Courtesy of Mass Communication Specialist Seaman Joshua Valcarcel, U.S. Navy. http://commons.wikimedia.org/wiki/File:Lunar_eclipse_March_2007.jpg . Public Domain
8. U.S. Navy photos by Mass Communication Specialist Seaman Joshua Valcarcel;Alexandra Lord. http://commons.wikimedia.org/wiki/File:Lunar_eclipse_March_2007.jpg;http://www.flickr.com/photos/atruzzi/5366046285/ . Public Domain;CC BY 2.0
9. User:Sagredo/Wikimedia Commons;Alexandra Lord. http://commons.wikimedia.org/wiki/File:Geometry_of_a_Lunar_Eclipse.svg;http://www.flickr.com/photos/atruzzi/5366046285/ . Public Domain;CC BY 2.0
10. U.S. Navy photos by Mass Communication Specialist Seaman Joshua Valcarcel;Courtesy of NASA;Alexandra Lord. http://commons.wikimedia.org/wiki/File:Lunar_eclipse_March_2007.jpg;Left: http://commons.wikimedia.org/wiki/File:Solar_eclipse_2006-03-28,_The_sun%27s_corona,_or_outer_atmosphere,_is_visible_during_totality.jpg; Right: http://commons.wikimedia.org/wiki/File:Solar_eclipse_from_space_29_Mar_2006.jpg;http://www.flickr.com/photos/atruzzi/5366046285/ . Public Domain;CC BY 2.0
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13. Alexandra Lord. http://www.flickr.com/photos/atruzzi/5366046285/ . CC BY 2.0
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# CHAPTER 3 Unit 3: Adapt or Die?

## Chapter Outline

3.1 FOSSILS
3.2 RELATIVE AGES OF ROCKS
3.3 GEOLOGIC TIME SCALE - ADVANCED
3.4 EVIDENCE FOR EVOLUTION
3.5 COMPARATIVE ANATOMY
3.6 NATURAL SELECTION
3.7 SIGNIFICANCE OF MUTATIONS - ADVANCED
3.8 GENETIC ENGINEERING
3.9 REFERENCES

# 3.1 Fossils

## Learning Objectives

- Define fossil.
- Describe how fossils help us understand the past.

### Would this be evidence of evolution?

Fossils, like this dinosaur fossil, provide evidence of species that lived in the past and have since gone extinct. In other words, these fossils are evidence of evolution.

## Fossil Evidence

In his book *On the Origin of Species*, Darwin included evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

**Fossils** are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in the **Figure** 3.8. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

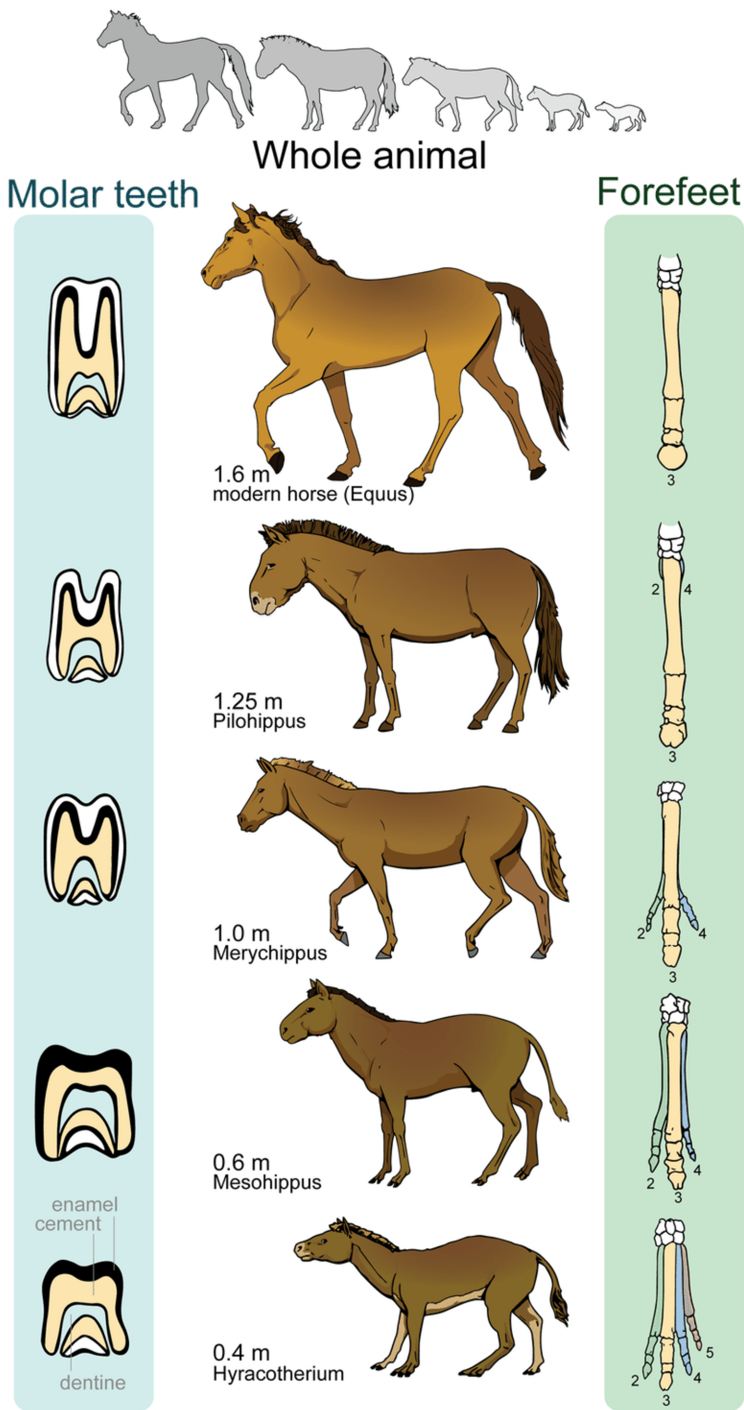
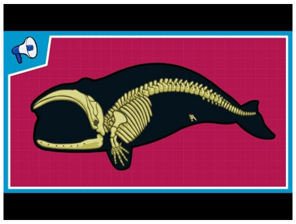



FIGURE 3.1

Evolution of the horse. Fossil evidence, depicted by the skeletal fragments, demonstrates evolutionary milestones in this process. Notice the 57 million year evolution of the horse leg bones and teeth. Especially obvious is the transformation of the leg bones from having four distinct digits to that of today's horse.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea.



MEDIA
Click image to the left or use the URL below.

### Science Friday: Millions of Fossils Can't Be Wrong

What's in a tar pit? In this video by Science Friday, Dr. John Harris describes how the La Brea Tar Pit has come to accumulate so many fossils.

MEDIA
Click image to the left or use the URL below.

## Summary

- Fossils provide a window into the past. They are evidence for evolution.
- Scientists who find and study fossils are called paleontologists.

## Review

1. What is a fossil?
2. How do paleontologists learn about evolution?
3. Describe what fossils reveal about the evolution of the horse.

# 3.2 Relative Ages of Rocks

## Lesson Objectives

- Explain how stratigraphy can be used to determine the relative ages of rocks.
- State how unconformities occur.
- Identify ways to match rock layers in different areas.
- Describe how Earth's history can be represented by the geologic time scale.

## Lesson Vocabulary

- geologic time scale
- key bed
- law of superposition
- relative age
- stratigraphy
- unconformity

## Introduction

Earth processes have not changed over time. The way things happen now is the same way things happened in the past. Mountains grow and mountains slowly wear away. The same process is at work the same as it was billions of years ago. As the environment changes, living creatures adapt. They change over time. Some organisms may not be able to adapt. They become **extinct.** Becoming extinct means they die out completely.

Some geologists study the history of the Earth. They want to learn about Earth's past. They use clues from rocks and fossils. They use these clues to make sense of events. The goal is to place things in the order they happened. They also want to know how long it took for those events to happen.

## Laws of Stratigraphy

Consider the study of the layers of rock. Layers of rock are called strata. The study of strata is called **stratigraphy**. A lot can be learned by looking at layers of rock. Scientists can learn about past environments. From fossils, they can learn about what plants and animals once lived in the area. If they know what type of plant or animal lived in an area, they can get a good idea about the type of climate. The fossil evidence will tell them if the area was land or marine. Even the type of rock can tell them about the past environment. The laws of stratigraphy can help scientists learn many things about Earth's past.

### Law of Superposition

Superposition refers to the position of rock layers. A lot can be learned by the position of rocks. We know the rocks on top are always younger than the rocks below. Knowing the relative age of rocks is very important to scientists. **Relative age** means age in comparison with other rocks. Are rocks older or younger than other rocks? The relative ages of rocks are important. They help scientists learn more about Earth's history. New rock layers are always deposited on top of existing rock layers. Therefore, deeper layers must be older than layers closer to the surface. This is the **law of superposition**. You can see an example in **Figure** 3.2.

FIGURE 3.2

Superposition. The rock layers at the bottom of this cliff are much older than those at the top. What force eroded the rocks and exposed the layers?

### Law of Lateral Continuity

Rock layers extend laterally, or out to the sides. They may cover very large areas. This is especially true if they formed at the bottom of ancient seas. Seas are very large areas of water. Over time, sediment builds up on the seabed. They will be covered with the same types of material. As rocks form out of this sediment it will all be the same type. The rocks may be forced up above the water as Earth's plates move. Rivers may eventually run across this area. The river will cut into the rock and erode it away. The layers of exposed rock on either side of the river will still "match up."

Look at the Grand Canyon in **Figure** 3.3. It's a good example of lateral continuity. You can clearly see the same rock layers on opposite sides of the canyon. The matching rock layers were deposited at the same time. They are the same age.

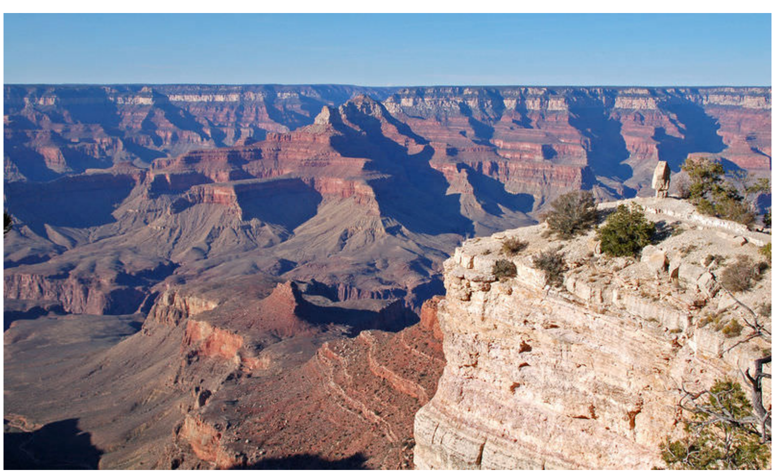


FIGURE 3.3

Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

### Law of Original Horizontality

Sediments were deposited in ancient seas in horizontal, or flat, layers. If sedimentary rock layers are tilted, they must have moved after they were deposited.

### Law of Cross-Cutting Relationships

Rock layers may have another rock cutting across them, like the igneous rock in **Figure** 3.4. Which rock is older? To determine this, we use the law of cross-cutting relationships. The cut rock layers are older than the rock that cuts across them.

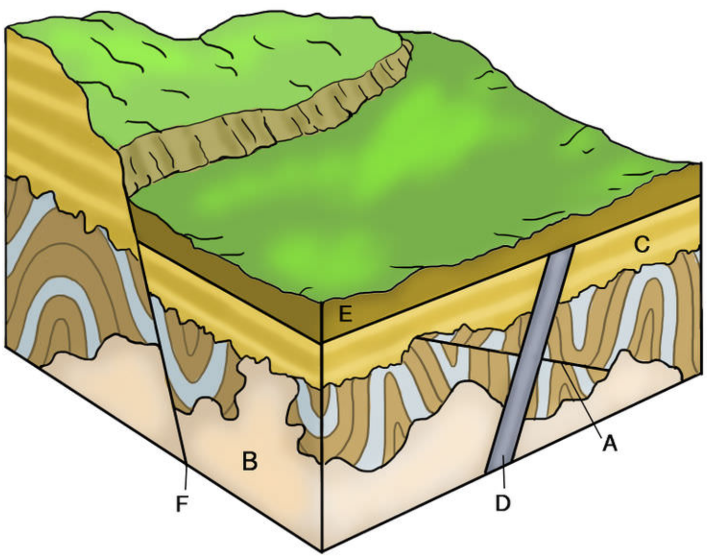



FIGURE 3.4
Cross-cutting relationships in rock layers. Rock D is a dike that cuts across all the other rocks. Is it older or younger than the other rocks?

### Matching Rock Layers

It is easy to match rock layers across a river. Unfortunately, matching rock layers is not always that easy. Sometimes, rock layers are not in the same place. They may be on different continents. So how do we match rock layers in this case? What evidence can we use to match the layers?

### Widespread Rock Layers

Some rock layers extend over a very wide area. They may even be found on more than one continent. For example, the famous White Cliffs of Dover are on the coast of southeastern England. These are very distinctive rocks. They can be matched to similar white cliffs in France, Belgium, Holland, Germany, and Denmark (see **Figure** 3.5). Why is this important to us? As it turns out, these cliffs are made of chalk. Chalk is a very soft rock. This rock extends from England to Europe. It extends under the English Channel. Because it is soft the Channel Tunnel connecting England and France was carved into it!

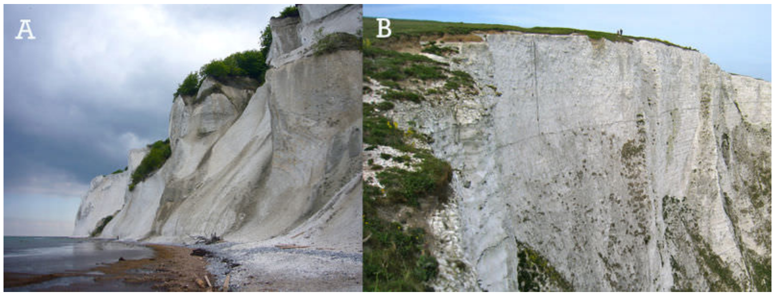



FIGURE 3.5
Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

### Key Beds

Like index fossils, key beds are used to match rock layers. A **key bed** is a thin layer of rock. The rock must be unique and widespread. For example, a key bed from around the time that the dinosaurs went extinct is very important. A thin layer of clay was deposited over much of Earth's surface. The clay has a large amount of the element iridium. Iridium is rare on Earth but common in asteroids. This unusual clay layer has been used to match rock layers all over the world. It also led to the hypothesis that a giant asteroid struck Earth. It was this event that may have caused dinosaurs to go extinct.

### Using Index Fossils

Fossils can be used to match up rock layers. As organisms change over time, they look different. Older fossils will look different than younger fossils. Some organisms only survived for a short time before going extinct. Knowing what organisms looked like at certain times also helps date rock layers. Some fossils are better than others for this use. The fossils that are very distinct at certain times of Earth's history are called index fossils. Index fossils are commonly used to match rock layers. You can see how this works in **Figure** 3.6. If two rock layers have the same index fossils, then they're probably about the same age.

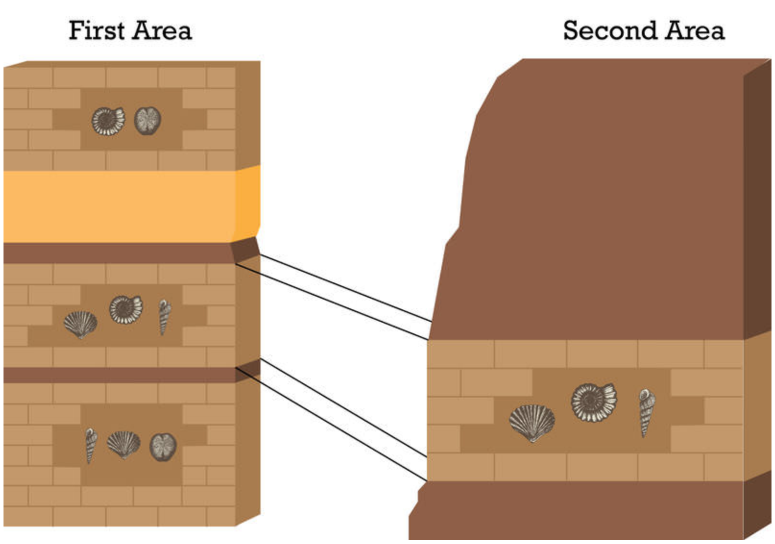



FIGURE 3.6
Using Index Fossils to Match Rock Layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

## Lesson Summary

- The study of rock layers is called stratigraphy. Laws of stratigraphy help scientists determine the relative ages of rocks. The main law is the law of superposition. This law states that deeper rock layers are older than layers closer to the surface.
- Other clues help determine the relative ages of rocks in different places. They include key beds and index fossils.

## Lesson Review Questions

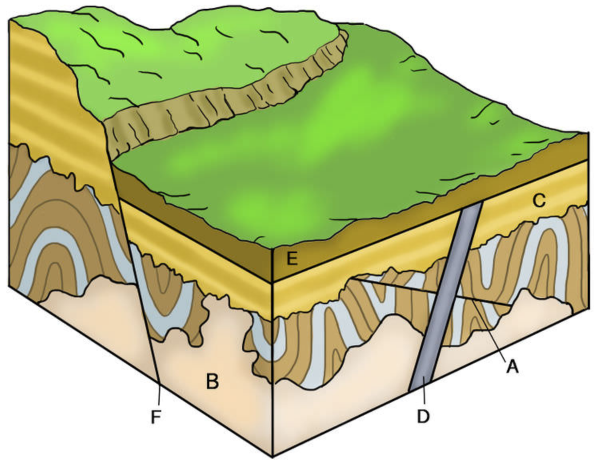
### Recall

1. Define stratigraphy.
2. What is the relative age of a rock?
3. State the law of superposition.
4. How do key beds help date rock layers?

### Apply Concepts

5. Apply laws of stratigraphy to explain the rock formation below.

6. Which rock in the illustration below formed first, the igneous rock (A) or the sedimentary rock (B)? Apply lesson concepts to support your answer.




### Think Critically

7. Use the law of lateral continuity to explain why the same rock layers are found on opposite sides of the Grand Canyon.

8. Why are sedimentary rocks more useful than metamorphic or igneous rocks in establishing the relative ages of rock?

### Points to Consider

In this lesson, you read how scientists determine the relative ages of sedimentary rock layers. The law of superposition determines which rock layers are younger or older than others.

- What about the actual ages of rocks? Is there a way to estimate their ages in years?

# 3.3 Geologic Time Scale - Advanced

## Learning Objectives

- Compare and contrast Geologic Time with absolute time. Include limits of each.
- Sequence the levels of organization of the Geologic Time Scale from largest to smallest.
- Arrange the four major Eons and one Supereon from youngest to oldest.

### What is a time scale?

Is it a way to measure time? Essentially it is. And in terms of the history of life, time needs to be measured in millions of years. Or hundreds of millions of years.

## A Geologic Time Scale Measures the Evolution of Life

In the *History of Life: Introduction (Advanced)* concept, the **Geologic Time Scale** was described as based on the observation of rock layers, dating techniques, and correlation of similar strata from around the world (**Figure** 3.7). How does the scale divide 4.6 billion years of history? What themes emerge from its stories of the past?

One theme is the almost unimaginable amount of time. 4.6 billion years is a tremendous amount of time, and it is, at times, illogical for humans to coherently understand how many evolutionary events can occur during that time frame. The deep time of Earth's history is far beyond our experience and our knowledge is far more detailed for recent millennia than for the distant past. A scale divided into evenly spaced periods of time would not show that detail. Instead, Geologic Time Scale divisions mark major events which highlight changes in climate, geography, atmosphere, and life. The largest units of time are **eons**. Eons include smaller **eras**, which in turn include **periods, epochs**, and **stages** or ages. Faunal stages identify specific fossil groups. Terms such as Upper/Late and Lower/Early divide parts of the scale into more recent and more distant subunits.

Four eons comprise the history of Earth, and their names refer to a second major theme of Earth's history: the evolution of life. The Phanerozoic ("visible life") Eon spans the most recent 544 million years and includes three Eras well known for their chronicle of life: the oldest Paleozoic, middle Mesozoic, and current Cenozoic. The Proterozoic ("before complex life") Eon precedes the Phanerozoic, extending back 2.5 billion years. The Archean ("ancient") and Hadean ("unseen") Eons reach back to the formation of the Earth. The Precambrian **Supereon** combines the oldest three eons, and refers to the time before the first great explosion of life recorded in the fossil record - the **Cambrian Period**, the first period of the Paleozoic Era. The name "Cambrian" refers to Wales, where these fossils were first studied. Before this first period of the Phanerozoic, animals lacked hard body parts to contribute to the fossil record. The Phanerozoic Eon is divided into three eras, which are further divided into 11 periods. This eon extends from the Cambrian Period to the present **Quaternary Period.**

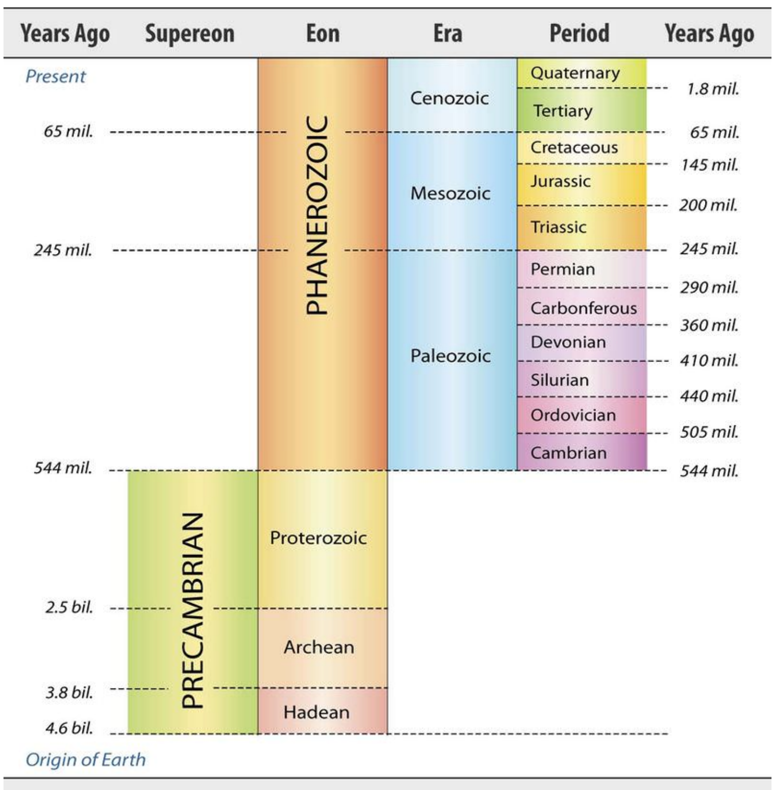



FIGURE 3.7

A linear arrangement of the Geologic Time Scale shows overall relationships between well-known time periods. Our knowledge of past life is concentrated in the most recent Eon, but the Phanerozoic occupies such a small proportion of the overall history of earth that eras, periods, and epochs are not precisely to scale. This diagram shows well-known time frames and is not complete.

## Summary

- Geologic Time Scale divisions mark major events which highlight changes in climate, geography, atmosphere, and life.
- The largest units of time are eons; the 4.6 billion years of earth's history are divided into four eons.
- The Phanerozoic Eon includes the most recent 545 million years and the most detailed fossil record.

### Review

1. Define Geologic Time Scale.
2. How old is the Earth's history?
3. Order the units of time from greatest to least.
4. When was the first great explosion of life recorded in the fossil record?

# 3.4 Evidence for Evolution

## Lesson Objectives

- Describe how fossils help us understand the past.
- Explain how evidence from living species gives clues about evolution.
- State how biogeography relates to evolutionary change.

## Vocabulary

- adaptive radiation
- analogous structure
- biogeography
- comparative anatomy
- comparative embryology
- homologous structure
- paleontologist
- vestigial structure

## Introduction

In his book *On the Origin of Species,* Darwin included a lot of evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

## Fossil Evidence

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in **Figure** 3.8. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

- They became taller, which would help them see predators while they fed in tall grasses.

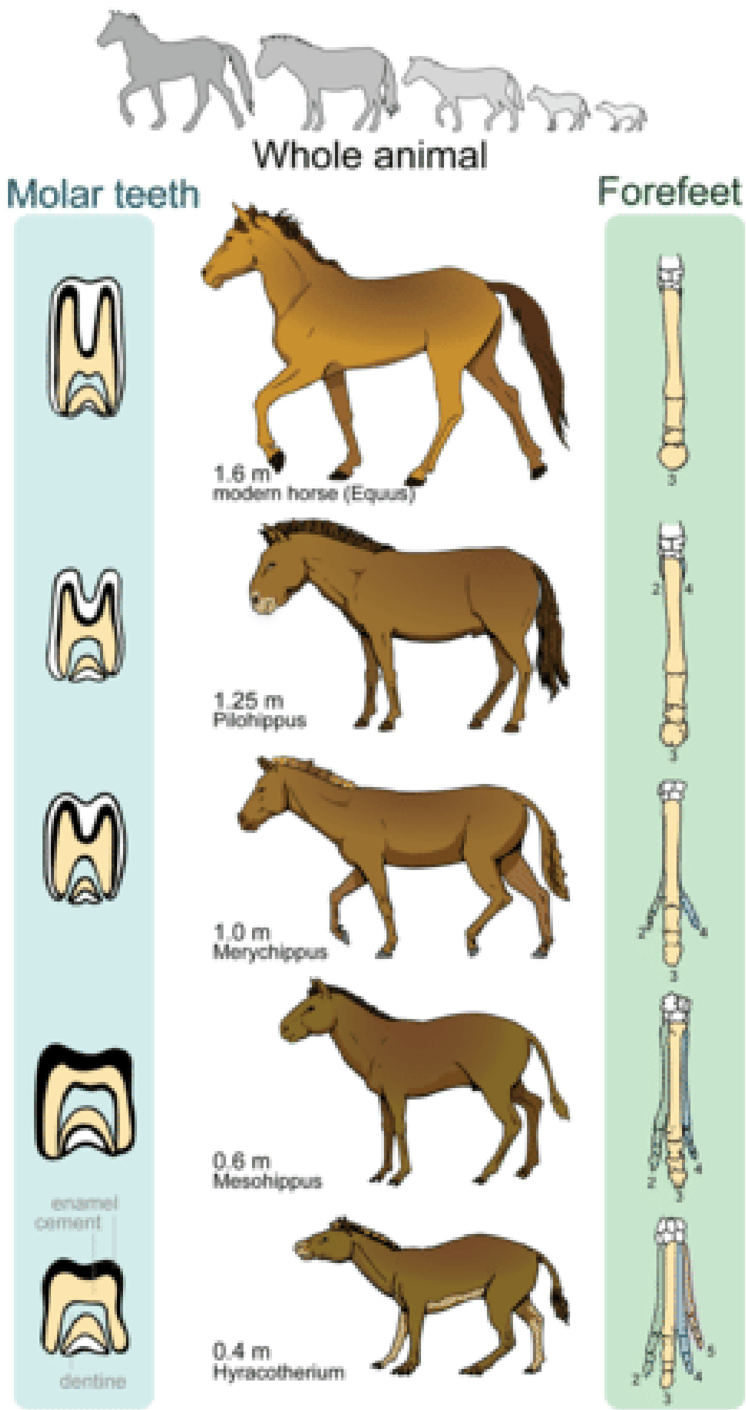



FIGURE 3.8
Evolution of the Horse. The fossil record reveals how horses evolved.

- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea. An animation of this process can be viewed at http://collections.tepapa.govt.nz/exhibitions/whales/Segment.aspx?irn=161 .

*Does The Fossil Record Support Evolution?* This video can be seen at http://www.youtube.com/watch?v=QWVoXZPOCGk (9:20).

## Evidence from Living Species

Just as Darwin did, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

### Comparative Anatomy

**Comparative anatomy** is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

**Homologous structures** are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 3.15 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

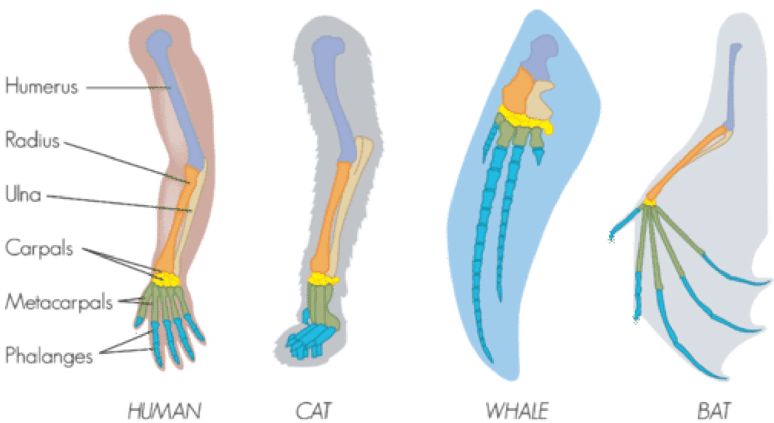



FIGURE 3.9
Hands of Different Mammals. The forelimbs of all mammals have the same basic bone structure.

**Analogous structures** are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 3.16, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

### Comparative Embryology

**Comparative embryology** is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage. See http://www.pbs.org/wgbh/evolution/library/04/2/pdf/l_042_03.pdf for additional information and a nice comparative diagram of human, monkey, pig, chicken and salamander embryos.

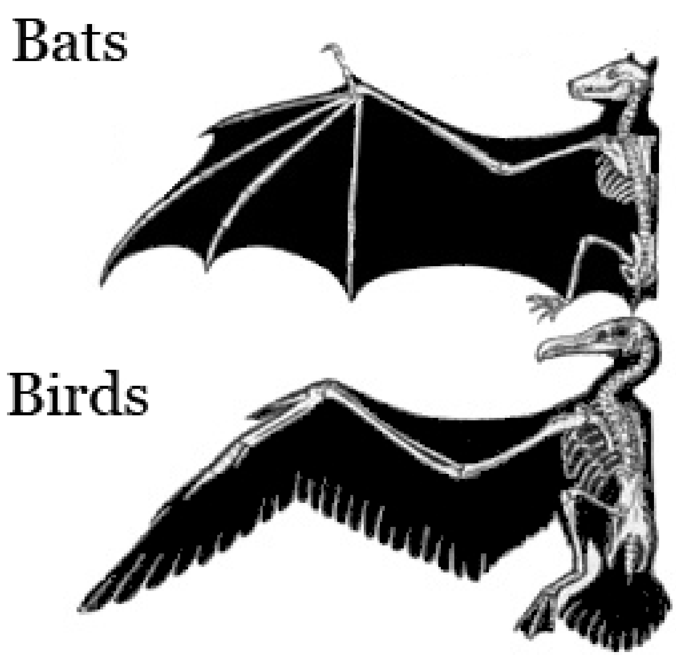



FIGURE 3.10
Wings of Bats and Birds. Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

### Vestigial Structures

Structures like the human tail bone are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?

### Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in **Figure** 3.17. It shows how humans and apes are related based on their DNA sequences.

Evolution and molecules are discussed at http://www.youtube.com/watch?v=nvJFI3ChOUU (3:52).

Using various types of information to understand evolutionary relationships is discussed in the following videos: http://www.youtube.com/watch?v=aZc1t2Os6UU (3:38), http://www.youtube.com/watch?v=6IRz85QNjz0 (6:45), http://www.youtube.com/watch?v=JgyTVT3dqGY (10:51).

## Evidence from Biogeography

**Biogeography** is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

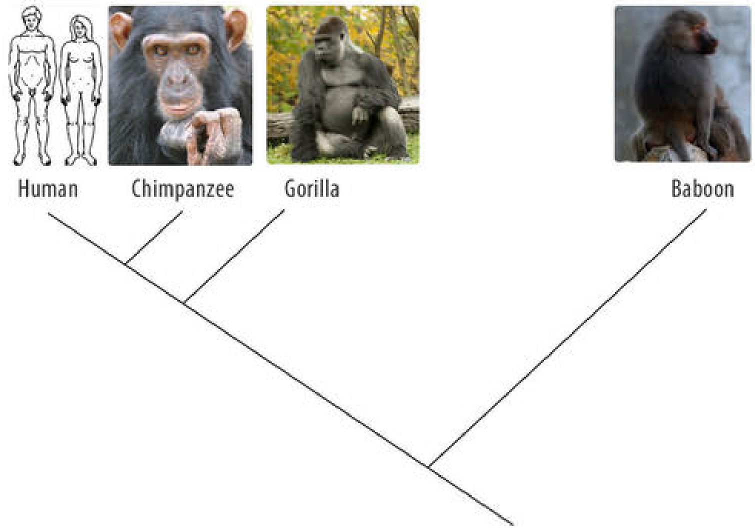



FIGURE 3.11
Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

### Biogeography of Camels: An Example

Today, the camel family includes different types of camels. They are shown in **Figure** 3.12. All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

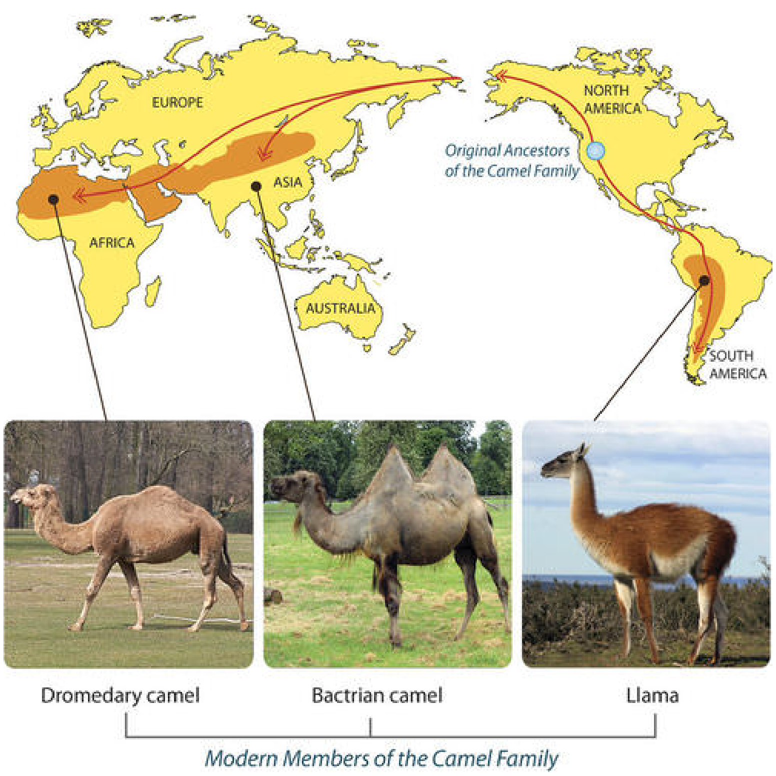



FIGURE 3.12
Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits. However, they share basic similarities. This is because they all evolved from a common ancestor. What differences and similarities do you see?

Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.

## Island Biogeography

The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see **Figure** 3.13). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of **adaptive radiation**. This is the process by which a single species evolves into many new species to fill available niches.

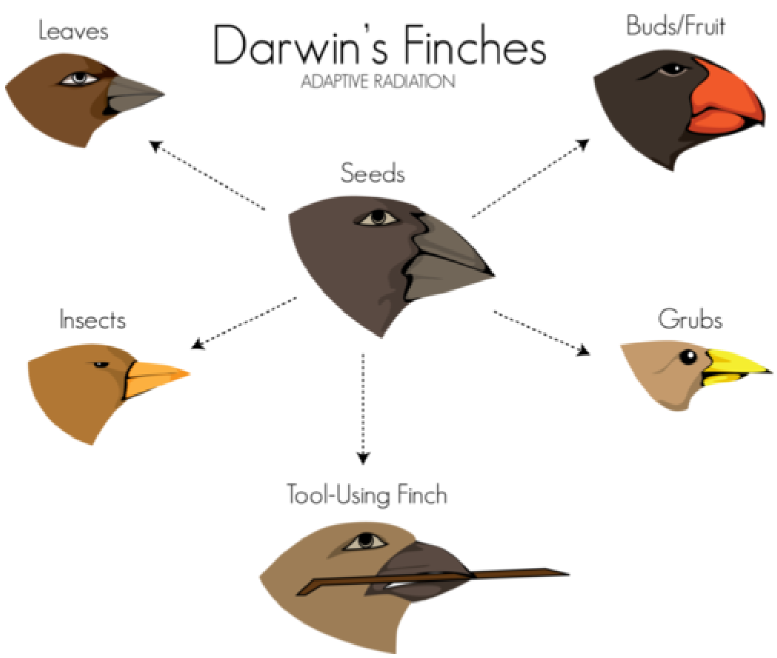



FIGURE 3.13
Galápagos finches differ in beak size and shape, depending on the type of food they eat.

## Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place.

While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see **Figure** 3.14). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

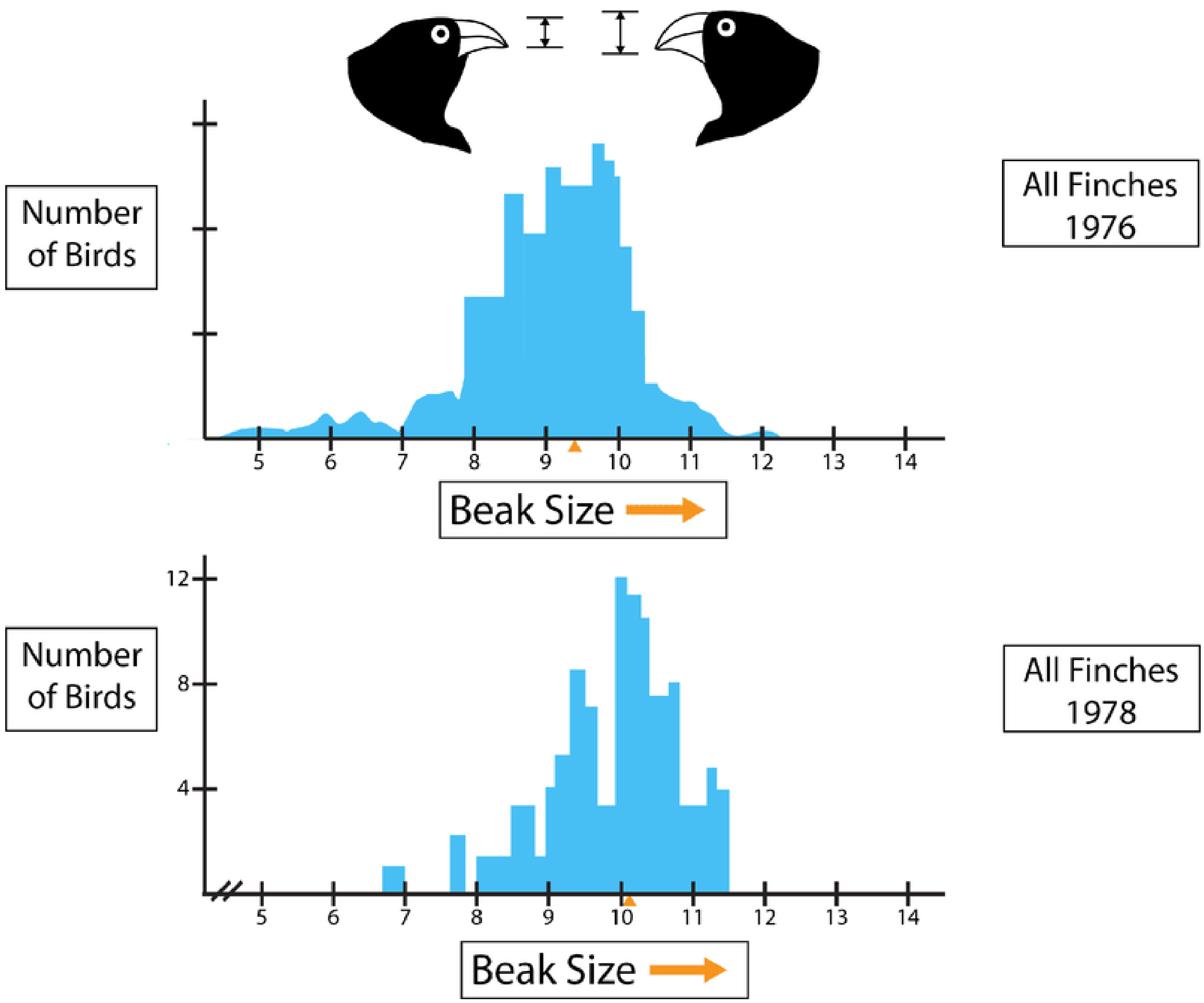



FIGURE 3.14

Evolution of Beak Size in Galápagos Finches. The top graph shows the beak sizes of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just 2 years, beak size increased.

## Lesson Summary

- Fossils provide a window into the past. They are evidence for evolution. Scientists who find and study fossils are called paleontologists.
- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved. Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor. Other evidence is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution. On island chains, such as the Galápagos, one species may evolve into many new species to fill

available niches. This is called adaptive radiation.

## Lesson Review Questions

### Recall

1. How do paleontologists learn about evolution?
2. Describe what fossils reveal about the evolution of the horse.
3. What are vestigial structures? Give an example.
4. Define biogeography.
5. Describe an example of island biogeography that provides evidence of evolution.

### Apply Concepts

6. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.

### Think Critically

7. Compare and contrast homologous and analogous structures. What do they reveal about evolution?
8. Why does comparative embryology show similarities between organisms that do not appear to be similar as adults?

## Points to Consider

The Grants saw evolution occurring from one generation to the next in a population of finches.

- What factors caused the short-term evolution the Grants witnessed? How did the Grants know that evolution had occurred?
- What other factors do you think might cause evolution to occur so quickly within a population?

# 3.5 Comparative Anatomy

## Learning Objectives

- Explain the significance of homologous structures, analogous structures, and vestigial structures.
- Describe the meaning of similar DNA sequences between two species.

**Is this evidence of evolution?**

Take a close look at this gorilla hand. The similarities to a human hand are remarkable. Comparing anatomy, and characterizing the similarities and differences, provides evidence of evolution.

## Evidence from Living Species

Just as Darwin did many years ago, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

### Comparative Anatomy

**Comparative anatomy** is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

**Homologous structures** are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 3.15 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

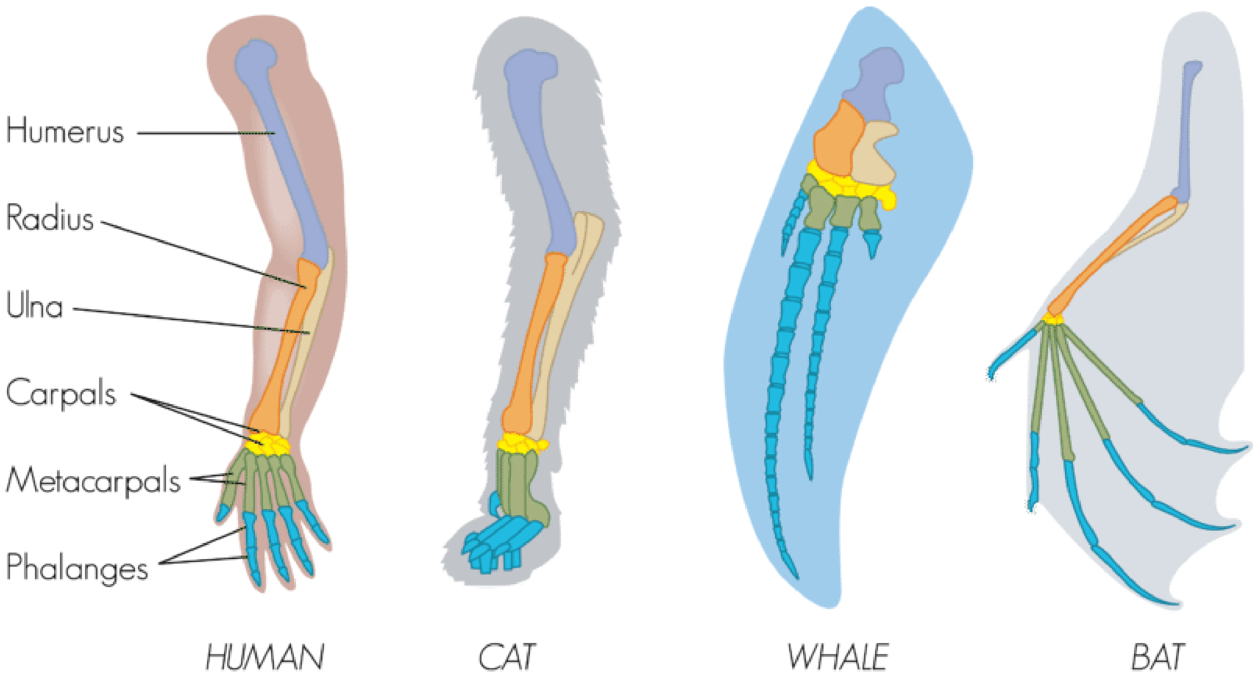
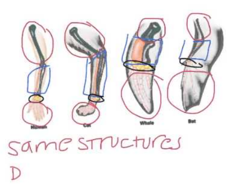



FIGURE 3.15
The forelimbs of all mammals have the same basic bone structure.

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**Analogous structures** are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 3.16, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

### Comparative Embryology

**Comparative embryology** is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. Most vertebrates, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood.

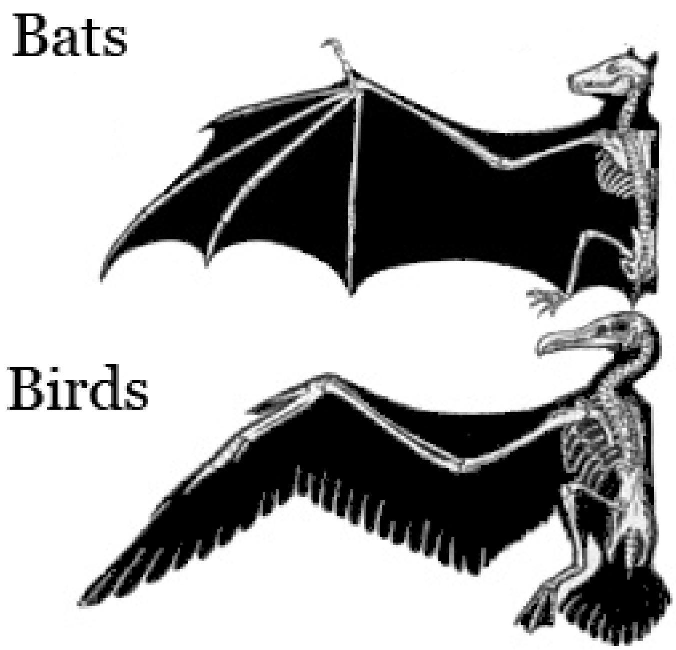
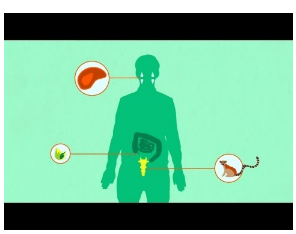



FIGURE 3.16
Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

This is why it is valuable to compare organisms in the embryonic stage.

### Vestigial Structures

Structures like the human tail bone and whale pelvis are called **vestigial structures**. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?



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### Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. More similarities in the

DNA sequence is evidence for a closer evolutionary relationship. Look at the cladogram in the **Figure** 3.17. It shows how humans and apes are related based on their DNA sequences.

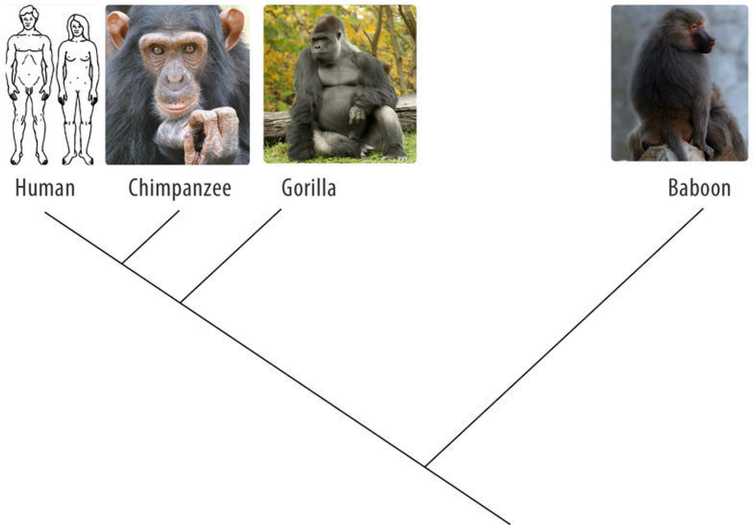


FIGURE 3.17
Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

## Summary

- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved.
- Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor.
- Other evidence for evolution is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Comparing DNA sequences provided some of the strongest evidence of evolutionary relationships.

## Review

1. What are vestigial structures? Give an example.
2. Compare homologous and analogous structures.
3. Why do vertebrate embryos show similarities between organisms that do not appear in the adults?
4. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.
5. What is the strongest evidence of evolution from a common ancestor?

# 3.6 Natural Selection

## Learning Objectives

- Define natural selection.
- Explain the relationship between adaptations and natural selection.
- Describe when natural selection occurs.
- Explain the relationship between evolution and natural selection.

**How is this deer mouse well adapted for life in the forest?**

Notice how its dark coloring would allow the deer mouse to easily hide from predators on the darkened forest floor. On the other hand, deer mice that live in the nearby Sand Hills are a lighter, sand-like color. What caused the deer mice to be so well adapted to their unique environments? Natural selection.


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### Natural Selection

The theory of evolution by natural selection means that the inherited traits of a population change over time. **Inherited traits** are features that are passed from one generation to the next. For example, your eye color is an inherited trait. You inherited your eye color from your parents. Inherited traits are different from **acquired traits**, or traits that organisms develop over a lifetime, such as strong muscles from working out (**Figure** 3.18).

FIGURE 3.18

Human earlobes may be attached or free. You inherited the particular shape of your earlobes from your parents. Inherited traits are influenced by genes, which are passed on to offspring and future generations. Things not influenced by genes are not passed on to your offspring. Natural selection only operates on traits like earlobe shape that have a genetic basis, not on traits that are acquired, like a summer tan.

**Natural selection** explains how organisms in a population develop traits that allow them to survive and reproduce. Natural selection means that traits that offer an advantage will most likely be passed on to offspring; individuals with those traits have a better chance of surviving. Evolution occurs by natural selection.

Take the giant tortoises on the Galápagos Islands as an example. If a short-necked tortoise lives on an island with fruit located at a high level, will the short-necked tortoise survive? No, it will not, because it will not be able to reach the food it needs to survive. If all of the short necked tortoises die, and the long-necked tortoises survive, then, over time, only the long-necked trait will be passed down to offspring. All of the tortoises with long-necks will be "naturally selected" to survive. Organisms that are not well-adapted, for whatever reason, to their environment, will naturally have less of a chance of surviving and reproducing.

Every plant and animal depends on its traits to survive. Survival may include getting food, building homes, and attracting mates. Traits that allow a plant, animal, or other organism to survive and reproduce in its environment are called **adaptations**.

Natural selection occurs when:

1. There is some variation in the inherited traits of organisms within a species. Without this variation, natural selection would not be possible.
2. Some of these traits will give individuals an advantage over others in surviving and reproducing.
3. These individuals will be likely to have more offspring.

Imagine how in the Arctic, dark fur makes a rabbit easy for foxes to spot and catch in the snow. Therefore, white fur is a beneficial trait that improves the chance that a rabbit will survive, reproduce, and pass the trait of white fur on to its offspring (**Figure** 3.19). Through this process of natural selection, dark fur rabbits will become uncommon over time. Rabbits will adapt to have white fur. In essence, the selection of rabbits with white fur - the beneficial trait - is a natural process.

FIGURE 3.19
The white fur of the Arctic hares may make it more difficult for fox and other predators to locate hares against the white snow.

### Why So Many Species?

Scientists estimate that there are between 5 million and 30 million species on the planet. But why are there so many? Different species are well-adapted to live and survive in many different types of environments. As environments change over time, organisms must constantly adapt to those environments. Diversity of species increases the chance that at least some organisms adapt and survive any major changes in the environment. For example, if a natural disaster kills all of the large organisms on the planet, then the small organisms will continue to survive.

## Further Reading

Evolution Acts on the Phenotype

## Summary

- Evolution occurs by natural selection, the process by which organisms with traits that better enable them to adapt to their environment will tend to survive and reproduce in greater numbers. Evolution is due to differences in the survival and reproduction of individuals within a population.
- Natural selection occurs when there is some variation in the inherited traits, some of these traits will give individuals an advantage over others, and the individuals with certain traits will be more likely to have more offspring.

## Review

1. What's the difference between an acquired and inherited trait?
2. Define natural selection.
3. What is an adaptation?
4. What is required for natural selection to take place?
5. How many species are there on the planet?

# 3.7 Significance of Mutations - Advanced

## Learning Objectives

- Discuss the significance of germline and somatic mutations.
- Explain why some mutations are harmful and some beneficial.
- Discuss the relationship between mutations and evolution.

### Is this rat hairless?

Yes. Why? The result of a mutation, a change in the DNA sequence. The effects of mutations can vary widely, from being beneficial, to having no effect, to having lethal consequences, and every possibility in between.

## Significance of Mutation

Are all mutations bad? No. Obviously large chromosomal changes are going to have a significant effect. But what about single base changes? Many single base mutations most likely have no effect, unless they change the reading frame. The effects of any one mutations can vary from having no effect to having lethal consequences.

Imagine the coding sequence (broken up into codons) TAC CCC GGG. This is a fairly generic coding sequence, and probably occurs many times in the human genome. It transcribes into the following mRNA: AUG GGG CCC, which would translate into start-glycine-proline. As glycine is encoded by four codons (GGG, GGA, GGC, GGU), any change in the third position of that codon will have no effect. The same is true for the codon for proline. If a mutation does not change the amino acid sequence in a protein, the mutation will have no effect. In fact, the overwhelming majority of mutations have no significant effect, since DNA repair mechanisms are able to mend most of the changes before they become permanent. Furthermore, many organisms have mechanisms for eliminating otherwise permanently mutated somatic cells.

But what about changes in the other nucleotides in the sequence? They could have potentially dramatic effects. The effects depend on the outcome of the mutation. Obviously any change to the start codon will interrupt the start of translation. Turning the simple glycine into the nonpolar (and relatively large) tryptophan (UGG codon) could have dramatic effects on the function of the protein. And any change to a stop codon will extend translation until the next in-frame stop codon.

Once again, a mutation is the change in the DNA or RNA sequence. In multicellular organisms, mutations can be subdivided into germline mutations and somatic mutations. **Germline mutations** occur in the DNA of sex cells, or gametes, and are therefore potentially very serious. These mutations can be passed to the next generation. If the zygote contains the mutation, every cell in the resulting organism will have that mutation. If the mutation results in a disease phenotype, the mutation causes what is called a hereditary disease. **Somatic mutations**, which occur in somatic, or body, cells, cannot be passed to the next generation (offspring). Mutations present in a somatic cell of an organism will be present (by DNA replication and mitosis) in all descendants of that cell. If the mutation is present in a gene that is not used in that cell type, the mutation may have no effect. On the other hand, the mutation may lead to a serious medical condition such as cancer.

### Mutations and Evolution

A **gene pool** is the complete set of unique alleles in a species or population. Mutations create variation in the gene pool. Populations with a large gene pool are said to be genetically diverse and very robust. They are able to survive intense times of natural selection against certain phenotypes. During these times of selection, individuals with less favorable phenotypes resulting from deleterious alleles (due to mutations) may be selected against and removed from the population. Concurrently, the more favorable mutations that cause beneficial or advantageous phenotypes tend to accumulate in that population, resulting, over time, in evolution. In fact, without any change in the gene pool, without any new alleles added due to new mutations, evolution could not occur. Genetic change is the driving force of evolution. In fact, **evolution** can be genetically defined as the change allele frequencies over time.

Mutations are the key to species evolving. Lets say an organism "mutates" due to a new allele for a gene that determines coat color. There are, theoretically, only three outcomes of that mutation:

1. The "new" coat color does not allow the organism to camouflage itself. The organism dies and the new allele dies with it.
2. The mutation has no significant effect on organism. The organism lives as before, passing the allele to its offspring.
3. The mutation is beneficial to the organism. The organism can hunt and survive more efficiently than before. Individuals with this beneficial allele live longer and reproduce more; they are more "fit" to survive in their environment. This is the basis of Darwin's "survival of the fittest" philosophy. Soon more individuals within the population have the beneficial allele.

### Beneficial Mutations

Heart disease is the number one killer of Americans, and a significant health concern all over the world. Except for a small community in Italy.

All humans have a gene for a protein called Apolipoprotein A1 (Apo-A1), which is part of the system that transports cholesterol through the bloodstream. Apo-A1 is an high density lipoprotein (HDL). HDLs are known as "good" cholesterol as they remove cholesterol from artery walls. A small community in Italy is known to have a mutant version of this protein, named Apolipoprotein A1-Milano (or Apo A1M). This protein is even more effective at removing cholesterol from cells and dissolving arterial plaques associated with heart disease. It also acts as an antioxidant, preventing arterial damage from inflammation that normally occurs in **arteriosclerosis**. People with the Apo-A1M gene have significantly lower levels of risk than the general population for heart disease.

Antioxidants are important for the health of a cell. An **antioxidant** is a molecule that inhibits the oxidation of other molecules. Oxidation is a chemical reaction that transfers electrons or hydrogen from a substance to an oxidizing agent, producing free radicals in the process. These free radicals initiate a chain reaction in the cell that can cause cell damage, or can lead to cell death. Antioxidants prevent these chain reactions from even initiating.

Beneficial mutations are also found in many bacteria that allow them to survive in the presence of antibiotic drugs. The mutations lead to **antibiotic-resistant** strains of bacteria, producing strains that have adapted to their environment. By definition, that is evolution.

### Harmful Mutations

Mutations can result in errors in protein sequence, creating partially or completely non-functional proteins. These can obviously result in harm to the cell and organism. To function correctly and maintain **homeostasis**, each cell depends on thousands of proteins to all work together to perform the functions of the cell. When a mutation alters a protein that plays a critical role in the cell, the cell, tissue, organ, or organ system may not function properly, resulting in a medical condition. A condition caused by mutations in one or more genes is called a **genetic disorder** or genetic disease. However, only a small percentage of mutations cause genetic disorders; most have no impact on health. If a mutation does not change the protein sequence or structure, resulting in the same function, it will have no effect on the cell. Often, these mutations are repaired by the DNA repair system of the cell. Each cell has a number of pathways through which enzymes recognize and repair mistakes in DNA (**Figure** 3.20). Because DNA can be damaged or mutated in many ways, the process of DNA repair is an important way in which the cell protects itself to maintain proper function.

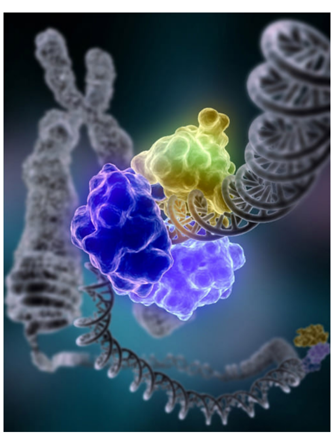

FIGURE 3.20

DNA repair. Shown is a model of DNA ligase repairing chromosomal damage. DNA ligase is an enzyme that joins broken nucleotides together by catalyzing the formation of a bond between the phosphate group and deoxyribose sugar of adjacent nucleotides in the DNA backbone.

Cystic fibrosis is an example of a genetic disorder. A mutation in a single gene causes the body to produce thick, sticky mucus that clogs the lungs and blocks ducts in digestive organs.

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**Cancer** is a disease in which cells grow out of control and form abnormal masses of cells. It is generally caused by mutations in genes that regulate the cell cycle. Because of the mutations, cells with damaged DNA are allowed to divide without limits. Cancer causing genes can be inherited.

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## Summary

- Mutations are essential for evolution to occur because they increase genetic variation and the potential for individuals to differ.
- The majority of mutations are neutral in their effects on the organisms in which they occur.
- Harmful mutations can result in errors in protein sequence, creating partially or completely non-functional proteins.
- Harmful mutations may cause genetic disorders or cancer.

## Review

1. What is a germline mutation? A somatic mutation?
2. Explain why some mutations are harmful and some beneficial.
3. Define a genetic disease.
4. Define cancer.

# 3.8 Genetic Engineering

Clone of Dolly and her lamb.

## How can learning about DNA solve new problems?

Once scientists recognized the importance of DNA and how DNA controlled the production of proteins, they began to use this knowledge to solve new problems. One problem that scientists had to solve was how to get DNA to make protein in the laboratory. For example, the pancreas of a person who has diabetes may not make insulin. Insulin is a protein that helps the body regulate the use of sugar. Until the 1980s, a person with diabetes had to take artificial insulin that was extracted from the body of a pig. But there were problems associated with using nonhuman insulin. Now human insulin can be made in a laboratory. The production of human insulin resulted from genetic engineering.

The process of getting genes to produce their proteins in the laboratory is called **genetic engineering**. Genetic engineering uses the quick reproducing capabilities of certain types of cells, such as bacterial cells, to make lots of copies of certain proteins, such as insulin. To do this, the genetic engineer must put the DNA gene for the protein to be produced into the bacteria in such a way that the bacteria will duplicate it. The new genetic material in the bacteria is called recombinant DNA (or rDNA).

Bacteria are important workhorses for genetic engineering because scientists can put foreign, recombinant DNA into them. Even though bacteria are simple cells, their own genetic material is very complex. It would be very difficult to put recombinant DNA into the bacterial chromosome. But bacteria can have little circles of DNA outside of their chromosome that replicate like the chromosome replicates. These circles of DNA are called plasmids. Molecular biologists have figured out how to put (or splice) DNA from other organisms into bacterial plasmids. Then the bacteria replicate these plasmids with the inserted genes. In this way, it is possible to use bacteria to make many, many copies of a gene. Making copies of a gene in this way is called **cloning**.

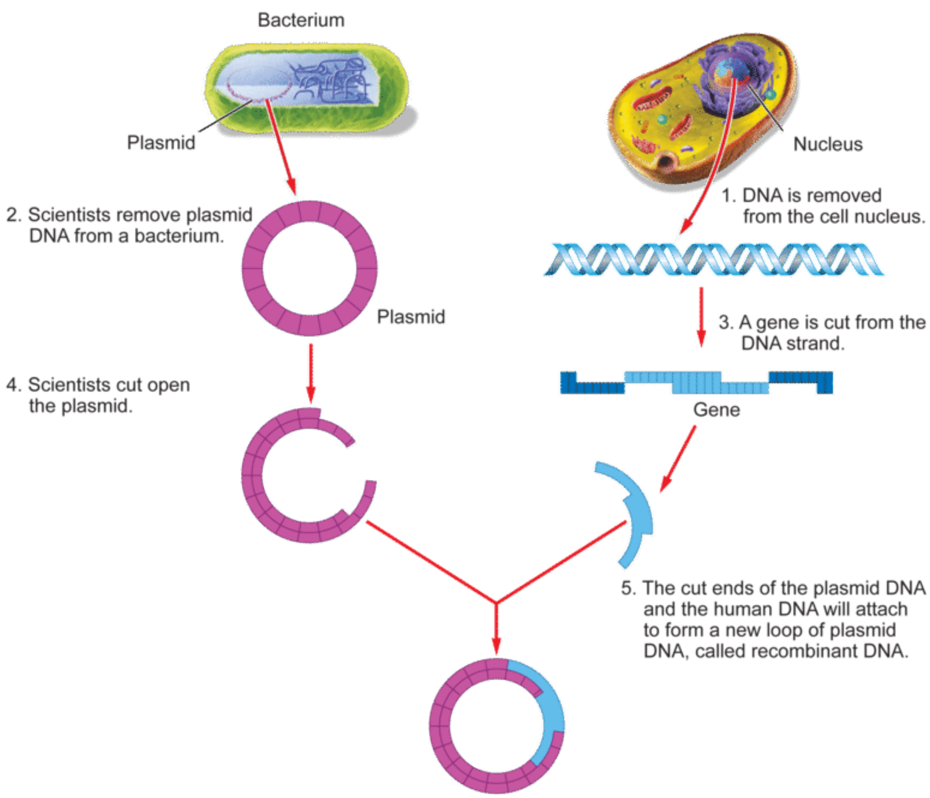


**Figure 9.1** The process for making recombinant DNA follows.

1. Scientists remove DNA from a cell nucleus.
2. Scientists remove plasmid DNA from a bacterium.
3. The gene is cut from the DNA strand.
4. Scientists cut open the plasmid.
5. The cut ends of the plasmid DNA and the human DNA will attach to form a new loop of plasmid DNA, called recombinant DNA.

Scientists use special containers that have all the nutrients these bacterial cells need to grow and reproduce as quickly as possible. After the bacterial cells grow and divide many times and produce all of the proteins coded by the plasmid DNA, the scientists open the cells and remove the proteins needed, such as insulin.

The illustration below summarizes how bacteria can be used to make human insulin.

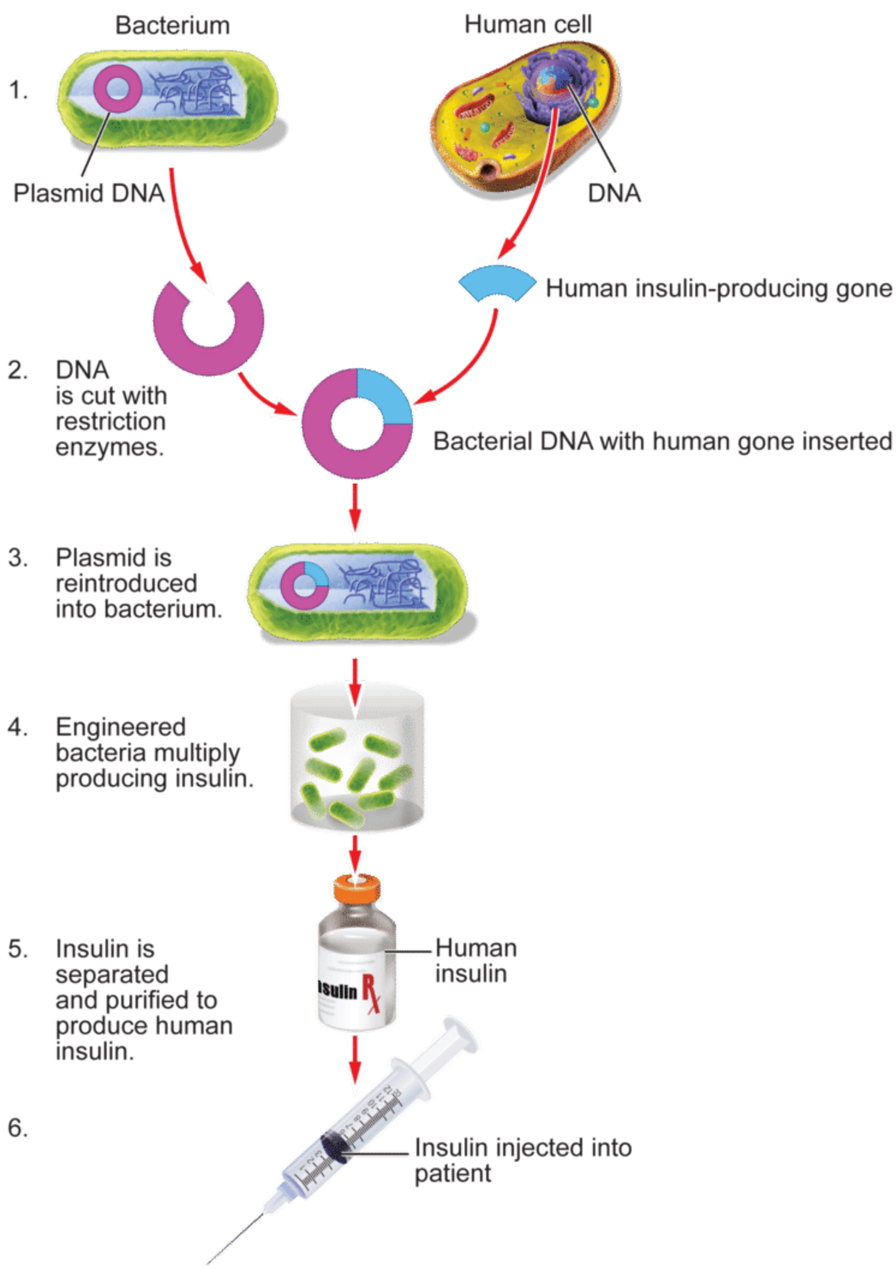


**Figure 9.2** The process for making insulin through genetic engineering follows.

1. Scientists remove DNA from a human cell nucleus and plasmid DNA from a bacterial cell.
2. The desired gene is removed from the human DNA and recombined with plasmid DNA.
3. The plasmid is put back into bacteria.
4. Scientists then grow colonies of bacteria in special vessels.
5. Scientists remove the desired proteins from the cells-in this case, insulin.
6. The insulin is purified and, then, is available for human use.

Mini-Activity

**Role-Play! Issues in Genetic Engineering**.
In groups of five, discuss the following question: Does scientific research, especially in the area of genetics, always serve the best interests of people?
Each person plays one of the following roles.

- Geneticist
- Ordinary person with little knowledge of genetics
- Person with a genetically inherited condition
- Owner of a large drug company that sells proteins such as insulin
- Elected government official, such as a senator

Decide what people's vested interests are. What helps them succeed in their jobs? For example, a geneticist depends on government funding for his or her research laboratory, and receiving that government funding depends on the geneticist's reputation for making new and important scientific discoveries. Or a government official might have many pharmaceutical companies in his or her state.

**What Do You Think?**

Think of a plant or a genetic condition that might be improved through DNA technology. Write a paragraph describing the improvements you might make. Also discuss some of the risks that might be involved in this genetic engineering project.

**Figure 9.2** makes these processes look simple. However, consider some of the problems that geneticists had to solve to develop this technology to produce insulin. Scientists had to

1. find the human gene that directs the production of insulin,
2. isolate the DNA containing the insulin gene,
3. put (splice) the insulin gene in a plasmid,
4. insert the plasmid into the bacterium,
5. get the plasmid DNA to replicate,
6. get the bacterium to reproduce, and
7. isolate those bacteria that have the plasmid with the human DNA.
8. get the human DNA to function in the bacteria, that is, get the human DNA to replicate and produce the insulin protein.
9. purify the insulin produced.

In spite of all these difficulties, recombinant DNA technology is a rapidly growing area of genetics called molecular genetics. Scientists have reproduced or are close to being able to reproduce the DNA coding for many proteins including the following.

- Insulin, the protein that controls diabetes
- Interferon, a protein that is used in cancer therapy and to prevent and/or cure certain viral diseases such as rabies, hepatitis, and herpes

- Human growth hormone
- An enzyme that breaks up protein
- Cloned anti-viral vaccines are being tested.

Scientists are also using recombinant DNA technology to improve food crops. Imagine a tomato plant that makes a protein that kills the bugs that eat it but is safe for humans. The potential for recombinant DNA technology is unlimited.

### Human Genome Project

The Human Genome Project is addressing one of the most monumental problems that scientists are working on-how to locate all of the human genes in the 23 pairs of chromosomes. To solve such a huge problem, geneticists, biologists, chemists, engineers, computer scientists, mathematicians, and many others from all over the world joined together in 1989 to create the Human Genome Project. **Genome** is a word meaning all the DNA-genes of a species. The process of determining the location of a gene on a chromosome is called **gene mapping**. The current estimate is that humans have about 20,000 to 24,000 genes. It also is estimated that there are over 3 billion pairs of nucleotides that make up human DNA.

Some people might ask, "Why would scientists want to be able to locate all of the human genes?" One answer is that scientists, as human beings, are curious about nature. They are always asking ***why***, and they want to know more. Another reason to locate all of the human genes is to improve health. There are thousands of genetic conditions that result in an illness or a handicap that are caused by single gene defects. Although some of these conditions have symptoms that can be treated, we have no way to treat the diseases themselves, let alone to cure the people who have the disease. Those working on the Human Genome Project hope that its research will enable us to learn more about genetic diseases and help lead to cures. In addition, those working on the Project believe that the research will provide tools for learning more about the causes of other human diseases including cancer, schizophrenia, and Alzheimer's disease.

**Journal Writing**

You are a United States senator arguing about continued funding for the Human Genome Project. Should the project continue to receive funding? If so, should the funding be limited to certain types of research? As a government-funded project, should the project be required to make all of its findings public?

The scientists working on the Human Genome Project expect that the entire human genome will be sequenced early in the 21st century. Already the entire genome of some organisms that are simpler than humans have been sequenced. The technology that made it possible to locate, isolate, splice, and clone the gene for insulin is the same technology that is being used in the Human Genome Project.

Exactly 6,218 genes were mapped as of April 19, 1998. Most of the known genes that have been mapped are genes that cause diseases, such as sickle-cell anemia and cystic fibrosis. There is still much work to be done on mapping human genes. But the most important work still remains-figuring out what all of the estimated 20,000 to 24,000 human genes do and how they do it. Also, questions about the variations in human genes need to be addressed. After all, whose genomes are being sequenced by the Human Genome Project? How do they differ from yours?

One important fact about human genes that has been learned is that a gene is not contained in a single continuous location on a chromosome. Rather, a gene seems to have three types of nucleotide sequences. **Figure 9.3** shows the three types of nucleotide sequences.

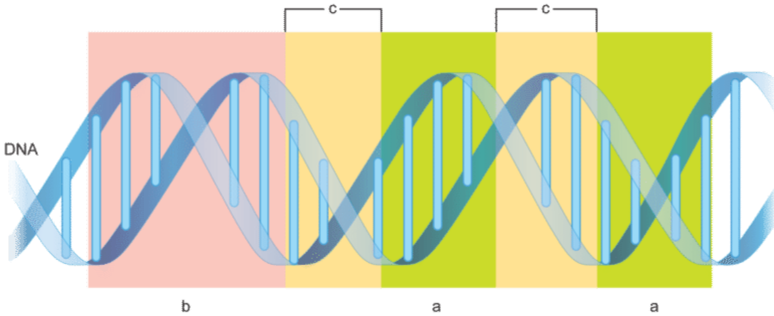


**Figure 9.3** Every gene has three types of nucleotide sequences interspersed along a length of DNA. One type of nucleotide sequence is the code for a particular protein (a). Another type of nucleotide sequence, usually at the start of the gene, tells the cell whether or not to make that gene's protein (b). That is, the (b) site turns on and turns off the (a) site. The last type is nucleotides that don't seem to code for anything (c).


**Gene Information** Imagine it is the year 2010, and the Human Genome Project has been successful. The names and locations of all of the human genes on chromosomes are known. Discuss the following questions with a group of your classmates.

1. The local hospital is offering free chromosome tests. The tests will take a day and you can learn if you have a genetic predisposition to develop cancer. Will you take the test? Why or why not?
2. You also can find out which other recessive alleles (alleles for traits that are not expressed) you are carrying. Will you take this test? Why or why not?
3. Would you take your children to have these tests? Why or why not? Discuss your responses with the class.


**Explaining Genetics** Pick one big idea from this unit and design a way to share that idea with someone who is not in your science class. You might choose a parent, since many of the things you studied were not known when your parents went to school. You might choose a younger person in your school or a sibling. Explain the idea with a cartoon, poster, or story.

Some scientists are calling the nucleotides that don't seem to code for anything "junk" DNA. But scientists are learning so much about DNA, we may someday learn that the junk DNA is doing something, may be even something important.

While the current genetic technology has helped scientists learn quite a lot about human DNA, genes, and chromosomes, it is slow, expensive, and still subject to error. The Human Genome Project itself, however, is improving the quality and precision of genetic technology.

Some people worry that the Human Genome Project will have harmful effects on human life. If we know where all the human genes are located, could parents order a human being with the variations they want, rather than allow the chromosomes with genes and alleles to sort at random (naturally)? Will knowing more about human genes and chromosomes increase tolerance for the great variety of humans or increase discrimination? As a result, one group of people in the Human Genome Project is studying the possible effects the project will have on people so we can avoid and solve potential problems.

### Summary

Genetics is the study of the biological causes of genetic continuity and diversity. To learn about continuity and diversity, geneticists study how traits and variations are inherited. Some geneticists study the inheritance of traits and variations at the cellular level. These geneticists are concerned with genes, alleles, and chromosomes. Other geneticists study traits and variations at the molecular level. These geneticists are concerned with the structure and function of DNA and with protein synthesis. Some geneticists are concerned with variations that cause people to be disabled. Other geneticists study inheritance among large groups of people rather than inheritance in individual families.

As a result of their research, geneticists are able to tell us many things about the inheritance of traits and variations. The results of their research also lead to more and more unanswered questions. Genetics is an area of science that is changing very rapidly as we learn more about the human genome. Some geneticists are even studying the ethical and public policy implications of new discoveries in genetics.

**Mini-Activity**

**Concept Map** Review your notes and the key ideas from each section of the text. With a partner, choose 10 concepts that have been presented in the genetics unit. Think like a geneticist and explain how they are related. Use a concept map to display those relationships.

## Activity 9-1: Biotechnology in the U.S. Senate

### Introduction

Participate in a Senate committee hearing on the future of biotechnology. Here is the scenario.

A molecular biologist has improved ways to clone organisms-plants, animals, and humans. Reactions from your constituents to this technology are mixed and range from support to violent opposition. The question you need to address is, *"Should there be new laws that regulate gene research and genetic engineering?"* You know that science, technology, politics, and ethics all come together to address this question. What will you recommend to the Senate?

Consider the following issues in determining your response.

- Will this development lead to cures for dreaded diseases such as cancer and AIDS?
- Should there be limits on genetically engineered fruits and vegetables?
- Should there be limits on cloning plants, humans, and other animals?
- How much financial support should the government provide for biotechnology research?

Conduct a Senate hearing to investigate research and applications in the field of biotechnology, specifically, genetic engineering.

### Materials

- Resources on: genetics; genetic diseases; biotechnology; cloning of plants, humans, and other animals; recombinant DNA technology; gene therapy; costumes and props; and ethical opinions.

### Procedure

***Step 1*** Assign the following roles-senator, expert witnesses such as scientists involved in genetic engineering, members of the public with different opinions on the risks and benefits of genetic engineering, and scientists from companies producing genetically engineered products.

***Step 2*** Research your assigned role. Become an expert. You are responsible for the information necessary to ask or answer questions. Make up a name and an identity. Dress in appropriate attire.

***Step 3*** Participate in the Senate hearing that is set up in your class.

***Step 4*** Submit an opinion paper to the Senate committee at the conclusion of the hearing. The Senate committee will consider your opinions as it prepares its recommendation for the Senate.

*Journal Writing*

Do you think the Human Genome Project is more likely to help or hurt humankind? Why? Defend your choice.

## Review Questions

1. What is recombinant DNA? Why is it important?
2. Why are bacteria used in genetic research?
3. What are five necessary steps in making recombinant DNA?
4. Why is mapping human genes important to scientists' knowledge of the human genome?

# 3.9 References


1. Mariana Ruiz Villarreal (LadyofHats) for CK-12 Foundation;Ernst Haeckel;Human: User:MrKimm/Wikimedia Commons; Chimpanzee: Afrika Force; Gorilla: Roger Luijten; Baboon: Birdseye Maple;Hana Zavadska;Frog in resin: Image copyright Galyna Andrushko, 2014; Footprint: Edmondo Gnerre. CK-12 Foundation;http://en.wikipedia.org/wiki/File:Age-of-Man-wiki.jpg;Human: http://commons.wikimedia.org/wiki/File:Human-gender-neutral.png; Chimpanzee: http://www.flickr.com/photos/afrikaforce/5187391191; Gorilla: http://www.flickr.com/photos/66555186@N02/6312198231; Baboon: http://www.flickr.com/photos/26198976@N04/4007297452;Frog in resin: http://www.shutterstock.com; Footprint: http://commons.wikimedia.org/wiki/File:Tuba_City_Dinosaur_Track.jpg . Human: Public Domain; Chimpanzee, Gorilla, Baboon: CC BY 2.0;CC BY-NC 3.0
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191; Gorilla: http://www.flickr.com/photos/66555186@N02/6312198231; Baboon: http://www.flickr.com/photos/26198976@N04/4007297452;http://commons.wikimedia.org/wiki/File:Homology.jpg;https://commons.wikimedia.org/wiki/File:Caribbean_reef_shark.jpg . Human: Public Domain; Chimpanzee, Gorilla, Baboon: CC BY 2.0

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# CHAPTER 4 Unit 4: Using Engineering & Technology to Sustain Our World

## Chapter Outline


4.1 POPULATION SIZE

4.2 REVOLUTIONS IN HUMAN POPULATION GROWTH

4.3 TYPES OF WAVES

4.4 REFLECTION OF MECHANICAL WAVES

4.5 PROPERTIES OF ELECTROMAGNETIC WAVES

4.6 WIND WAVES

4.7 REFERENCES

# 4.1 Population Size

## Learning Objectives

- Describe the factors that regulate population size.

### How many penguins are the right number for this beach?

As many as can survive and have healthy offspring! A population will tend to grow as big as it can for the resources it needs. Once it is too large, some of its members will die off. This keeps the population size at the right number.

## Populations

Biotic and abiotic factors determine the population size of a species in an ecosystem. What are some important biotic factors? Biotic factors include the amount of food that is available to that species and the number of organisms that also use that food source. What are some important abiotic factors? Space, water, and climate all help determine a species population.

When does a population grow? A population grows when the number of births is greater than the number of deaths. When does a population shrink? When deaths exceed births.

What causes a population to grow? For a population to grow there must be ample resources and no major problems. What causes a population to shrink? A population can shrink either because of biotic or abiotic limits. An increase in predators, the emergence of a new disease, or the loss of habitat are just three possible problems that will decrease a population. A population may also shrink if it grows too large for the resources required to support it.

### Carrying Capacity

When the number of births equals the number of deaths, the population is at its **carrying capacity** for that habitat. In a population at its carrying capacity, there are as many organisms of that species as the habitat can support. The carrying capacity depends on biotic and abiotic factors. If these factors improve, the carrying capacity increases. If the factors become less plentiful, the carrying capacity drops. If resources are being used faster than they are being replenished, then the species has exceeded its carrying capacity. If this occurs, the population will then decrease in size.

### Limiting Factors

Every stable population has one or more factors that limit its growth. A **limiting factor** determines the carrying capacity for a species. A limiting factor can be any biotic or abiotic factor: nutrient, space, and water availability are examples (**Figure** 4.1). The size of a population is tied to its limiting factor.

FIGURE 4.1

In a desert such as this, what is the limiting factor on plant populations? What would make the population increase? What would make the population decrease?

What happens if a limiting factor increases a lot? Is it still a limiting factor? If a limiting factor increases a lot, another factor will most likely become the new limiting factor.

This may be a bit confusing, so let's look at an example of limiting factors. Say you want to make as many chocolate chip cookies as you can with the ingredients you have on hand. It turns out that you have plenty of flour and other ingredients, but only two eggs. You can make only one batch of cookies, because eggs are the limiting factor. But then your neighbor comes over with a dozen eggs. Now you have enough eggs for seven batches of cookies, but only two pounds of butter. You can make four batches of cookies, with butter as the limiting factor. If you get more butter, some other ingredient will be limiting.

Species ordinarily produce more offspring than their habitat can support (**Figure** 4.2). If conditions improve, more young survive and the population grows. If conditions worsen, or if too many young are born, there is competition between individuals. As in any competition, there are some winners and some losers. Those individuals that survive to fill the available spots in the niche are those that are the most fit for their habitat.

FIGURE 4.2
A frog in frog spawn. An animal produces many more offspring than will survive.

MEDIA
Click image to the left or use the URL below.

## Summary

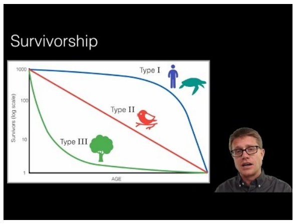
- Biotic factors that a population needs include food availability. Abiotic factors may include space, water, and climate.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

## Review

1. Why don't populations continue to grow and grow?
2. What happens if a population exceeds its carrying capacity?
3. What happens if a factor that has limited a population's size becomes more available?

## Explore More

Use this resource to answer the questions that follow.




MEDIA

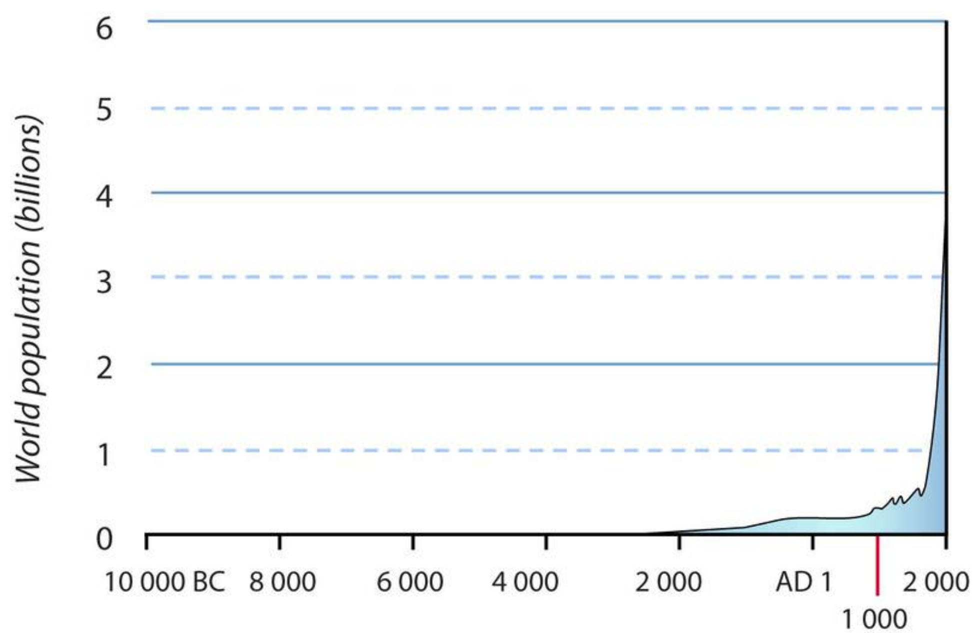
Click image to the left or use the URL below.

1. Under what circumstances can population growth be exponential?
2. What is carrying capacity?
3. What does reaching the carrying capacity do to population growth?
4. What does carrying capacity depend on?
5. What happens if a population exceeds its carrying capacity?
6. Is the carrying capacity constant? What changes it?
7. What are the two ways to eliminate a pest from your home?
8. Give the definition of density dependent factors that are limiting to population growth.
9. Give four examples and explain them for density dependent factors.
10. How do natural disasters affect the population size in a region?

# 4.2 Revolutions in Human Population Growth

## Learning Objectives

- Explain what has caused the rises in human population numbers.




### Where on the graph are the major population changes?

Let's look at this graph again. It shows human population from 10,000 BC through 2000 AD. Where are the big changes in slope of the line? Can you identify them? In this concept, we'll learn what causes them.

## What Causes Human Populations to Grow?

Look at the graph above. Human population increased dramatically at certain times. The graph begins 10,000 BC, although you can't really see the line. Population starts to rise perceptibly at around 1800 BC. The numbers begin to rise dramatically about 200 years ago. What causes these changes?

### Agricultural Revolution

Farming was developed about 10,000 years ago. Farming meant a steady supply of food. People could settle in villages. The rise at around 1800 BC is due to increased farming and the rise of cities and towns. The population rises steadily until around 1800 AD. At that time it shoots up dramatically. Really dramatically. What happened?

### Industrial Revolution

The **Industrial Revolution** is what happened. The Industrial Revolution began in the late 1700s in Europe, North America, and a few other places. Before the Industrial Revolution, most labor was done by people. The Industrial Revolution changed the source of power from humans to fossil fuels. This allowed more work to be done and more food to be grown. People began to move into cities.

Where the Industrial Revolution was taking place, the human population started to grow really fast. The birth rate was always high. What changed was the death rate. The population grew because more people stayed alive. The death rate fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (**Figure** 4.3). This helped reduce the spread of disease.

FIGURE 4.3
Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for awhile. This caused rapid population growth.

### The Green Revolution

The most recent increase in the slope of the population line is because of another advance in agriculture. The **Green Revolution** began in the mid-1900s. The Green Revolution has allowed billions of people to be added to the population in the past few decades. New methods and products increased how much food could be grown. These advances include:

- Improving crops by selecting for certain genetic traits. The desired traits promote productivity. Recently, genetically engineered crops have been introduced.
- Increasing the use of artificial fertilizers and chemical **pesticides**.
- Increasing the use of agricultural machinery: plowing, tilling, fertilizing, picking, and transporting. These machines are powered by fossil fuels, rather than humans.
- Increasing access to water. Many rivers have been dammed. Wells tap into many groundwater aquifers.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

### The Health Revolution

Health care has been improving over the most recent centuries. **Vaccines** were developed that could prevent many diseases (**Figure** 4.4). **Antibiotics** were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.

FIGURE 4.4
This child is getting a polio vaccine. She will never get sick with polio, which could save her life or keep her from becoming crippled.

## Summary

- Farming allowed people to have a steady food source and settle down. The Green Revolution has dramatically increased agricultural productivity.
- The Industrial Revolution brought new machinery, increased the food supply, and improved sanitation.
- Vaccinations and antibiotics have greatly improved human health.
- With a dramatically lower death rate, human populations have grown.

## Review

1. What caused the first rise in human population?
2. Why has the Industrial Revolution altered human population numbers?
3. How has the Green Revolution increased agricultural productivity?
4. If the birth rate doesn't change but the death rate goes down, what happens to population?

## Explore More

Use the resources below to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.

1. Where did most people work in the late 1700s? Who did they work for?
2. What did the new machines do?
3. What became more affordable?
4. Why did families move? Where did they move from and to?
5. Who were the workers? Who did they work for?
6. What problems did industrialization cause?
7. Where were the worst conditions?

8. Why were unions formed?

# 4.3 Types of Waves

## Learning Objectives

- Compare and contrast a longitudinal wave and a transverse wave.
- Describe general wave properties.

The **period**, $T$, is the amount of time for the harmonic motion to repeat itself, or for the object to go one full cycle. In SHM, $T$ is the time it takes the object to return to its exact starting point and starting direction. The period of a wave depends on the period of oscillation of the object creating the wave.

The **frequency**, $f$, is the number of cycles an object or wave goes through in 1 second. Frequency is measured in Hertz (Hz). 1 Hz = 1 cycle per sec.

The **amplitude**, $A$, is the distance from the *equilibrium* (or center) *point* of motion to either its lowest or highest point (*end points*). The amplitude, therefore, is half of the total distance covered by the oscillating object. The amplitude can vary in harmonic motion but is constant in SHM. The amplitude of a wave often determines its strength or intensity; the exact meaning of "strength" depends on the type of wave. For example, a sound wave with a large amplitude is a loud sound and a light wave with a large amplitude is very bright.

A **medium** is the substance through which the wave travels. For example, water acts as the medium for ocean waves, while air molecules act as the medium for sound waves. When a wave passes through a medium, the medium is only temporarily disturbed. When an ocean wave travels from one side of the Mediterranean Sea to the other, no actual water molecules move this great distance. Only the *disturbance* propagates (moves) through the medium. An object oscillating with frequency $f$ will create waves which oscillate with the same frequency $f$. The **speed** $v$ **and wavelength** $\lambda$ of a wave depend on the nature of the medium through which the wave travels.

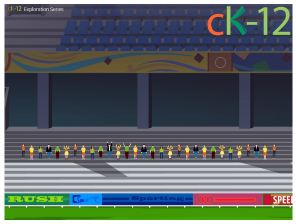
There are two main types of waves we will consider: **longitudinal** and **transverse** waves.

In **longitudinal** waves, the vibrations of the medium are in the *same direction* as the wave motion. A classic example is a wave traveling down a line of standing dominoes: each domino will fall in the same direction as the motion of the wave. A more physical example is a sound wave. For sound waves, high and low pressure zones move both forward and backward as the wave moves through them.

In **transverse** waves, the vibrations of the medium are *perpendicular* to the direction of motion. A classic example is a wave created in a long rope: the wave travels from one end of the rope to the other, but the actual rope moves up and down, and not from left to right as the wave does. Water waves act as a mix of longitudinal and transverse waves. A typical water molecule pretty much moves in a circle when a wave passes through it.

Most wave media act like a series of connected oscillators. For instance, a rope can be thought of as a large number of masses (molecules) connected by springs (intermolecular forces). The speed of a wave through connected harmonic oscillators depends on the distance between them, the spring constant, and the mass. In this way, we can model wave media using the principles of simple harmonic motion. The speed of a wave on a string depends on the material the string is made of, as well as the tension in the string. This fact is why *tightening* a string on your violin or guitar will *increase* the frequency, or pitch, of the sound it produces.

## Interactive Simulation



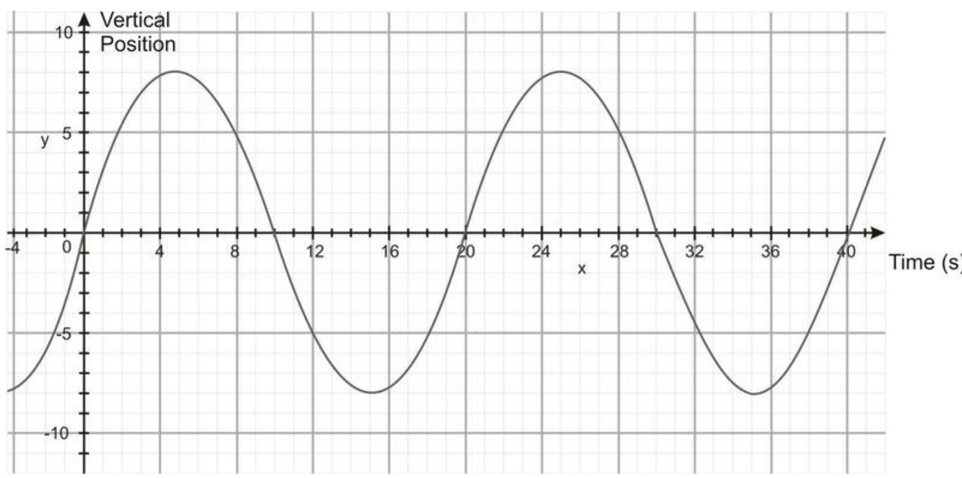
SIMULATION

Use a classic sports stadium

URL: https://romer.ck12.org/physics/wave-speed/simulationint/Stadium-Wave

## Review

1. Reread the difference between transverse and longitudinal waves. For each of the following types of waves, tell what type it is and why. (Include a sketch for each.)
   a. sound waves
   b. water waves in the wake of a boat
   c. a vibrating string on a guitar
   d. a swinging jump rope
   e. the vibrating surface of a drum
   f. the "wave" done by spectators at a sports event
   g. slowly moving traffic jams
2. A mass is oscillating up and down on a spring. Below is a graph of its vertical position as a function of time.




   a. Determine the
      i. amplitude,
      ii. period and
      iii. frequency.
   b. What is the amplitude at $t = 32$ seconds?
   c. At what times is the mass momentarily at rest? How do you know?
   d. Velocity is defined as change in position over time. Can you see that would be the slope of this graph? (slope = rise over run and in this case the 'rise' is position and the 'run' is time). Find the instantaneous speed at $t = 20$ sec.

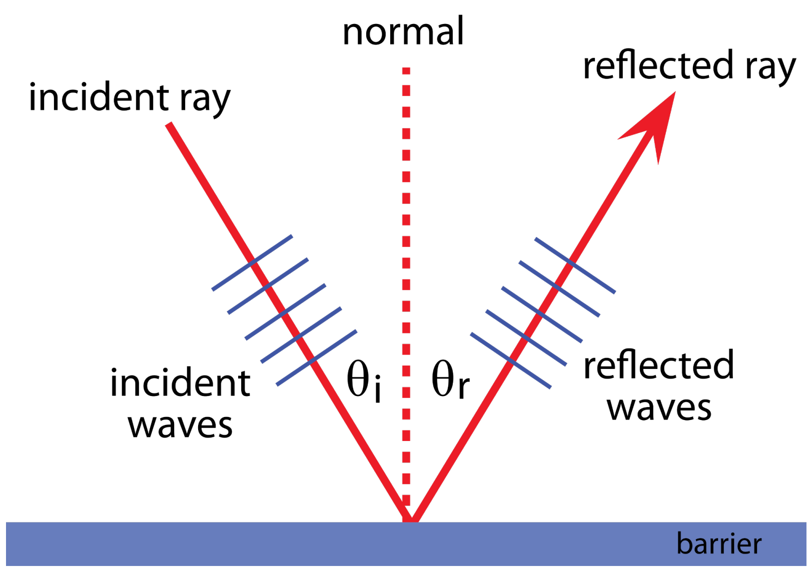
## Review (Answers)

1. a. longitudinal b. transverse c. transverse d. transverse e. transverse f. transverse g. longitudinal
2. a. i. 8 m ii. 20 s iii. 0.05 Hz b. - 4 m c. The mass is momentarily at rest at peaks (maximums) and valleys (minimums) d. $\sim$ 2.3 m/s

# 4.4 Reflection of Mechanical Waves

## Learning Objectives

- State the law of reflection.
- Solve problems using the law of reflection.
- Given data about the media on either side of a barrier, determine whether the reflected wave will be upright or inverted.



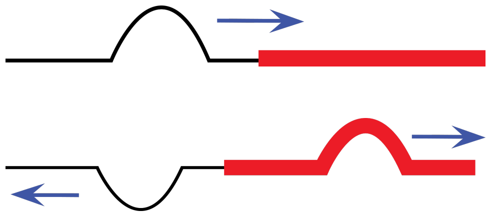

When mechanical waves strike a barrier, at least part of the energy of the waves will be reflected back into the media from which they came. You experience this anytime you hear an echo reflecting off of a wall.

## Reflection of Mechanical Waves

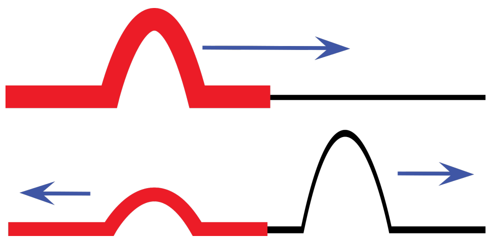
When a wave strikes an obstacle or comes to the end of the medium it is traveling in, some portion of the wave is reflected back into the original medium. It reflects back at an equal angle that it came in. These angles are called the **angle of incidence** and the **angle of reflection**. The normal line, the incident and reflected rays, and the angles of incidence and reflection are all shown in the diagram sketched above. The **law of reflection** states that the angle of incidence equals the angle of reflection. These rules of **reflection** apply in the cases of water waves bouncing off the side of a pool, sound waves echoing off a distant cliff, or wave pulses traveling down a rope or a slinky.

Consider the change that would occur with a light rope joined to a heavier rope. When a wave pulse travels down the rope and encounters the media change, a reflection will occur. Look at the image below. In the top sketch, we see a lightweight (black) rope attached to a heavier rope (red). There is a wave pulse traveling down the rope from left to right. When the wave pulse encounters the barrier (the change in rope weight), part of the wave moves into the new medium and part of the wave is reflected back into the old medium.

As you can see in the bottom half of the diagram, the transmitted portion of the wave continues into the new medium right side up. The transmitted wave is somewhat diminished because some of the energy of the wave was reflected and also because the rope to be lifted is heavier. The reflected wave is also diminished because some of the energy was transmitted through the barrier. The reflected wave is also inverted (upside down). This is a general rule for mechanical waves passing from a less dense medium into a more dense medium, that is, the reflected wave will be inverted.

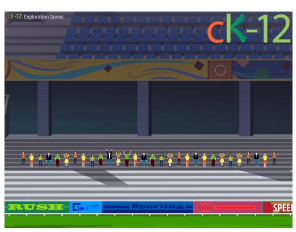


The situation changes when the wave is passing from a more dense medium into a less dense medium. As you can see in the sketch below, when a wave pulse moving in denser medium encounters a media interface to a medium of less density, the reflected wave is upright rather than inverted.



It is also possible for a mechanical wave to encounter an impenetrable barrier, that is, a barrier which does not allow any transmission at all. In such a case, the complete wave pulse will be reflected and the reflected wave will be inverted.

## CK-12 Interactive




SIMULATION

Use a classic sports stadium

URL: https://romer.ck12.org/physics/wave-speed/simulationint/Stadium-Wave

## Summary

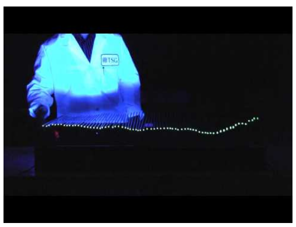
- When a wave strikes an obstacle or comes to the end of the medium it is traveling in, some part of the wave is reflected back into the original medium.
- The law of reflection states that the angle of incidence equals the angle of reflection.
- The general rule, for mechanical waves passing from a less dense medium into a more dense medium, the reflected wave will be inverted.
- When a wave pulse moving in denser medium encounters a media interface to a medium of lesser density, the reflected wave is upright rather than inverted.
- When a mechanical wave encounters an impenetrable barrier, the complete wave pulse will be reflected and the reflected wave will be inverted.

## Review

1. Draw a diagram showing a surface with a normal line. On the diagram, show a wave ray striking the surface with an angle of incidence of 60°. Draw the reflection ray on the diagram and label the angle of reflection.
2. A sound wave strikes a smooth surface at 30° to the normal. What will the angle of reflection be?
3. If the angle between the incident ray and the reflected ray is 90°, what is the angle of incidence?
4. When a water wave is reflected from a concrete wall, will the reflected wave be inverted or upright?
5. If you tie a heavy spring to a light spring and send a wave pulse down the heavy spring, some of the wave will be reflected when the wave passes into the lighter spring. Will the reflected pulse be upright or inverted?

## Explore More

Use this video to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

1. What happens to the wave when it is reflected from an open end?
2. What happens to the wave when it is reflected from a fixed end?

## Vocabulary

- **reflection:** The change in direction of a wavefront at an interface between two different media so that the wavefront returns into the medium from which it originated.
- **law of reflection:** Says the angle at which the wave is incident on the surface equals the angle at which it is reflected.
- **angle of incidence:** The angle formed by a ray incident on a surface and a perpendicular to the surface at the point of incidence.
- **angle of reflection:** The angle formed by a reflected ray and a perpendicular to the surface at the point of reflection.

# 4.5 Properties of Electromagnetic Waves

## Learning Objectives

- State the speed of light.
- Describe wavelengths and frequencies of electromagnetic waves.
- Relate wave frequency to wave energy.
- Show how to calculate wavelength or wave frequency if the other value is known.


What do these two photos have in common? They both represent electromagnetic waves. These are waves that consist of vibrating electric and magnetic fields. They transmit energy through matter or across space. Some electromagnetic waves are generally harmless. The light we use to see is a good example. Other electromagnetic waves can be very harmful and care must be taken to avoid too much exposure to them. X rays are a familiar example. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

## Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the **speed of light**, is about 300 million meters per second (3.0 x $10^8$ m/s). Nothing else in the universe is known to travel this fast. The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second!

## Wavelength and Frequency of Electromagnetic Waves

Although all electromagnetic waves travel at the same speed across space, they may differ in their wavelengths, frequencies, and energy levels.

- Wavelength is the distance between corresponding points of adjacent waves (see the **Figure** 4.5). Wavelengths of electromagnetic waves range from longer than a soccer field to shorter than the diameter of an atom.
- Wave frequency is the number of waves that pass a fixed point in a given amount of time. Frequencies of electromagnetic waves range from thousands of waves per second to trillions of waves per second.

- The energy of electromagnetic waves depends on their frequency. Low-frequency waves have little energy and are normally harmless. High-frequency waves have a lot of energy and are potentially very harmful.

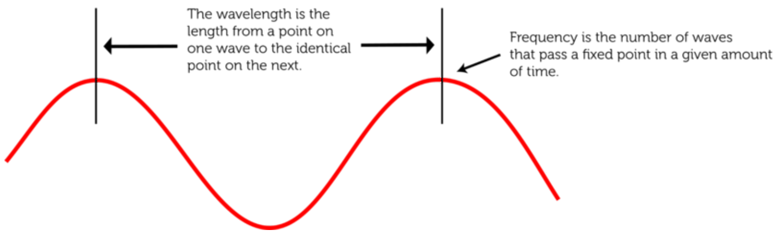



FIGURE 4.5

**Q:** Which electromagnetic waves do you think have higher frequencies: visible light or X rays?

**A:** X rays are harmful but visible light is harmless, so you can infer that X rays have higher frequencies than visible light.

## Speed, Wavelength, and Frequency

The speed of a wave is a product of its wavelength and frequency. Because all electromagnetic waves travel at the same speed through space, a wave with a shorter wavelength must have a higher frequency, and vice versa. This relationship is represented by the equation:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

The equation for wave speed can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if either wavelength or frequency is known, the missing value can be calculated. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is $3.0 \times 10^8$ meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$\text{Frequency} = \frac{3.0 \times 10^8 \text{ m/s}}{3.0 \text{ m}} = 1.0 \times 10^8 \text{ waves/s, or } 1.0 \times 10^8 \text{ Hz}$$

**Q:** What is the wavelength of an electromagnetic wave that has a frequency of $3.0 \times 10^8$ hertz?

**A:** Use the wavelength equation:

$$\text{Wavelength} = \frac{3.0 \times 10^8 \text{ m/s}}{3.0 \times 10^8 \text{ waves/s}} = 1.0 \text{ m}$$

## Summary

- All electromagnetic waves travel across space at the speed of light, which is about 300 million meters per second (3.0 x $10^8$ m/s).
- Electromagnetic waves vary in wavelength and frequency. Longer wavelength electromagnetic waves have lower frequencies, and shorter wavelength waves have higher frequencies. Higher frequency waves have more energy.
- The speed of a wave is a product of its wavelength and frequency. Because the speed of electromagnetic waves through space is constant, the wavelength or frequency of an electromagnetic wave can be calculated if the other value is known.

### Review

1. What is the speed of light across space?
2. Describe the range of wavelengths and frequencies of electromagnetic waves.
3. How is the energy of an electromagnetic wave related to its frequency?
4. If the frequency of an electromagnetic wave is $6.0 \times 10^8$ Hz, what is its wavelength?

# 4.6 Wind Waves

## Learning Objectives

- Describe the characteristics of ocean waves.
- Explain how wind forms ocean waves.

### Surfin' U.S.A.

Jaws Beach in Maui, Hawaii has legendary waves. The largest waves come when winds are very strong, usually in the winter. The rocks and reef offshore magnify the size of the incoming wave energy. Cowabunga!

## Waves

Most ocean waves are caused by winds. A **wave** is the transfer of energy through matter. A wave that travels across miles of ocean is traveling energy, not water. Ocean waves transfer energy from wind to the water. The energy is transferred from one water molecule to the next. The energy of a wave may travel for thousands of miles. The water itself moves very little. The picture below shows how water molecules move when a wave goes by (**Figure** 4.6). Once the wave starts, it doesn't need more wind to keep it going.

### The Size of Waves

The figure above also shows how the size of waves is measured (**Figure** 4.6). The highest point of a wave is the **crest**. The lowest point is the **trough**. The vertical distance between a crest and a trough is the **wave height**. Wave height is also called **amplitude**. The horizontal distance between two crests is the **wavelength**. Both amplitude and wavelength are measures of wave size.

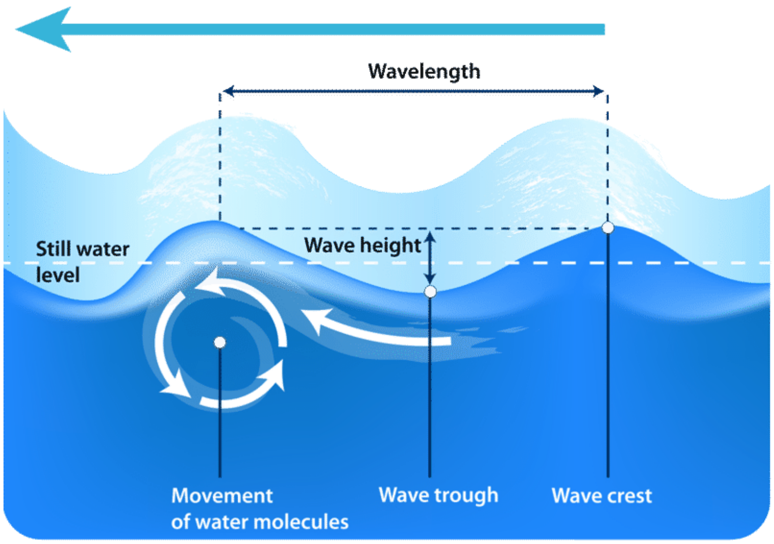



FIGURE 4.6
A wave travels through the water. How would you describe the movement of water molecules as a wave passes through?

The size of an ocean wave depends on how fast, over how great a distance, and how long the wind blows. The greater each of these factors is, the bigger a wave will be. Some of the biggest waves occur with hurricanes. A hurricane is a storm that forms over the ocean. Its winds may blow more than 150 miles per hour! The winds also travel over long distances and may last for many days.

### Breaking Waves

The figure below shows what happens to waves near shore (**Figure** 4.7). As waves move into shallow water, they start to touch the bottom. The base of the waves drag and slow. Soon the waves slow down and pile up. They get steeper and unstable as the top moves faster than the base. When they reach the shore, the waves topple over and break.

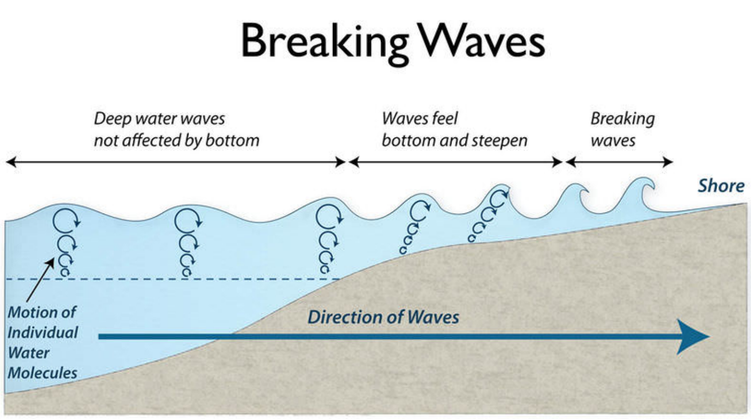



FIGURE 4.7
Waves break when they reach the shore.

## Storm Surge

Some of the damage done by storms is from **storm surge**. Low pressure in a storm pulls water upward. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft). This can be devastating in a shallow land area when winds, waves, and rain are intense.

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves.

MEDIA
Click image to the left or use the URL below.

## Summary

- The largest wind waves are built when a strong wind blows for a long time over a large area.
- It is not the water that travels in a wave; it is the energy that is transferred from where the wave formed.
- A wave breaks when it is too tall to be supported by its base. This is common as a wave moves up the shore.

## Review

1. How does a wave break onshore? How does a wave break in the ocean?
2. How does a wave move across the ocean?
3. How do hurricanes create large waves?

## Explore More

Use the resources below to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.

1. What can cause waves?
2. Where does the energy in a wave come from and how does it get into the wave?
3. What three factors affect the size and strength of waves?
4. How are large waves created?

MEDIA
Click image to the left or use the URL below.

5. What causes a wave to break at the shore?

# 4.7 References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