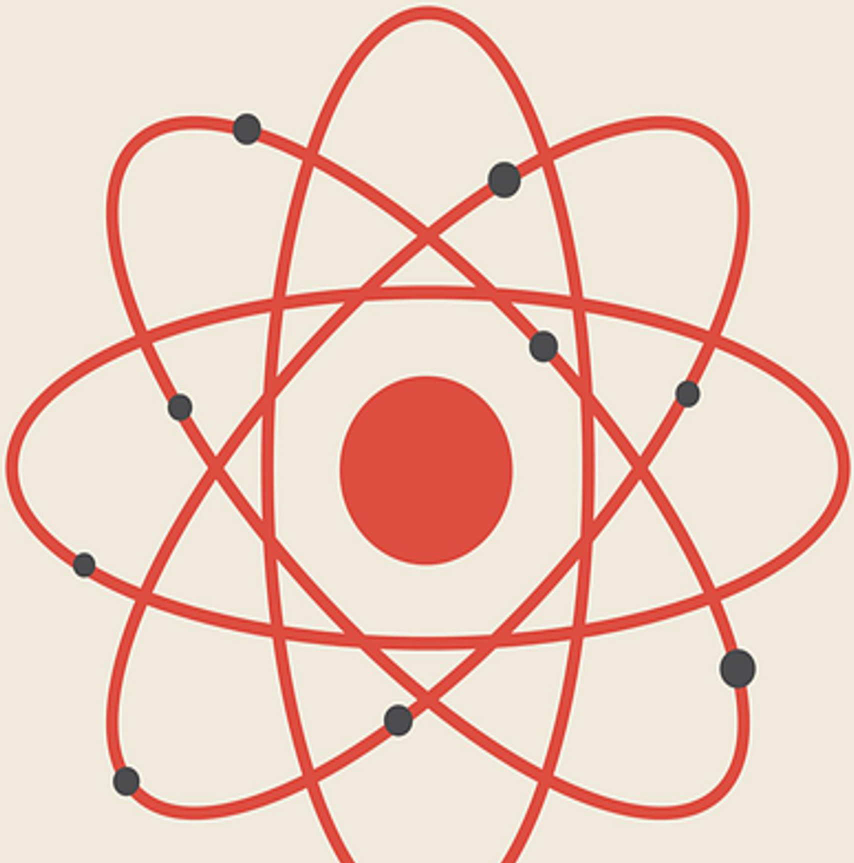
American HS Physical Science



American HS Physical Science

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MAIN CONTENT

CHAPTER 1

Introduction to Physical Science

Chapter Outline

1.1 Nature of Science

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Last Modified: Jul 30, 2020

[Figure 1]

Does the word *science* make you think of high-tech labs and researchers in white coats like the ones in this picture? This is often an accurate image of science but not always. If you look up science in a dictionary, you would find that it comes from a Latin word that means "having knowledge." However, this isn't an adequate definition either.

What is Science?

Science is more about gaining knowledge than it is about simply having knowledge. **Science** is a way of learning about the natural world that is based on evidence and logic. In other words, science is a process, not just a body of facts. Through the process of science, our knowledge of the world advances.

The Goal of Science

Scientists may focus on very different aspects of the natural world. For example, some scientists focus on the world of tiny objects, such as atoms and molecules. Other scientists devote their attention to huge objects, such as the sun and other stars. But all scientists have at least one thing in common. They want to understand how and why things happen. Achieving this understanding is the goal of science.

Have you ever experienced the thrill of an exciting fireworks show like the one pictured in the **Figure** below? Fireworks show how the goal of science leads to discovery. Fireworks were invented at least 2000 years ago in China, but explaining how and why they work didn't happen until much later. It wasn't until scientists had learned about elements and chemical reactions that they could explain what caused fireworks to create brilliant bursts of light and deep rumbling booms.

[Figure 2]

Fireworks were invented long before scientists could actually explain how and why they explode.

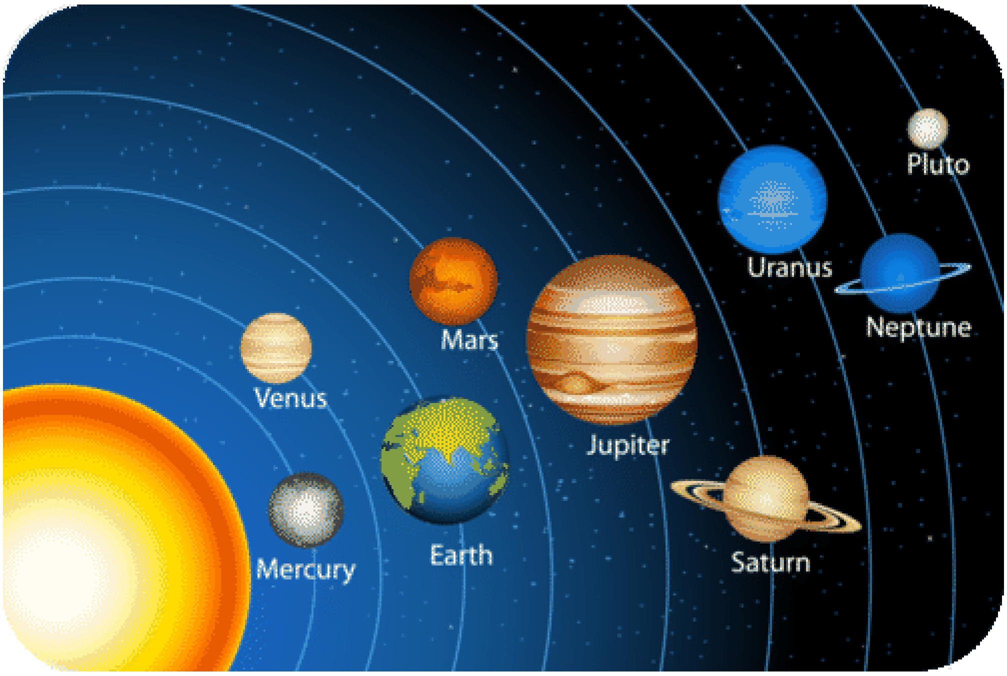
How Science Advances

Sometimes learning about science is frustrating because scientific knowledge is always changing. But that's also what makes science exciting. Occasionally, science moves forward in giant steps. More commonly, however, science advances in baby steps.

Giant steps in science may occur if a scientist introduces a major new idea. For example, in 1666, Isaac Newton introduced the idea that gravity is universal. People had long known that things fall to the ground because they are attracted by Earth. But Newton proposed that everything in the universe exerts a force of attraction on everything else. This idea is known as Newton's law of universal gravitation.

Q: How do you think Newton's law of universal gravitation might have influenced the advancement of science?

A: Newton's law helped scientists predict the motion of many other objects. It helped them study the motion of objects as they fall down toward the ground or roll downhill. It was further applied to larger objects and advanced our understanding of why the planets in our solar system orbit the sun or why the moon orbits the Earth. For example, the idea of universal gravity even helped scientists discover the planets Neptune and Pluto. The caption and diagram in the **Figure** below explain how.



[Figure 3]

In the early 1800s, astronomers noticed a wobble in Uranus' orbit around the sun. They predicted that the wobble was caused by the pull of gravity of another, not-yet-discovered planet. Scientists searched the skies for the "missing" planet. When they discovered Neptune in 1846, they thought they had found their missing planet. After the astronomers took into account the effects of Neptune's gravity, they saw that Uranus still had an unexplained wobble. They predicted that there must be another planet beyond Neptune. That planet, now called Pluto, was finally discovered in 1930. Of special note, as of 2006, the International Astronomical Union (IAU) demoted Pluto from its planet status as it does not meet one of the criteria for planetary standards.

Baby steps in science occur as small bits of evidence gradually accumulate. The accumulating evidence lets scientists refine and expand on earlier ideas. For example, the scientific idea of the atom was introduced in the early 1800s. But scientists came to understand the structure of the atom only as evidence accumulated over the next two centuries. Their understanding of atomic structure continues to expand today.

The advancement of science is sometimes a very bumpy road. New knowledge and ideas aren't always accepted at first, and scientists may be mocked for their ideas. The idea that Earth's continents drift on the planet's surface is a good example. This idea was first proposed by a scientist named Alfred Wegener in the early 1900s. Wegener also proposed that all of the present continents had once formed one supercontinent, which he named Pangaea. You can see a sketch of Pangaea in **Figure** below. Other scientists not only rejected Wegener's ideas, but ridiculed Wegener for even suggesting them. It wasn't until the 1950s that enough evidence had accumulated for scientists to realize that Wegener had been right. Unfortunately, Wegener did not live long enough to see his ideas accepted.

[Figure 4]

This map shows the supercontinent Pangaea, which was first proposed by Alfred Wegener. Pangaea included all of the separate continents we know today. Scientists now know that the individual continents drifted apart to their present locations over millions of years.

Q: What types of evidence might support Wegener's ideas?

A: Several types of evidence support Wegener's ideas. For example, similar fossils and rock formations have been found on continents that are now separated by oceans. It is also now known that Earth's crust consists of rigid plates that slide over molten rock below them. This explains how continents can drift. Even the shapes of today's continents show how they once fit together, like pieces of a giant jigsaw puzzle.

Summary

- Science is a way of learning about the natural world that is based on evidence and logic.
- The goal of science is to understand how and why things happen.
- Science advances as new evidence accumulates and allows scientists to replace, refine, or expand on accepted ideas about the natural world.

Review

1. Define science.
2. What is the goal of science?
3. Use examples to show how science may advance.

Resources

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1.2 Inductive Reasoning

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[Figure 1]

The man in this photo is a police detective. He's examining and gathering clues that may help solve a crime. Based on all of the clues he finds, he may be able to conclude who committed the crime. Working scientifically is similar to solving crimes. It also involves gathering evidence and drawing conclusions. Both detective work and science use inductive reasoning.

What Is Inductive Reasoning?

Inductive reasoning is the process of drawing general conclusions based on many clues, or pieces of evidence. Many crimes are solved using inductive reasoning. It is also the hallmark of science and the basis of the scientific method.

Q: How might the police detective pictured above use inductive reasoning to solve the crime?

A: The detective might gather clues that provide evidence about the identity of the person who committed the crime. For example, he might find fingerprints or other evidence left behind by the perpetrator. The detective might eventually find enough clues to be able to conclude the identity of the most likely suspect.

[Figure 2]

Inductive Reasoning in Science

A simple example will help you understand how inductive reasoning works in science. Suppose you grew up on a planet named Quim, where there is no gravity. In fact, assume you've never even heard of gravity. You travel to Earth (on a student exchange program) and immediately notice things are very different here than on your home planet. For one thing, when you step out of your spacecraft, you fall directly to the ground. Then, when you let go of your communications device, it falls to the ground as well. On Quim, nothing ever falls to the ground. For example, if you had let go of your communications device back home, it would have just stayed in place by your upper appendage. You notice that everything you let go of falls to the ground. Using inductive reasoning, you conclude that all objects fall to the ground on Earth.

Then, you make the observation pictured (**Figure** below). You see round objects rising up into the sky, rather than falling toward the ground as you expect. Clearly, your first conclusion—although based on many pieces of evidence—is incorrect. You need to gather more evidence to come to a conclusion that explains all of your observations.

[Figure 3]

Evidence that not everything falls to the ground on Earth.

Q: What conclusion might you draw based on the additional evidence of the balloons rising instead of falling?

A: With this and other evidence, you might conclude that objects heavier than air fall to the ground but objects lighter than air do not.

Limits on Inductive Reasoning

Inductive reasoning can't solve a crime or arrive at the correct scientific conclusion with 100 percent certainty. It's always possible that some piece of evidence remains to be found that would disprove the conclusion. That's why jurors in a trial are told to decide whether the defendant is guilty "without a *reasonable* doubt"—not without a shred of doubt. Similarly, a scientific theory is never really proven conclusively to be true. However, it can be supported by so much evidence that it is accepted "without a reasonable doubt."

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Summary

- Inductive reasoning is the process of drawing general conclusions based on many pieces of evidence. This type of reasoning is the basis of the scientific method.
- In science, inductive reasoning is used to draw general conclusions from evidence. The conclusions are changed if necessary to explain new evidence as it becomes available.

- Inductive reasoning cannot prove conclusively that an idea is true, but it may lead to conclusions that are very likely to be true.

Review

1. What is inductive reasoning?
2. Describe how inductive reasoning is used in science.
3. Rayna studied rats in a lab. She observed that all 50 rats in her sample preferred to eat brand A rat food and would eat brand B food only when brand A was not available. Can she correctly conclude that all rats prefer brand A rat food over brand B food? Why or why not?

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1.3 Scientific Method

FlexBooks® 2.0 > American HS Physical Science > Scientific Method

Last Modified: Sep 11, 2021

[Figure 1]

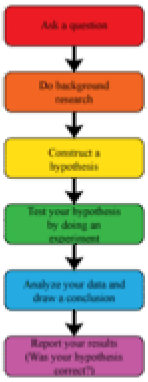
What do you think the scientists in this picture are studying? In science fiction, scientists may be portrayed as singular geniuses who do all of the work themselves, but that portrayal couldn't be farther from the truth. Real scientists are disciplined professionals who collaborate with each other, and scientific investigations are very organized and methodical.

Investigations in Science

Investigations are at the heart of science. They are how scientists add to scientific knowledge and gain a better understanding of the world. Scientific investigations produce evidence that helps answer questions. Even if the evidence cannot provide answers, it may still be useful. It may lead to new questions for investigation. As more knowledge is discovered, science advances.

Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and questions. However, most scientists follow the general steps outlined in the **Figure** below. This approach is sometimes called the scientific method. Keep in mind that the scientific method is a general approach and not a strict sequence of steps. For example, scientists may follow the steps in a different order. Or they may skip or repeat some of the steps.



[Figure 2]

The general steps followed in the scientific method.

Using the Scientific Method: a Simple Example

A simple example will help you understand how the scientific method works. While Cody eats a bowl of cereal (**Figure** below), he reads the ingredients list on the cereal box. He notices that the cereal contains iron. Cody is studying magnets in school and knows that magnets attract objects that contain iron. He wonders whether there is enough iron in a flake of the cereal for it to be attracted by a strong magnet. He thinks that the iron content is probably too low for this to happen, even if he uses a strong magnet.

[Figure 3]

Cody makes an observation that raises a question. Curiosity about observations is how most scientific investigations begin.

Q: If Cody were doing a scientific investigation, what would be his question and hypothesis?

A: Cody's question would be, "Is there enough iron in a flake of cereal for it to be attracted by a strong magnet?" His hypothesis would be, "The iron content of a flake of cereal is too low for it to be attracted by a strong magnet."

Cody decides to do an experiment to test his hypothesis. He gets a strong magnet from his mom's toolbox and places a dry flake of cereal on the table. Then he slowly moves the magnet closer to the flake. To his surprise, when the magnet gets very close to the flake, the flake moves the rest of the way to the magnet.

Q: Based on this evidence, what should Cody conclude?

A: Cody should conclude that his hypothesis is incorrect. There is enough iron in a flake of cereal for it to be attracted by a strong magnet.

Q: If Cody were a scientist doing an actual scientific investigation, what should he do next?

A: He should report his results to other scientists.

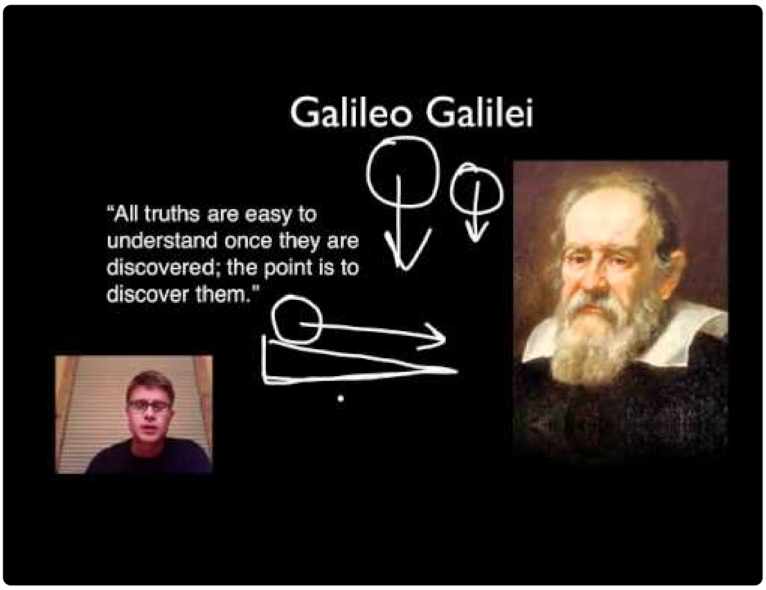
Summary

- Investigations are at the heart of science. They produce evidence that helps scientists answer questions and better understand the world.
- Most scientists follow the same general approach to investigation, which is called the scientific method. It includes the following steps: ask a question, do background research, construct a hypothesis, test the hypothesis by doing an experiment, analyze the data and draw a conclusion, and report the results.

Review

1. What is the role of investigation in science?
2. List the steps of the scientific method.
3. Assume that Cody used a weak magnet and the flake of cereal was not attracted to it. What conclusion might he have drawn then?

Resources



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1.4 Scientific Theory

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Last Modified: Apr 19, 2019

[Figure 1]

This photo shows a girl and her parents. They are having a discussion. As you can see, the girl is rolling her eyes. What do you think her parents may have said that caused this reaction? Could it be they have just grounded her for some reason? That's certainly one possibility, but without any other information to go on, it's "just a theory." In other words, it's just a hunch or a guess. Theories are very important in science, but in science a theory is never a hunch or a guess. It is much more than that.

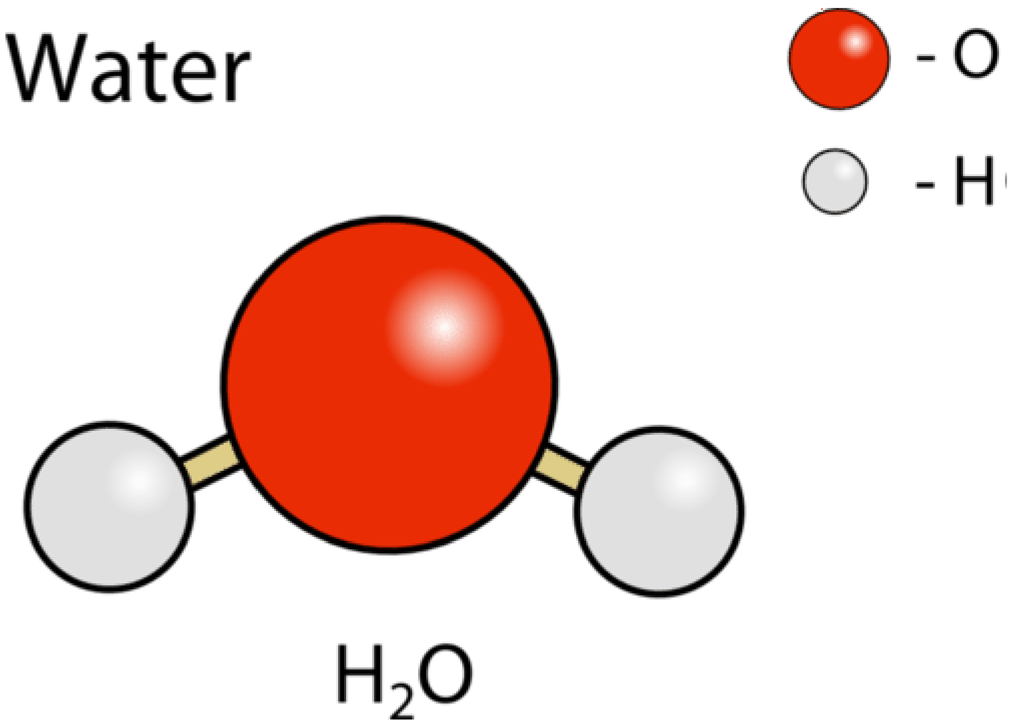
Not "Just a Theory"

The term *theory* is used differently in science than it is used in everyday language. A **scientific theory** is a broad explanation that is widely accepted because it is supported by a great deal of evidence. Because it is so well supported, a scientific theory has a very good chance of being a correct explanation for events in nature. Because it is a broad explanation, it can explain many observations and pieces of evidence. In other words, it can help connect and make sense of many phenomena in the natural world.

Examples of Theories in Physical Science

A number of theories in science were first proposed many decades or even centuries ago, but they have withstood the test of time. An example of a physical science theory that has mainly withstood the test of time is Dalton's atomic theory. John Dalton was a British chemist who lived in the late 1700s and early 1800s. Around 1800, he published his atomic theory, which is one of the most important theories in science. According to Dalton's atomic theory, all substances consist of tiny particles called atoms. Furthermore, all the atoms of a given element are identical, whereas the atoms of different elements are always different. These parts of Dalton's atomic theory are still accepted today, although some other details of his theory have since been disproven.

Dalton based his theory on many pieces of evidence. For example, he studied many substances called compounds. These are substances that consist of two or more different elements. Dalton determined that a given compound always consists of the same elements in exactly the same proportions, no matter how small the sample of the compound. This idea is illustrated for the compound water in the **Figure** below. Dalton concluded from this evidence that elements must be made up of tiny particles in order to always combine in the same specific proportions in any given compound.



[Figure 2]

Water is a compound that consists of the elements hydrogen (H) and oxygen (O). Like other compounds, the smallest particles of water are called molecules. Each molecule of water (H_2O) contains two atoms of hydrogen and one atom of oxygen.

Q: Dalton thought that atoms are the smallest particles of matter. Scientists now know that atoms are composed of even smaller particles. Does this mean that the rest of Dalton's atomic theory should be thrown out?

A: The discovery of particles smaller than atoms doesn't mean that we should scrap the entire theory. Atoms are still known to be the smallest particles of elements that have the properties of the elements. Also, it is atoms—not particles of atoms—that combine in fixed proportions in compounds. Instead of throwing out Dalton's theory, scientists have refined and expanded on it.

There are many other important physical science theories. Here are three more examples:

- Einstein's theory of gravity
- Kinetic theory of matter
- Wave-particle theory of light

Keep It Simple

The formation of scientific theories is generally guided by the law of parsimony. The word *parsimony* means "thriftiness." The law of parsimony states that, when choosing between competing theories, you should select the theory that makes the fewest assumptions. In other words, the simpler theory is more likely to be correct. For example, you probably know that Earth and the other planets of our solar system orbit around the sun. But several centuries ago, it was believed that Earth is at the center of the solar system and the other planets orbit around Earth. While it is possible to explain the movement of planets according to this theory, the explanation is unnecessarily complex.

Q: Why do you think parsimony is an important characteristic of scientific theories?

A: The more assumptions that must be made to form a scientific theory, the more chances there are for the theory to be incorrect. If one assumption is wrong, so is the theory. Conversely, the theory that makes the fewest assumptions, assuming it is well supported by evidence, is most likely to be correct.

Summary

- A scientific theory is a broad explanation that is widely accepted because it is supported by a great deal of evidence.
- Examples of theories in physical science include Dalton's atomic theory, Einstein's theory of gravity, and the kinetic theory of matter.
- The formation of scientific theories is generally guided by the law of parsimony. According to this law, the simplest of competing theories is most likely to be correct.

Review

1. What is a scientific theory?
2. Compare and contrast how the term *theory* is used in science and in everyday language.
3. Identify two physical science theories.
4. Relate scientific theories to the law of parsimony.

Explore More

Watch the first presentation by Dr. Eugenie Scot. Then answer the questions below.

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1. How does Dr. Scott define scientific theory?
2. From most to least important in science, how would Dr. Scott rank the following concepts? theory, fact, law, hypothesis
3. Based on the presentation, explain the importance of theories in science.

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1.5 Hypothesis

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"I've narrowed it down to two hypothesis: it grew, or we shrunk."

[Figure 1]

Although this cartoon pokes fun at scientific hypotheses, the concept of hypothesis is one of the most important in science. Scientific investigations discover evidence that helps science advance, and the purpose of scientific investigations generally is to test hypotheses. Finding evidence to support or disprove hypotheses is how science advances.

What is a Scientific Hypothesis?

The word *hypothesis* can be defined as an "educated guess." For example, it might be an educated guess about why a natural event occurs. But not all hypotheses—even those about the natural world—are scientific hypotheses. What makes a statement a scientific hypothesis rather than just an educated guess? A scientific **hypothesis** must meet two criteria:

- A scientific hypothesis must be testable.
- A scientific hypothesis must be falsifiable.

A Scientific Hypothesis Must Be Testable

For a hypothesis to be testable means that it is possible to make observations that agree or disagree with it. If a hypothesis cannot be tested by making observations, it is not scientific. Consider this statement:

> *"There are invisible creatures all around us that we can never observe in any way."*

This statement may or may not be true, but it is not a scientific hypothesis. That's because it can't be tested. Given the nature of the hypothesis, there are no observations a scientist could make to test whether or not it is false.

A Scientific Hypothesis Must Be Falsifiable

A hypothesis may be testable, but even that isn't enough for it to be a scientific hypothesis. In addition, it must be possible to show that the hypothesis is false if it really is false. Consider this statement:

> *"There are other planets in the universe where life exists."*

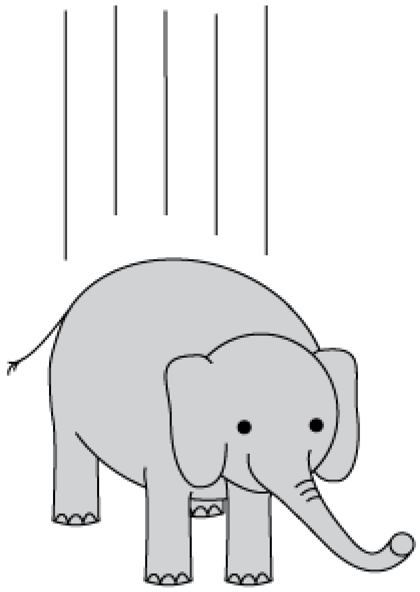
This statement is testable. If it is true, it is at least theoretically possible to find evidence showing that it's true. For example, a spacecraft could be sent from Earth to explore the universe and report back if it discovers an inhabited planet. If such a planet were found, it would prove the statement is true. However, the statement isn't a scientific hypothesis. Why? If it is false, it's not possible to show that it's false. The spacecraft may never find an inhabited planet, but that doesn't necessarily mean there isn't one. Given the vastness of the universe, we would never be able to check every planet for life!

Both Testable and Falsifiable

Let's consider one last example, which is illustrated in the **Figure** below:

> *"Any two objects dropped at the same time from the same height will reach the ground at the same time (assuming the absence of air resistance)."*

Is this statement testable? Yes. You could drop two objects at the same time from the same height and observe when they reach the ground. Of course, you would have to drop the objects in the absence of air to prevent air resistance, but at least such a test is theoretically possible. Is the statement falsifiable if it really is false? Again, the answer is yes. You can easily test many combinations of two objects and if any two objects do not reach the ground at the same time, then the hypothesis is false. If a hypothesis really is false, it should be relatively easy to disprove it.

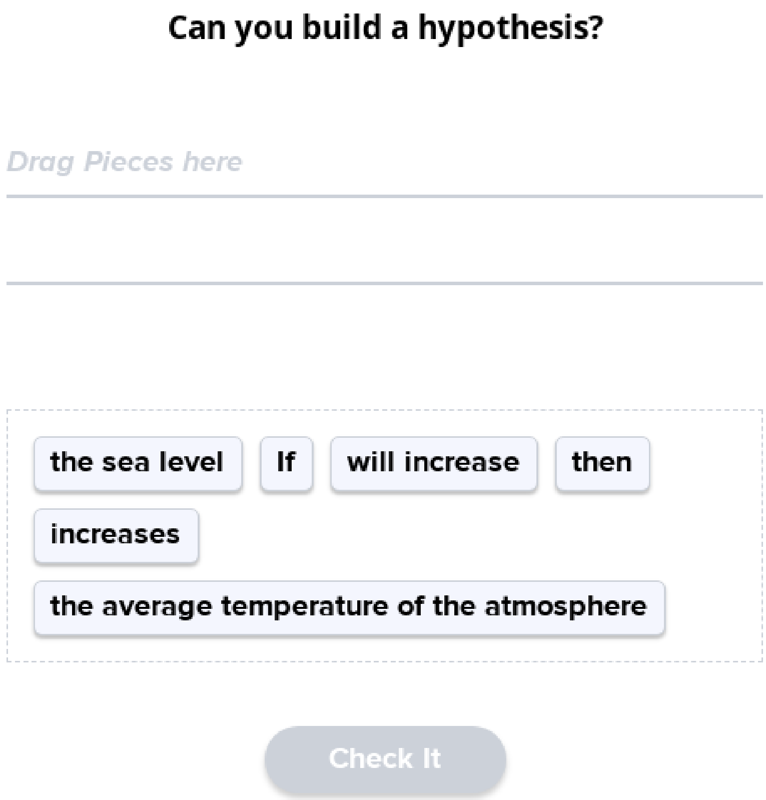


[Figure 2]

Both the elephant and the boy are falling to the ground because of gravity. The force of gravity (Fgrav) is greater for the elephant than it is for the boy because the elephant is much more massive. Nonetheless, both of them will reach the ground at the same time (assuming they fall from the same height at the same time and there is no air resistance.)

Can You Prove a Hypothesis Is True?

If the hypothesis above about falling objects really were false, it is likely that this would be discovered sooner or later after enough objects had been dropped. It takes just one exception to disprove a hypothesis. But what if the hypothesis really is true? Can this be demonstrated as well? No; it would require testing all possible combinations of objects to show that they always reach the ground at the same time. This is impossible. New objects are being made all the time that would have to be tested. It's always possible an exception would be found in the future to disprove the hypothesis. Although you can't prove conclusively that a hypothesis is true, the more evidence you gather in support of it, the more likely it is to be true.



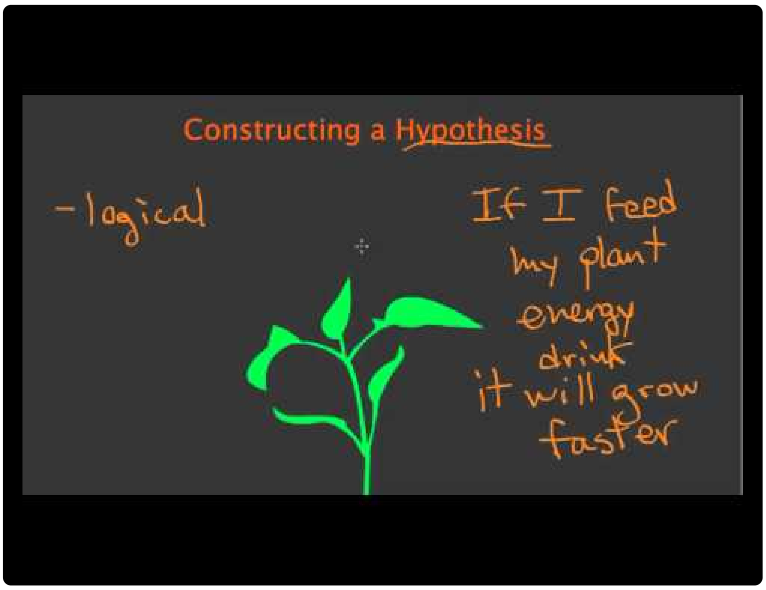
Summary

- In science, a hypothesis is an educated guess that can be tested with observations and falsified if it really is false.
- You cannot prove conclusively that most hypotheses are true because it's generally impossible to examine all possible cases for exceptions that would disprove them.

Review

1. Identify the role of the hypothesis in science.
2. State two criteria of a scientific hypothesis.
3. Which of these two statements meets the criteria of a scientific hypothesis?
   a. Acids turn red litmus paper blue.
   b. All life in the universe exists on Earth.
4. Why is it usually impossible to prove that a hypothesis is true?

Resources



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1.6 Experiment

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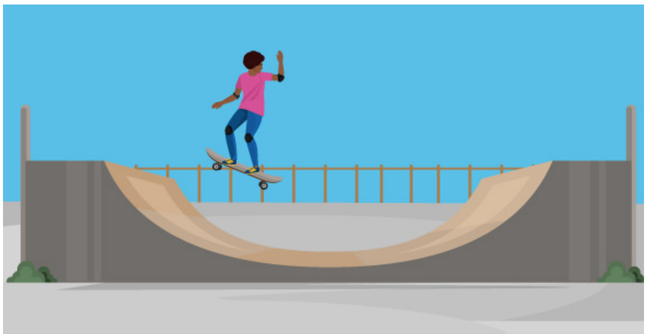


[Figure 1]

It's exciting to roll down a skateboarding ramp, especially if you're going fast. The steeper the ramp, the faster you'll go. What else besides the steepness of a ramp influences how fast an object goes down it? You could do experiments to find out.

What is an Experiment?

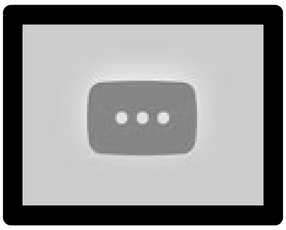
An **experiment** is a controlled scientific study of specific variables. A variable is a factor that can take on different values. For example, the speed of an object down a ramp might be one variable, and the steepness of the ramp might be another.

Experimental Variables

There must be at least two variables in any experiment: a manipulated variable and a responding variable.

- A **manipulated variable** is a variable that is changed by the researcher. A manipulated variable is also called an independent variable.
- A **responding variable** is a variable that the researcher predicts will change if the manipulated variable changes. A responding variable is also called a dependent variable.

You can learn how to identify manipulated and responding variables in an experiment by watching this video about bouncing balls:



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Q: If you were to do an experiment to find out what influences the speed of an object down a ramp, what would be the responding variable? How could you measure it?

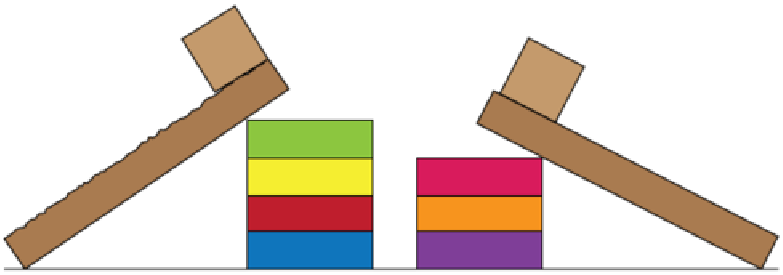
A: The responding variable would be the speed of the object. You could measure it indirectly with a stopwatch. You could clock the time it takes the object to travel from the top to the bottom of the ramp. The less time it takes, the faster the average speed down the ramp.

Q: What variables might affect the speed of an object down a ramp?

A: Variables might include factors relating to the ramp or to the object. An example of a variable relating to the ramp is its steepness. An example of a variable relating to the object is the way it moves—it might roll or slide down the ramp. Either of these variables could be manipulated by the researcher, so you could choose one of them for your manipulated variable.

Controlling Variables

Assume you are sliding wooden blocks down a ramp in your experiment. You choose steepness of the ramp for your manipulated variable. You want to measure how changes in steepness affect the time it takes a block to reach the bottom of the ramp. You decide to test two blocks on two ramps, one steeper than the other, and see which block reaches the bottom first. You use a shiny piece of varnished wood for one ramp and a rough board for the other ramp. You raise the rough board higher so it has a steeper slope (see sketch below). You let go of both blocks at the same time and observe that the block on the ramp with the gentler slope reaches the bottom sooner. You're surprised, because you expected the block on the steeper ramp to go faster and get to the bottom first.

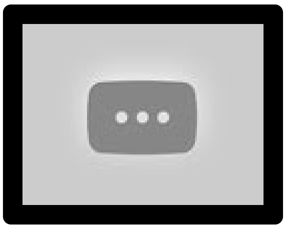


[Figure 2]

Q: What explains your result?

A: The block on the steeper ramp would have reached the bottom sooner if all else was equal. The problem is that all else was not equal. The ramps varied not only in steepness but also in smoothness. The block on the smoother ramp went faster than the block on the rougher ramp, even though the rougher ramp was steeper.

This example illustrates another important aspect of experiments: **controlled variables**. A controlled variable is a variable that is intentionally kept constant so it won't influence the outcome of an experiment. By controlling any variables that could have an effect on the results of an experiment, we can be confident that the manipulated variable is responsible for our results. In the case of your ramp experiment, smoothness of the ramps should have been controlled by making each ramp out of the same material. For other examples of controlled variables in an experiment, watch the video below. It is Part II of the above video on bouncing balls.



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Q: What other variables do you think might influence the outcome of your ramp experiment? How could these other variables be controlled?

A: Other variables might include variables relating to the block. For example, a smoother block would be expected to go down a ramp faster than a rougher block. You could control variables relating to the block by using two identical blocks.

Summary

- An experiment is a controlled scientific study of specific variables. A variable is a factor that can take on different values.
- There must be at least two variables in any experiment: a manipulated variable and a responding variable.
- A control is a variable that must be held constant so it won't influence the outcome of an experiment.

Review

1. What is an experiment?
2. Distinguish between the manipulated variable and the responding variable in an experiment.
3. Why is it important for other variables in an experiment to be controlled?

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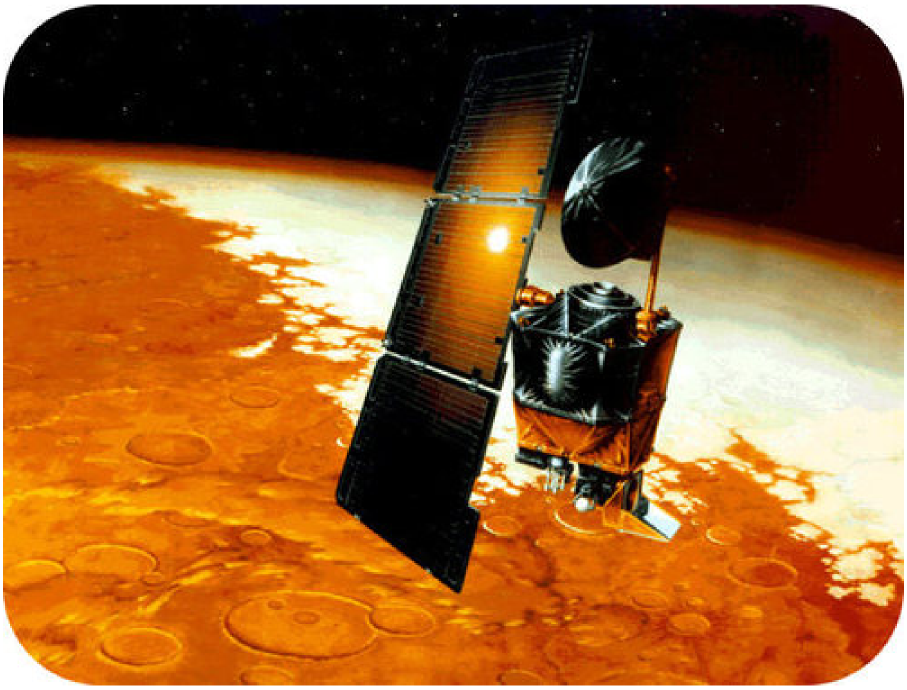
1.7 International System of Units (SI)

FlexBooks® 2.0 > American HS Physical Science > International System of Units (SI)

Last Modified: Sep 11, 2021



[Figure 1]

In 1999, NASA's Mars Climate Orbiter, pictured here, burned up as it passed through Mars' atmosphere. The satellite was programmed to orbit Mars at high altitude and gather climate data. Instead, the Orbiter flew too low and entered the red planet's atmosphere. Why did the Orbiter fly off course? The answer is human error. The flight system software on the Orbiter was written using scientific units of measurement, but the ground crew was entering data using common English units.

SI Units

The example of the Mars Climate Orbiter shows the importance of using a standard system of measurement in science and technology. The measurement system used by most scientists and engineers is the International System of Units, or **SI**. There are a total of seven basic SI units, including units for length (meter) and mass (kilogram).

Can you match the type of measurement with its base unit?

Time	Kilogram
Mass	Seconds
Number of particles	Mole
Current	Kelvin
Length	Meter
Temperature	Ampere

SI units are easy to use because they are based on the number 10. Basic units are multiplied or divided by powers of ten to arrive at bigger or smaller units. Prefixes are added to the names of the units to indicate the powers of ten, as shown in the **Table** below.

Prefixes of SI Units

Prefix	Multiply Basic Unit ×	Basic Unit of Length = Meter (m)
kilo- (k)	1000	kilometer (km) = 1000 m
deci- (d)	0.1	decimeter (dm) = 0.1 m
centi- (c)	0.01	centimeter (cm) = 0.01 m
milli- (m)	0.001	millimeter (mm) = 0.001 m
micro- (μ)	0.000001	micrometer (μm) = 0.000001 m
nano- (n)	0.000000001	nanometer (nm) = 0.000000001 m

Q: What is the name of the unit that is one-hundredth (0.01) of a meter?

A: The name of this unit is the centimeter.

Q: What fraction of a meter is a decimeter?

A: A decimeter is one-tenth (0.1) of a meter.

Unit Conversions

In the **Table** below, two basic SI units are compared with their English system equivalents. You can use the information in the table to convert SI units to English units or vice versa. For example, from the table you know that 1 meter equals 39.37 inches. How many inches are there in 3 meters?

$$3 \text{ m} = 3(39.37 \text{ in}) = 118.11 \text{ in}$$

Unit Conversions

Measure	SI Unit	English Unit Equivalent
Length	meter (m)	1 m = 39.37 in
Mass	kilogram (kg)	1 kg = 2.20 lb

Q: Rod needs to buy a meter of wire for a science experiment, but the wire is sold only by the yard. If he buys a yard of wire, will he have enough? (*Hint:* There are 36 inches in a yard.)

A: Rod needs 39.37 inches (a meter) of wire, but a yard is only 36 inches, so if he buys a yard of wire he won't have enough.

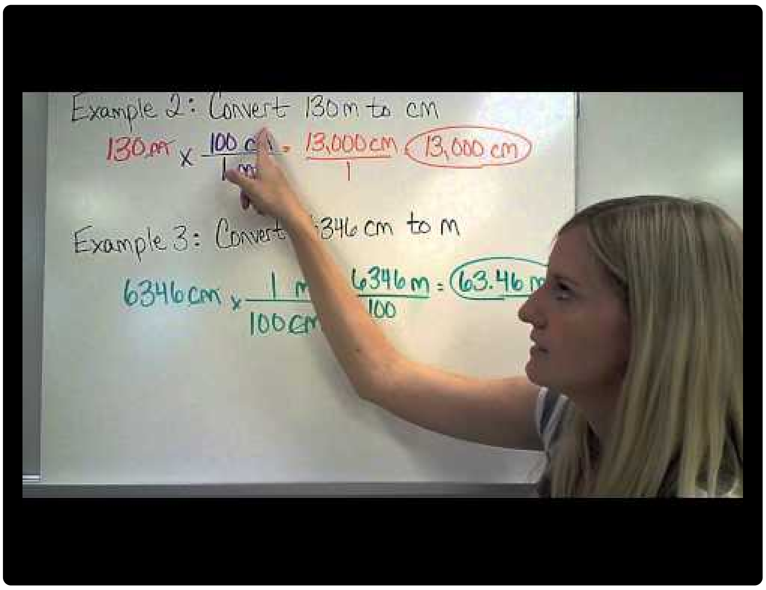
Summary

- The measurement system used by most scientists and engineers is the International System of Units, or SI. There are seven basic SI units, including units for length and mass.
- If you know the English equivalents of SI units, you can convert SI units to English units or vice versa.

Review

1. What does SI stand for?
2. Why is it important for scientists and engineers to adopt a common system of measurement units?
3. How many grams equal 1 kilogram?
4. What fraction of a meter is a millimeter?
5. How many pounds equal 5 kilograms?

Resources



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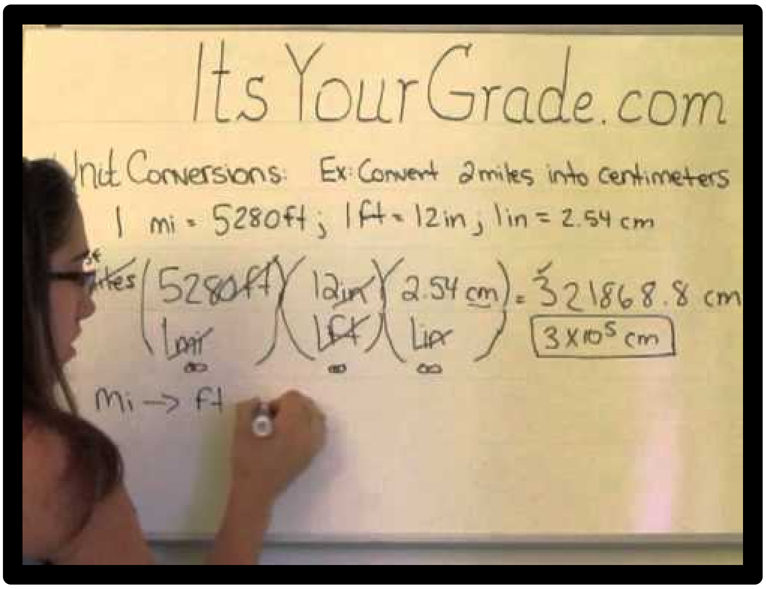

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1.8 Significant Figures

FlexBooks® 2.0 > American HS Physical Science > Significant Figures

Last Modified: Sep 11, 2021

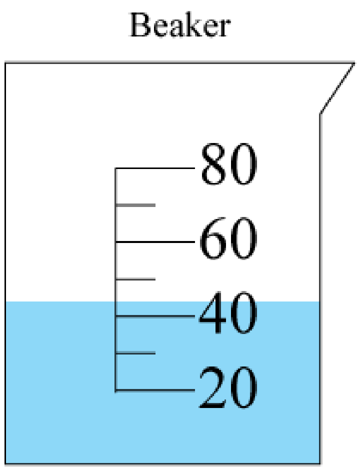
[Figure 1]

Jerod has a homework problem that involves finding the area of a rectangle. He knows that the area of a rectangle equals its length times its width. The rectangle in question has a length of 6.9 m and a width of 6.5 m, so he multiplies the two numbers on his calculator. The answer he gets is 44.85 m^2, which he records on his homework. To his surprise, his teacher marks this answer wrong. The reason? The answer has too many significant figures.

What Are Significant Figures?

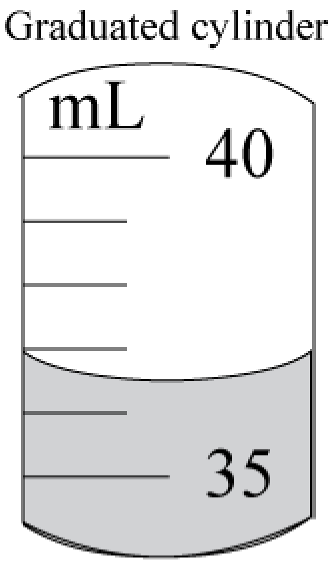
In any measurement, the number of **significant figures** is the number of digits thought to be correct by the person doing the measuring. It includes all digits that can be read directly from the measuring device plus one estimated digit.

Look at the sketch of a beaker below. How much blue liquid does the beaker contain? The top of the liquid falls between the mark for 40 mL and 50 mL, but it's closer to 40 mL. A reasonable estimate is 43 mL. In this measurement, the first digit (4) is known for certain and the second digit (3) is an estimate, so the measurement has two significant figures.



[Figure 2]

Now look at the graduated cylinder sketched below. How much gray liquid does it contain? First, it's important to note that you should read the amount of liquid at the bottom of its curved surface. This falls about half way between the mark for 36 mL and the mark for 37 mL, so a reasonable estimate would be 36.5 mL.



[Figure 3]

Q: How many significant figures does this measurement have?

A: There are three significant figures in this measurement. You know that the first two digits (3 and 6) are accurate. The third digit (5) is an estimate.

Rules for Counting Significant Figures

The examples above show that it's easy to count the number of significant figures when you are making a measurement. But what if someone else has made the measurement? How do you know which digits are known for certain and which are estimated? How can you tell how many significant figures there are in the measurement? There are several rules for counting significant figures:

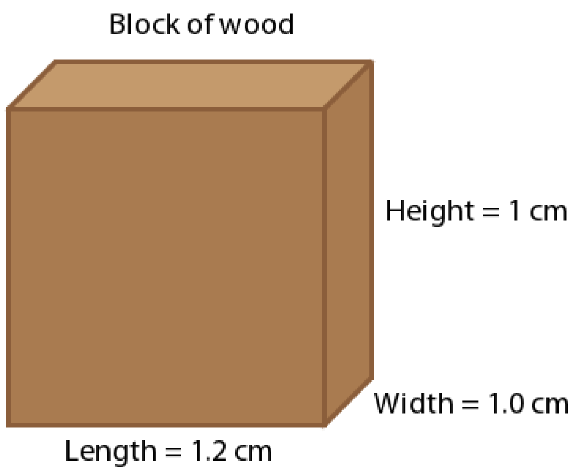
- Leading zeros are never significant. For example, in the number 006.1, only the 6 and 1 are significant.
- Zeros within a number between nonzero digits are always significant. For example, in the number 106.1, the zero is significant, so this number has four significant figures.
- Zeros that show only where the decimal point falls are not significant. For example, the number 470,000 has just two significant figures (4 and 7). The zeros just show that the 4 represents hundreds of thousands and the 7 represents tens of thousands. Therefore, these zeros are not significant.
- Trailing zeros that aren't needed to show where the decimal point falls are significant. For example, 4.00 has three significant figures.

Q: How many significant figures are there in each of these numbers: 20,080, 2.080, and 2000?

A: Both 20,080 and 2.080 contain four significant figures, but 2000 has just one significant figure.

Determining Significant Figures in Calculations

When measurements are used in a calculation, the answer cannot have more significant figures than the measurement with the fewest significant figures. This explains why the homework answer above is wrong. It has more significant figures than the measurement with the fewest significant figures. As another example, assume that you want to calculate the volume of the block of wood shown below.



[Figure 4]

The volume of the block is represented by the formula:

$$\text{Volume} = \text{length} \times \text{width} \times \text{height}$$

Therefore, you would do the following calculation:

$$\text{Volume} = 1.2\ \text{cm} \times 1.0\ \text{cm} \times 1\ \text{cm} = 1.2\ \text{cm}^3$$

Q: Does this answer have the correct number of significant figures?

A: No, it has too many significant figures. The correct answer is 1 cm^3. That's because the height of the block has just one significant figure. Therefore, the answer can have only one significant figure.

Rules for Rounding

To get the correct answer in the volume calculation above, rounding was necessary. Rounding is done when one or more ending digits are dropped to get the correct number of significant figures. In this example, the answer was rounded down to a lower number (from 1.2 to 1). Sometimes the answer is rounded up to a higher number. How do you know which way to round? Follow these simple rules:

- If the digit to be rounded (dropped) is less than 5, then round down. For example, when rounding 2.344 to three significant figures, round down to 2.34.
- If the digit to be rounded is greater than 5, then round up. For example, when rounding 2.346 to three significant figures, round up to 2.35.
- If the digit to be rounded is 5, round up if the digit before 5 is odd, and round down if digit before 5 is even. For example, when rounding 2.345 to three significant figures, round down to 2.34. This rule may seem arbitrary, but in a series of many calculations, any rounding errors should cancel each other out.

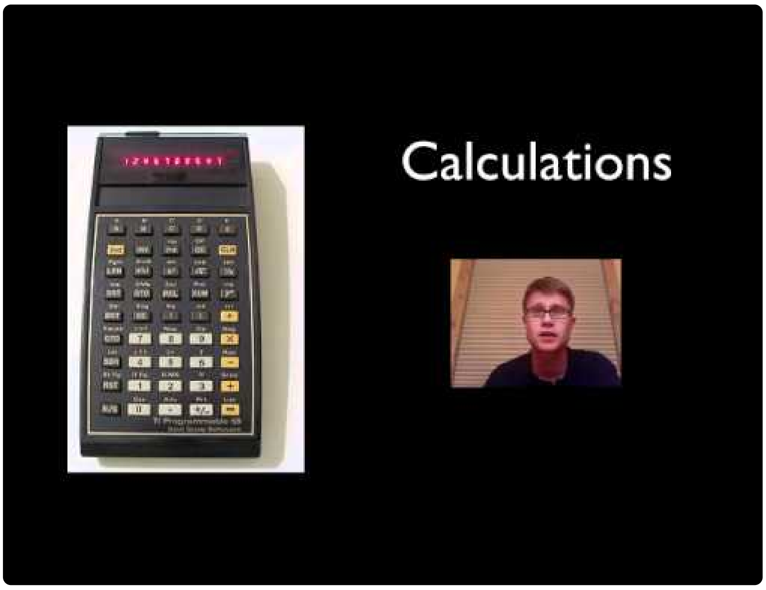
Summary

- In any measurement, the number of significant figures is the number of digits thought to be correct by the person doing the measuring. It includes all digits that can be read directly from the measuring device plus one estimated digit.
- To determine the number of significant figures in a measurement that someone else has made, follow the rules for counting significant figures.
- When measurements are used in a calculation, the answer cannot have more significant figures than the measurement with the fewest significant figures.
- Rounding is done when one or more ending digits are dropped to get the correct number of significant figures. Simple rules state when to round up and when to round down.

Review

1. How do you determine the number of significant figures when you make a measurement?
2. Measure the width of a sheet of standard-sized (8.5 in x 11.0 in) loose-leaf notebook paper. Make the measurement in centimeters and express the answer with the correct number of significant figures.
3. How many significant figures do each of these measurements have?
   a. 0.04
   b. 500
   c. 1.50
4. In this calculation, how many significant figures should there be in the answer? 1.0234 + 1.1 + 0.0056
5. Round each of these numbers to three significant figures:
   a. 1258
   b. 3274
   c. 6845

Resources



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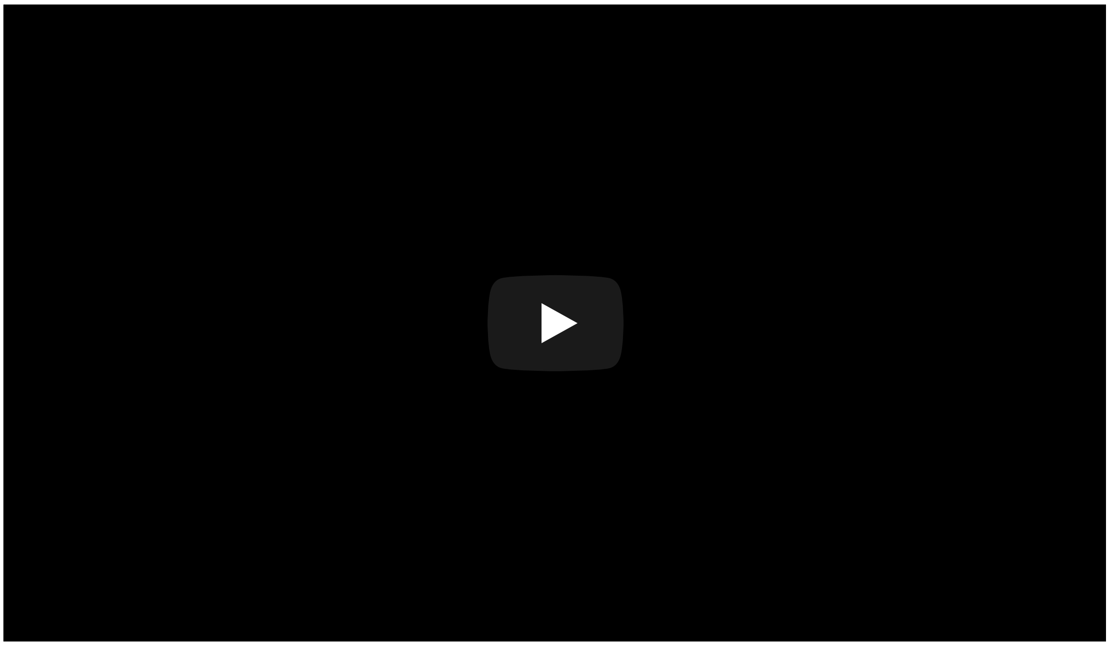

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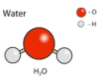	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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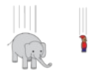	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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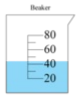
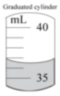
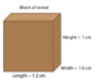
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 2

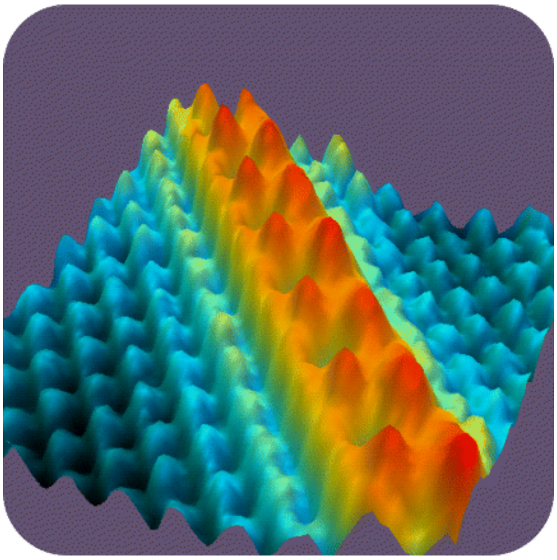
Matter and Change

Chapter Outline

2.1 Matter, Mass, and Volume

FlexBooks® 2.0 > American HS Physical Science > Matter, Mass, and Volume

Last Modified: Aug 30, 2021



[Figure 1]

Can you guess what this colorful image shows?

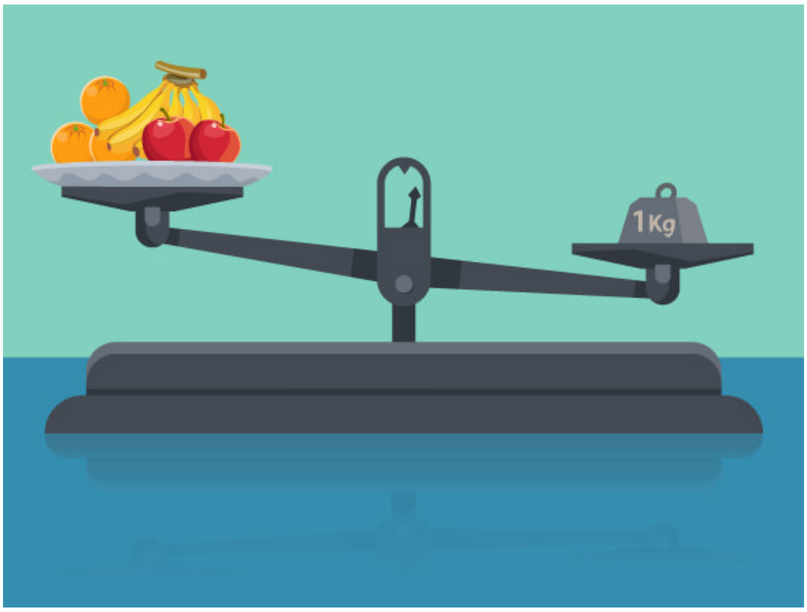
Believe it or not, it actually depicts individual atoms of cesium (reddish-orange) on a surface of gallium arsenide molecules (blue). The image was created with an extremely powerful microscope, called a scanning tunneling microscope. This is one of a few types of microscope that can make images of atoms, the basic building blocks of matter.

What's the Matter?

Matter is all the "stuff" that exists in the universe. Everything you can see and touch is made of matter, including you! The only things that aren't matter are forms of energy, such as light and sound. In science, **matter** is defined as anything that has mass and volume. Mass and volume measure different aspects of matter.

Mass

Mass is a measure of the amount of matter in a substance or an object. The basic SI unit for mass is the kilogram (kg), but smaller masses may be measured in grams (g). To measure mass, you would use a balance. In the lab, mass may be measured with a triple beam balance or an electronic balance, but the old-fashioned balance pictured below may give you a better idea of what mass is. If both sides of this balance were at the same level, it would mean that the fruit in the left pan has the same mass as the iron object in the right pan. In that case, the fruit would have a mass of 1 kg, the same as the iron. As you can see, however, the fruit is at a higher level than the iron. This means that the fruit has less mass than the iron, that is, the fruit's mass is less than 1 kg.



[Figure 2]

Q: Refer to the picture above. If the fruit were at a lower level than the iron object, what would be the mass of the fruit?

A: The mass of the fruit would be greater than 1 kg.

Mass vs. Weight

Mass is commonly confused with weight. The two are closely related, but they measure different things. Whereas mass measures the amount of matter in an object, weight measures the force of gravity acting on an object. The force of gravity on an object depends on its mass but also on the strength of gravity. If the strength of gravity is held constant (as it is all over Earth), then an object mass is directly proportional to the objects weight, so a greater mass also has a greater weight.

Q: With Earth's gravity, an object with a mass of 1 kg has a weight of 2.2 lb. How much does a 10 kg object weigh on Earth?

A: A 10 kg object weighs ten times as much as a 1 kg object: 10 × 2.2 lb = **22 lb**

Volume

Volume is a measure of the amount of space that a substance or an object takes up. The basic SI unit for volume is the cubic meter (m^3), but smaller volumes may be measured in cm^3, and liquids may be measured in liters (L) or milliliters (mL). How the volume of matter is measured depends on its state.

- The volume of a liquid is measured with a measuring container, such as a measuring cup or graduated cylinder.
- The volume of a gas depends on the volume of its container: gases expand to fill whatever space is available to them.
- The volume of a regularly shaped solid can be calculated from its dimensions. For example, the volume of a rectangular solid is the product of its length, width, and height.
- The volume of an irregularly shaped solid can be measured by the displacement method. You can read below how this method works.

Calculating Volume from Dimensions

Q: How could you find the volume of air in an otherwise empty room?

A: If the room has a regular shape, you could calculate its volume from its dimensions. For example, the volume of a rectangular room can be calculated with the formula:

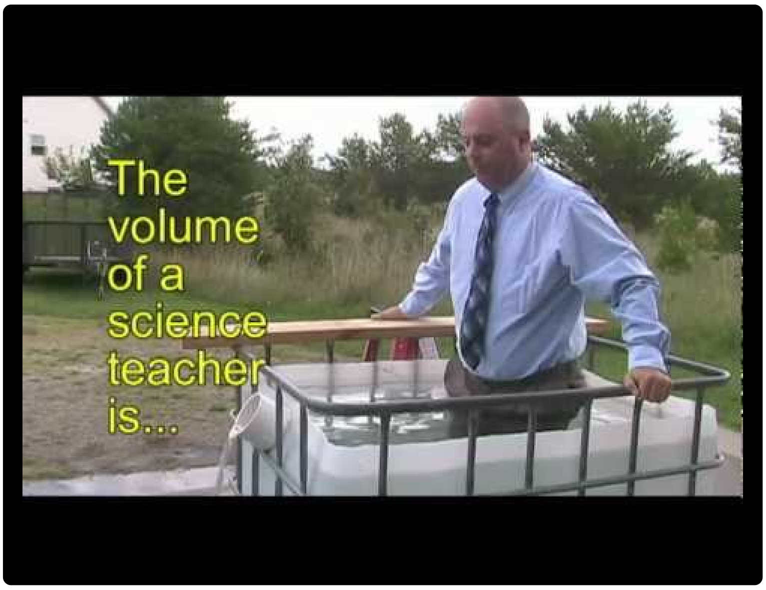
Volume = length × width × height

If the length of the room is 5.0 meters, the width is 3.0 meters, and the height is 2.5 meters, then the volume of the room is:

Volume = 5.0 m × 3.0 m × 2.5 m = 37.5 m^3

Measuring Volume Using the Displacement Method

The following video shows how the volume of an irregular shaped object, like your science teacher can be measured by the displacement method.



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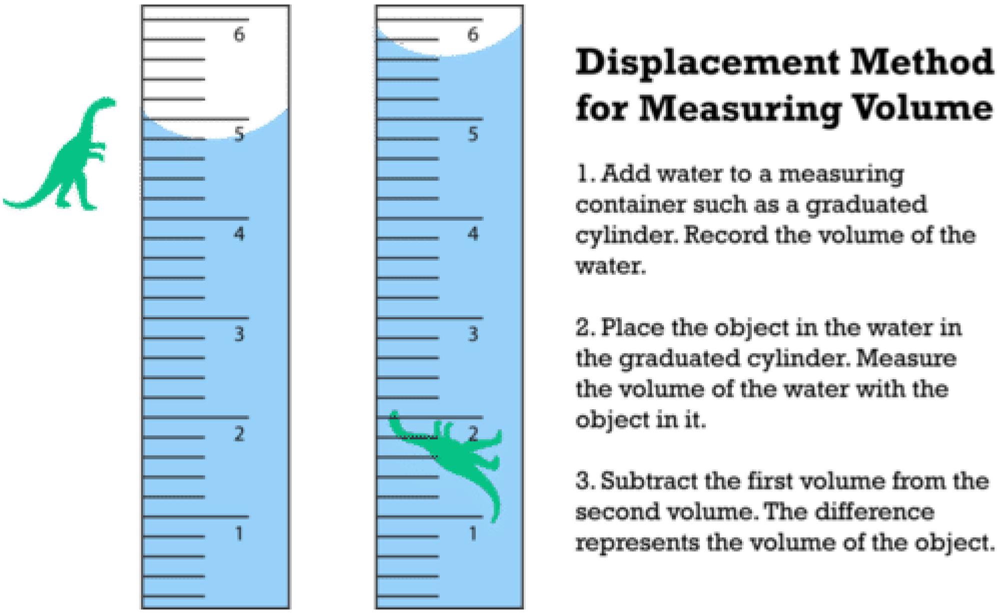
Q: What is the volume of the dinosaur in the diagram below?



[Figure 3]

A: The volume of the water alone is 4.8 mL. The volume of the water and dinosaur together is 5.6 mL. Therefore, the volume of the dinosaur alone is 5.6 mL – 4.8 mL = 0.8 mL.

Summary

- Matter is all the "stuff" that exists in the universe. It has both mass and volume.
- Mass measures the amount of matter in a substance or an object. The basic SI unit for mass is the kilogram (kg).
- Volume measures the amount of space that a substance or an object takes up. The basic SI unit for volume is the cubic meter (m^3).

Review

1. How do scientists define matter?
2. What is mass? What is the basic SI unit of mass?
3. What does volume measure? Name two different units that might be used to measure volume.
4. Explain how to use the displacement method to find the volume of an irregularly shaped object.

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2.2 Physical Properties of Matter

FlexBooks® 2.0 > American HS Physical Science > Physical Properties of Matter

Last Modified: Aug 10, 2020

[Figure 1]

Both of these people are participating in a board sport, but the man on the left is snowboarding in Norway while the woman on the right is sandboarding in Dubai. Snow and sand are both kinds of matter, but they have different properties. What are some ways snow and sand differ? One difference is the temperature at which they melt. Snow melts at 0°C, whereas sand melts at about 1600°C! The temperature at which something melts is its melting point. Melting point is just one of many physical properties of matter.

What Are Physical Properties?

Physical properties of matter are properties that can be measured or observed without matter changing to an entirely different substance. Physical properties are typically things you can detect with your senses. For example, they may be things that you can see, hear, smell, or feel.

Q: What differences between snow and sand can you detect with your senses?

A: You can see that snow and sand have a different color. You can also feel that snow is softer than sand. Both color and hardness are physical properties of matter.

Additional Physical Properties

In addition to these properties, other physical properties of matter include the state of matter. States of matter include liquid, solid, and gaseous states. For example at 20°C, coal exists as a solid and water exists as a liquid. Additional examples of physical properties include:

- odor
- boiling point

- ability to conduct heat
- ability to conduct electricity
- ability to dissolve in other substances

Some of these properties are illustrated in the **Figures** below.

[Figure 2]

The strong smell of swimming pool water is the odor of chlorine, which is added to the water to kill germs and algae. In contrast, bottled spring water, which contains no chlorine, does not have an odor.

[Figure 3]

Coolant is added to the water in a car radiator to keep the water from boiling and evaporating. Coolant has a higher boiling point than water and adding it to the water increases the boiling point of the solution.

[Figure 4]

This teakettle is made of aluminum except for its handle, which is made of plastic. Aluminum is a good conductor of heat. It conducts heat from the flames on the range to the water inside the kettle, so the water heats quickly. Plastic, on the other hand, is not a good conductor of heat. It stays cool enough to touch even when the rest of the teakettle becomes very hot.

[Figure 5]

Copper is a good conductor of electricity. That's why electric wires are often made of copper. They are covered with a protective coating of plastic, which does not conduct electricity.

Q: The coolant that is added to a car radiator also has a lower freezing point than water. Why is this physical property useful?

A: When coolant is added to water in a car radiator, it lowers the freezing point of the water. This prevents the water in the radiator from freezing when the temperature drops below 0°C, which is the freezing point of pure water.

Q: Besides being able to conduct electricity, what other physical property of copper makes it well suited for electric wires?

A: Copper, like other metals, is ductile. This means that it can be rolled and stretched into long thin shapes such as wires.

Summary

- Physical properties of matter are properties that can be measured or observed without matter changing to an entirely different substance. Physical properties are typically things you can detect with your senses.
- Examples of physical properties of matter include melting point, color, hardness, state of matter, odor, and boiling point.

Review

1. What is a physical property of matter?
2. List three examples of physical properties.
3. Compare and contrast two physical properties of apples and oranges.

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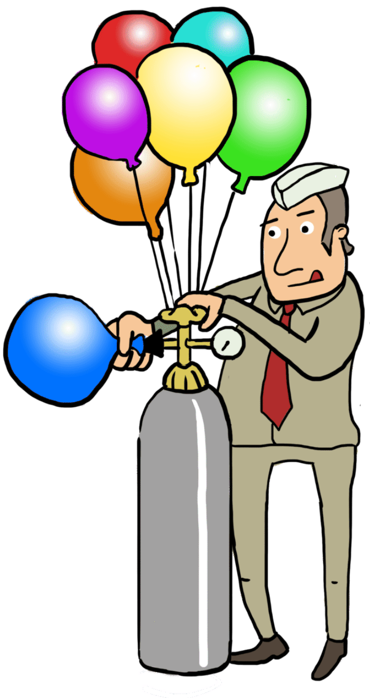
2.3 Density

FlexBooks® 2.0 > American HS Physical Science > Density

Last Modified: Sep 06, 2018



[Figure 1]

The man in this cartoon is filling balloons with helium gas. What will happen if he lets go of the filled balloons? They will rise up into the air until they reach the ceiling. Do you know why? It's because helium has less density than air.

Defining Density

Density is an important physical property of matter. It reflects how closely packed the particles of matter are. When particles are packed together more tightly, matter has greater density. Differences in density of matter explain many phenomena, not just why helium balloons rise. For example, differences in density of cool and warm ocean water explain why currents such as the Gulf Stream flow through the oceans.

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To better understand density, think about a bowling ball and volleyball, pictured in the **Figure** below. Imagine lifting each ball. The two balls are about the same size, but the bowling ball feels much heavier than the volleyball. That's because the bowling ball is made of solid plastic, which contains a lot of tightly packed particles of matter. The volleyball, in contrast, is full of air, which contains fewer, more widely spaced particles of matter. In other words, the matter inside the bowling ball is denser than the matter inside the volleyball.

[Figure 2]

A bowling ball is denser than a volleyball. Although both balls are similar in size, the bowling ball feels much heavier than the volleyball.

Q: If you ever went bowling, you may have noticed that some bowling balls feel heavier than others even though they are the same size. How can this be?

A: Bowling balls that feel lighter are made of matter that is less dense.

Calculating Density

The density of matter is actually the amount of matter in a given space. The amount of matter is measured by its mass, and the space matter takes up is measured by its volume. Therefore, the density of matter can be calculated with this formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Assume, for example, that a book has a mass of 500 g and a volume of 1000 cm^3. Then the density of the book is:

$$\text{Density} = \frac{500\text{ g}}{1000\text{ cm}^3} = 0.5\text{ g/cm}^3$$

Q: What is the density of a liquid that has a volume of 30 mL and a mass of 300 g?

A: The density of the liquid is:

$$\text{Density} = \frac{300\text{ g}}{30\text{ mL}} = 10\text{ g/mL}$$

Summary

- Density is an important physical property of matter. It reflects how closely packed the particles of matter are.
- The density of matter can be calculated by dividing its mass by its volume.

Review

1. What is density?
2. Find the density of an object that has a mass of 5 kg and a volume of 50 cm^3.
3. Create a sketch that shows the particles of matter in two substances that differ in density. Label the sketch to show which substance has greater density.

Report Content Errors

2.4 Chemical Properties of Matter

FlexBooks® 2.0 > American HS Physical Science > Chemical Properties of Matter

Last Modified: Nov 03, 2021

[Figure 1]

Look at the two garden trowels pictured here. Both trowels were left outside for several weeks. One tool became rusty, but the other did not. The tool that rusted is made of iron, and the other tool is made of aluminum. The ability to rust is a chemical property of iron but not aluminum.

What Are Chemical Properties?

Chemical properties are properties that can be measured or observed only when matter undergoes a change to become an entirely different kind of matter. For example, the ability of iron to rust can only be observed when iron actually rusts. When it does, it combines with oxygen to become a different substance called iron oxide. Iron is very hard and silver in color, whereas iron oxide is flakey and reddish brown. Besides the ability to rust, other chemical properties include reactivity and flammability.

Reactivity

Reactivity is the ability of matter to combine chemically with other substances. Some kinds of matter are extremely reactive; others are extremely unreactive. For example, potassium is very reactive, even with water. When a pea-sized piece of potassium is added to a small amount of water, it reacts explosively. You can observe this reaction in the video below. (*Caution:* Don't try this at home!) In contrast, noble gases such as helium almost never react with any other substances.

https://flexbooks.ck12.org/flx/render/embeddedobject/125138

Flammability

Flammability is the ability of matter to burn. When matter burns, it combines with oxygen and changes to different substances. Wood is an example of flammable matter, as seen in **Figure** below.

[Figure 2]

When wood burns, it changes to ashes, carbon dioxide, water vapor, and other gases. You can see ashes in the wood fire pictured here. The gases are invisible.

Q: How can you tell that wood ashes are a different substance than wood?

A: Ashes have different properties than wood. For example, ashes are gray and powdery, whereas wood is brown and hard.

Q: What are some other substances that have the property of flammability?

A: Substances called fuels have the property of flammability. They include fossil fuels such as coal, natural gas, and petroleum, as well as fuels made from petroleum, such as gasoline and kerosene. Substances made of wood, such as paper and cardboard, are also flammable.

Summary

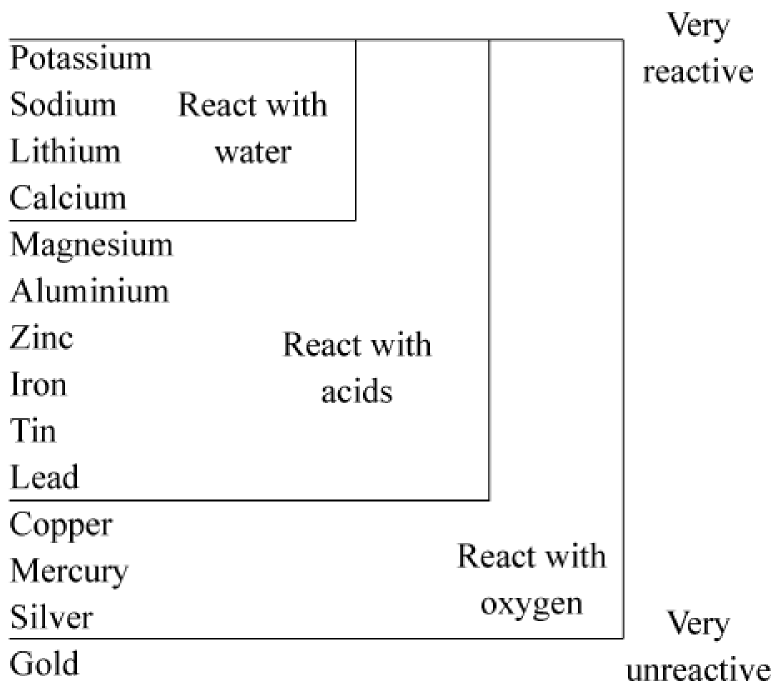
- Chemical properties are properties that can be measured or observed only when matter undergoes a change to become an entirely different kind of matter. They include reactivity, flammability, and the ability to rust.
- Reactivity is the ability of matter to react chemically with other substances.
- Flammability is the ability of matter to burn.

Review

1. What is a chemical property?
2. Define the chemical property called reactivity.
3. What is flammability? Identify examples of flammable matter.

Explore More

The chart below shows the reactivity of several different metals. The metals range from very reactive to very unreactive. Study the chart and then answer the questions below.



[Figure 3]

1. What is the most reactive metal in the chart? What is the least reactive metal?
2. Complete this sentence: Only the most reactive metals in the chart react with ________________.
3. Is this statement true or false? Most metals in the chart react with oxygen.
4. Which of the following metals reacts with oxygen and acids but is not very reactive with water?
   a. calcium
   b. magnesium
   c. copper

Report Content Errors

2.5 Element

FlexBooks® 2.0 > American HS Physical Science > Element

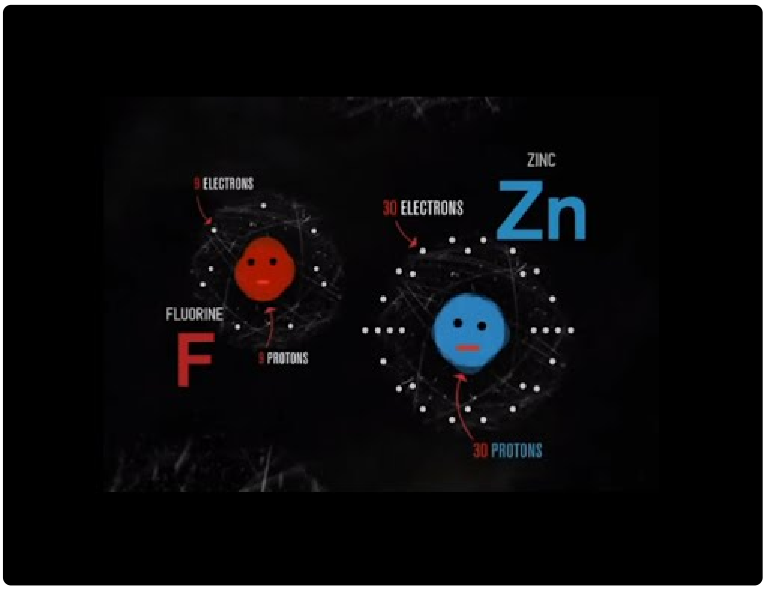
Last Modified: Mar 25, 2021

[Figure 1]

As this mountain of trash suggests, there are many different kinds of matter. In fact, there are millions of different kinds of matter in the universe. Yet all kinds of matter actually consist of relatively few pure substances.

Pure Substances

A pure substance is called an **element**. An element is a pure substance because it cannot be separated into any other substances. Currently, 92 different elements are known to exist in nature, although additional elements have been formed in labs. All matter consists of one or more of these elements. Some elements are very common; others are relatively rare. The most common element in the universe is hydrogen, which is part of Earth's atmosphere and a component of water. The most common element in Earth's atmosphere is nitrogen, and the most common element in Earth's crust is oxygen.



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Elemental Properties

Each element has a unique set of properties that is different from the set of properties of any other element. For example, the element iron is a solid that is attracted by a magnet and can be made into a magnet, like the compass needle shown in the **Figure** below. The element neon, on the other hand, is a gas that gives off a red glow when electricity flows through it. The lighted sign in the **Figure** below contains neon.

[Figure 2]

The needle of this compass is made of the element iron.

[Figure 3]

The red lights in this sign contain the element neon.

Q: Do you know properties of any other elements? For example, what do you know about helium?

A: Helium is a gas that has a lower density than air. That's why helium balloons have to be weighted down so they won't float away.

Q: Living things, like all matter, are made of elements. Do you know which element is most common in living things?

A: Carbon is the most common element in living things. It has the unique property of being able to combine with many other elements as well as with itself. This allows carbon to form a huge number of different substances.

History of Elements

For thousands of years, people have wondered about the substances that make up matter. About 2500 years ago, the Greek philosopher Aristotle argued that all matter is made up of just four elements, which he identified as earth, air, water, and fire. He thought that different substances vary in their properties because they contain different proportions of these four elements. Aristotle had the right idea, but he was wrong about which substances are elements. Nonetheless, his four elements were accepted until just a few hundred years ago. Then scientists started discovering many of the elements with which we are familiar today. Eventually they discovered dozens of different elements.

Particles of Elements

The smallest particle of an element that still has the properties of that element is the **atom**. Atoms actually consist of smaller particles, including protons and electrons, but these smaller particles are the same for all elements. All the atoms of an element are like one another, and are different from the atoms of all other elements. For example, the atoms of each element have a unique number of protons.

Consider carbon as an example. Carbon atoms have six protons. They also have six electrons. All carbon atoms are the same whether they are found in a lump of coal or a teaspoon of table sugar (**Figure** below). On the other hand, carbon atoms are different from the atoms of hydrogen, which are also found in coal and sugar. Each hydrogen atom has just one proton and one electron.

[Figure 4]

Carbon is the main element in coal (left). Carbon is also a major component of sugar (right).

Q: Why do you think coal and sugar are so different from one another when carbon is a major component of each substance?

A: Coal and sugar differ from one another because they contain different proportions of carbon and other elements. For example, coal is about 85 percent carbon, whereas table sugar is about 42 percent carbon. Both coal and sugar also contain the elements hydrogen and oxygen but in different proportions. In addition, coal contains the elements nitrogen and sulfur.

Summary

- An element is a pure substance that cannot be separated into any other substances. There are 92 naturally occurring elements.
- Each element has a unique set of properties that is different from the set of properties of any other element.

- For about 2000 years, people accepted Aristotle's idea that all matter is made up of just four elements: earth, air, water, and fire. Starting about 500 years ago, scientists began discovering all of the elements that are known today.
- The smallest particle of an element that still has the properties of that element is the atom. All the atoms of an element are like one another, and are different from the atoms of all other elements.

Review

1. What is an element?
2. Why can an element be identified by its properties?
3. Explain why the following statement is either true or false: The idea that all matter consists of the elements was first introduced a few hundred years ago.
4. How are atoms related to elements?

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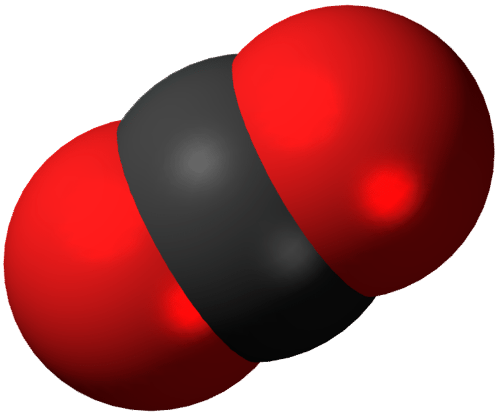
2.6 Compound

FlexBooks® 2.0 > American HS Physical Science > Compound

Last Modified: Sep 06, 2018



[Figure 1]

What is this strange-looking object? Can you guess what it is? It's a model of a certain type of matter. Some types of matter are elements, or pure substances that cannot be broken down into simpler substances. Many other types of matter are compounds. The model above represents a compound. The compound it represents is carbon dioxide, a gas you exhale each time you breathe.

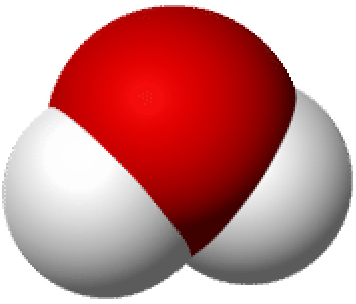
What Is a Compound?

A **compound** is a unique substance that forms when two or more elements combine chemically. For example, the compound carbon dioxide forms when one atom of carbon (grey in the model above) combines with two atoms of oxygen (red in the model). Another example of a compound is water. It forms when two hydrogen atoms combine with one oxygen atom.

https://flexbooks.ck12.org/flx/render/embeddedobject/195

Q: How could a water molecule be represented?

A: It could be represented by a model like the one for carbon dioxide in the opening image. You can see a sample **Figure** below.



[Figure 2]

A model of water.

Two things are true of all compounds:

- A compound always has the same elements in the same proportions. For example, carbon dioxide always has two atoms of oxygen for each atom of carbon, and water always has two atoms of hydrogen for each atom of oxygen.
- A compound always has the same composition throughout. For example, all the carbon dioxide in the atmosphere and all the water in the ocean have these same proportions of

elements.

Q: How do you think the properties of compounds compare with the properties of the elements that form them?

A: You might expect the properties of a compound to be similar to the properties of the elements that make up the compound. But you would be wrong.

Properties of Compounds

The properties of compounds are different from the properties of the elements that form them—sometimes very different. That's because elements in a compound combine and become an entirely different substance with its own unique properties. Do you put salt on your food? Table salt is the compound sodium chloride. It contains sodium and chlorine. As shown in the **Figure** below, sodium is a solid that reacts explosively with water, and chlorine is a poisonous gas. But together in table salt, sodium and chlorine form a harmless unreactive compound that you can safely eat.

[Figure 3]

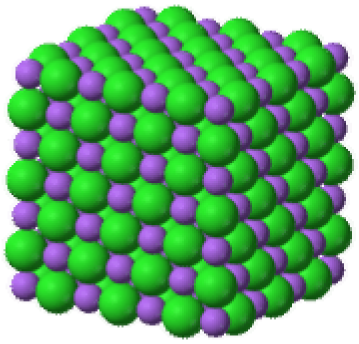
Sodium and chlorine combine to form sodium chloride, or table salt.

Q: The compound sodium chloride is very different from the elements sodium and chlorine that combine to form it. What are some properties of sodium chloride?

A: Sodium chloride is an odorless white solid that is harmless unless consumed in large quantities. In fact, it is a necessary component of the human diet.

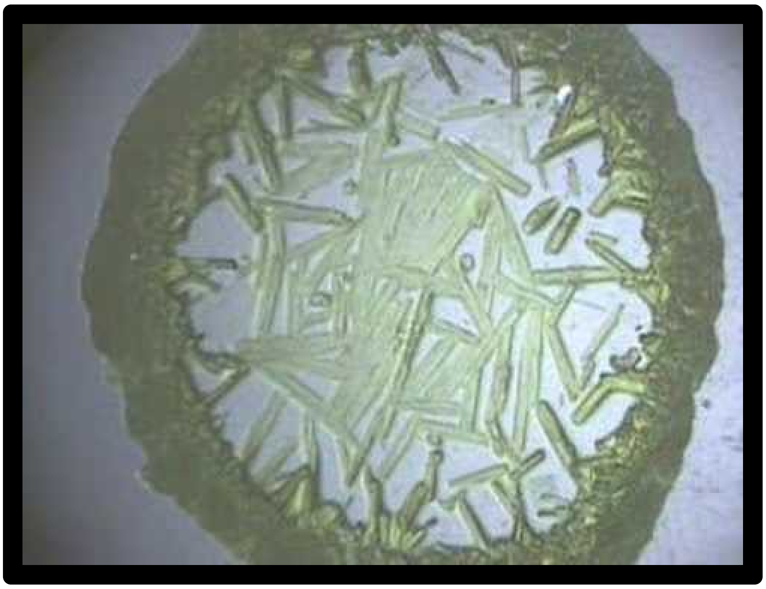
Structure of Compounds

Compounds like sodium chloride form structures called crystals. A **crystal** is a rigid framework of many ions locked together in a repeating pattern. Ions are electrically charged forms of atoms. You can see a crystal of sodium chloride in the **Figure** below. It is made up of many sodium and chloride ions.



[Figure 4]

A sodium chloride crystal consists of many sodium ions (blue) and chloride ions (green) arranged in a rigid framework.



https://flexbooks.ck12.org/flx/render/embeddedobject/54904

Compounds such as carbon dioxide and water form molecules instead of crystals. A **molecule** is the smallest particle of a compound that still has the compound's properties. It consists of two or more atoms bonded together. You saw models of carbon dioxide and water molecules above.

Summary

- A compound is a unique substance that forms when two or more elements combine chemically. A compound always has the same elements in the same proportions.
- The properties of compounds may be very different from the properties of the elements that form them.
- Some compounds form rigid frameworks called crystals. Other compounds form individual molecules. A molecule is the smallest particle of a compound that still has the compound's properties.

Review

1. What are compounds? List three examples.
2. How do the properties of compounds compare with the properties of the elements that form them?
3. Compare and contrast crystals and molecules.

Report Content Errors

2.7 Mixture

FlexBooks® 2.0 > American HS Physical Science > Mixture

Last Modified: Aug 30, 2021

[Figure 1]

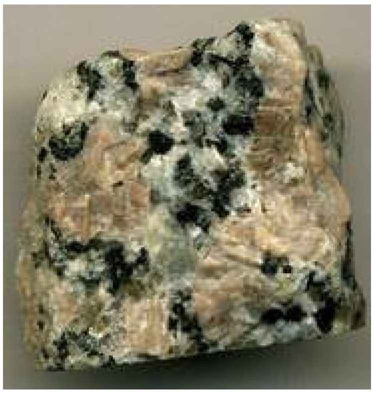
Ahhhh! A tall glass of ice-cold lemonade is really refreshing on a hot day. Lemonade is a combination of lemon juice, water, and sugar. Do you know what kind of matter lemonade is? It's obviously not an element because it consists of more than one substance. Is it a compound? Not all combined substances are compounds. Some—including lemonade—are mixtures.

What Is a Mixture?

A **mixture** is a combination of two or more substances in any proportion. This is different from a compound, which consists of substances in fixed proportions. The substances in a mixture also do not combine chemically to form a new substance, as they do in a compound. Instead, they just intermingle and keep their original properties. The lemonade pictured above is a mixture because it doesn't have fixed proportions of ingredients. It could have more or less lemon juice, for example, or more or less sugar, and it would still be lemonade.

Q: What are some other examples of mixtures?

A: Other examples of liquid mixtures include salt water and salad dressing. Air is a mixture of gases, mainly nitrogen and oxygen. The rock pictured in the **Figure** below is a solid mixture.



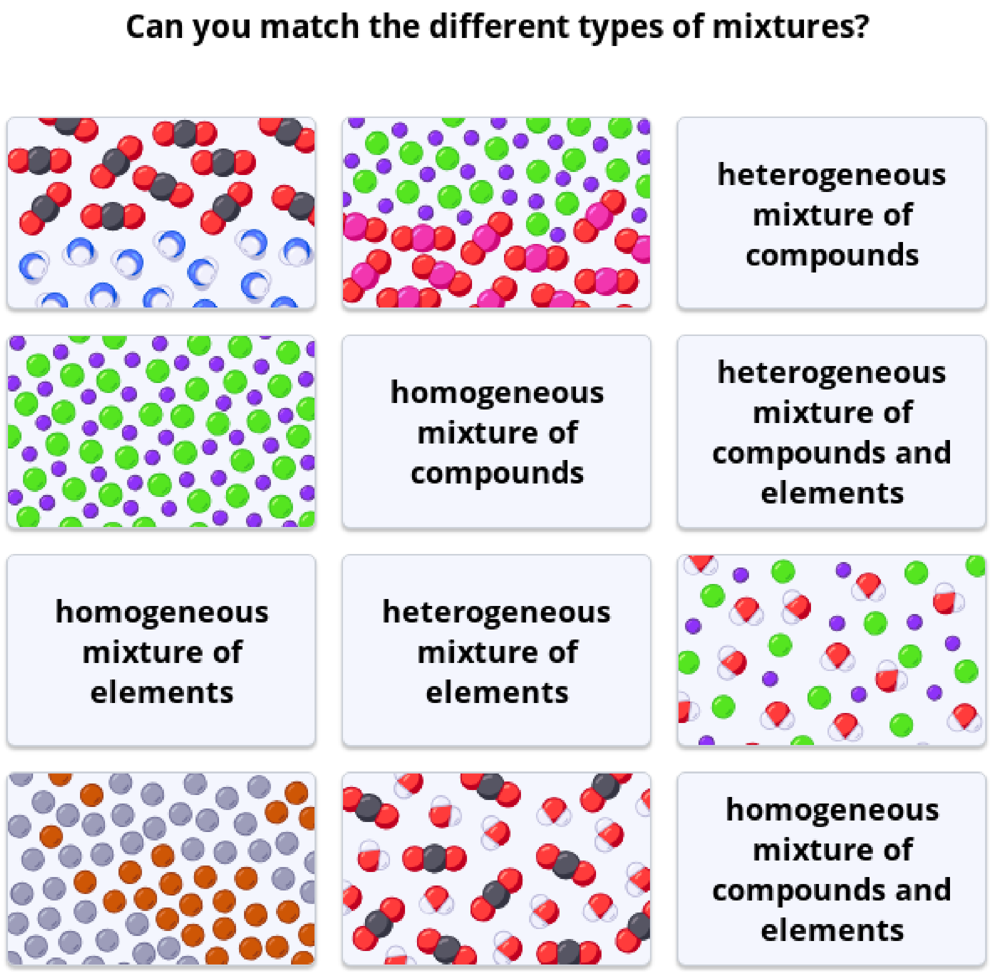
[Figure 2]

This rock is a mixture of smaller rocks and minerals.

Homogeneous or Heterogeneous?

The lemonade in the opening picture is an example of a homogeneous mixture. A homogeneous mixture has the same composition throughout. Another example of a homogeneous mixture is salt water. If you analyzed samples of ocean water in different places, you would find that the proportion of salt in each sample is the same: 3.5 percent.

The rock in **Figure** above is an example of a heterogeneous mixture. A heterogeneous mixture varies in its composition. The black nuggets, for example, are not distributed evenly throughout the rock.



Types of Mixtures

Mixtures have different properties depending on the size of their particles. Three types of mixtures based on particle size are solutions, suspensions, and colloids, all of which are described in the **Table** below.

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Solutions, Suspensions, and Colloids

Type of Mixture	Description
Solutions  [Figure 3]	A **solution** is a homogeneous mixture with tiny particles. The particles are too small to see and also too small to settle or be filtered out of the mixture. When the salt is thoroughly mixed into the water in this glass, it will form a solution. The salt will no longer be visible in the water, and it won't settle to the bottom of the glass.
Colloids  [Figure 4]	A **colloid** is a homogeneous mixture with medium-sized particles. The particles are large enough to see but not large enough to settle or be filtered out of the mixture. The gelatin in this dish is a colloid. It looks red because you can see the red gelatin particles in the mixture. However, the particles are too small to settle to the bottom of the dish.
Suspensions  [Figure 5]	A **suspension** is a heterogeneous mixture with large particles. The particles are large enough to see and also to settle or be filtered out of the mixture. The salad dressing in this bottle is a suspension. It contains oil, vinegar, herbs, and spices. If the bottle sits undisturbed for very long, the mixture will separate into its component parts. That's why you should shake it before you use it.

Q: If you buy a can of paint at a paint store, a store employee may put the can on a shaker machine to mix up the paint in the can. What type of mixture is the paint?

A: The paint is a suspension. Some of the components of the paint settle out of the mixture when it sits undisturbed for a long time. This explains why you need to shake (or stir) the paint before you use it.

Q: The milk you buy in the supermarket has gone through a process called homogenization. This process breaks up the cream in the milk into smaller particles. As a result, the cream doesn't separate out of the milk no matter how long it sits on the shelf. Which type of mixture is homogenized milk?

A: Homogenized milk is a colloid. The particles in the milk are large enough to see—that's why milk is white instead of clear like water, which is the main component of milk. However, the particles are not large enough to settle out of the mixture.

Separating Mixtures

The components of a mixture keep their own identity when they combine, so they retain their physical properties. Examples of physical properties include boiling point, ability to dissolve, and particle size. When components of mixtures vary in physical properties such as these, processes such as boiling, dissolving, or filtering can be used to separate them.

Look at the **Figure** below of the Great Salt Lake in Utah. The water in the lake is a solution of salt and water. Do you see the white salt deposits near the shore? How did the salt separate from the salt water? Water has a lower boiling point than salt, and it evaporates in the heat of the sun. With its higher boiling point, the salt doesn't get hot enough to evaporate, so it is left behind.

[Figure 6]

Q: Suppose you have a mixture of salt and pepper. What properties of the salt and pepper might allow you to separate them?

A: Salt dissolves in water but pepper does not. If you mix salt and pepper with water, only the salt will dissolve, leaving the pepper floating in the water. You can separate the pepper from the water by pouring the mixture through a filter, such as a coffee filter.

Q: After you separate the pepper from the salt water, how could you separate the salt from the water?

A: You could heat the water until it boils and evaporates. The salt would be left behind.

Summary

- A mixture is a combination of two or more substances in any proportions. The substances in a mixture do not combine chemically, so they retain their physical properties.
- A homogeneous mixture has the same composition throughout. A heterogeneous mixture varies in its composition.
- Mixtures can be classified on the basis of particle size into three different types: solutions, suspensions, and colloids.
- The components of a mixture retain their own physical properties. These properties can be used to separate the components by filtering, boiling, or other physical processes.

Review

1. What is a mixture?
2. What is the difference between a homogeneous and a heterogeneous mixture?
3. Make a table to compare and contrast solutions, colloids, and suspensions. Include an example of each type of mixture in your table.
4. Iron filings are attracted by a magnet. This is a physical property of iron but not of most other materials, including sand. How could you use this difference in physical properties to separate a mixture of iron filings and sand?

Report Content Errors

2.8 Physical Change

FlexBooks® 2.0 > American HS Physical Science > Physical Change

Last Modified: Jun 19, 2019

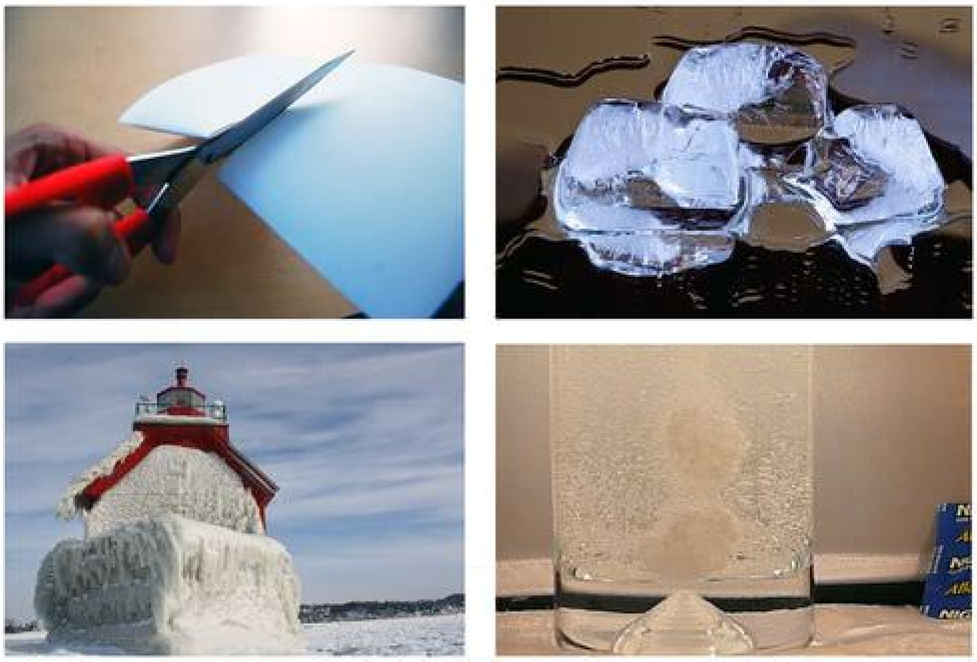
[Figure 1]

How do rocks change over time?

These stunning rock arches in Utah were carved by wind-blown sand. Repeated scouring by the sand wore away the rock, bit by tiny bit, like sandpaper on wood. The bits of rock worn away by the sand still contain the same minerals as they did when they were part of the large rock. They have not changed chemically in any way. Only the size and shape of the rock have changed, from a single large rock to millions of tiny bits of rock. Changes in size and shape are physical changes in matter.

What Is a Physical Change?

A **physical change** is a change in one or more physical properties of matter without any change in chemical properties. In other words, matter doesn't change into a different substance in a physical change. Examples of physical change include changes in the size or shape of matter. Changes of state—for example, from solid to liquid or from liquid to gas—are also physical changes. Some of the processes that cause physical changes include cutting, bending, dissolving, freezing, boiling, and melting. Four examples of physical change are pictured in the **Figure** below.



[Figure 2]

Q: In the **Figure** above, what physical changes are occurring?

A: The paper is being cut into smaller pieces, which is changing its size and shape. The ice cubes are turning into a puddle of liquid water because they are melting. This is a change of state. The tablet is disappearing in the glass of water because it is dissolving into particles that are too small to see. The lighthouse is becoming coated with ice as ocean spray freezes on its surface. This is another change of state.

Reversing Physical Changes

When matter undergoes physical change, it doesn't become a different substance. Therefore, physical changes are often easy to reverse. For example, when liquid water freezes to form ice, it can be changed back to liquid water by heating and melting the ice.

Q: Salt dissolving in water is a physical change. How could this change be reversed?

A: The salt water could be boiled until the water evaporates, leaving behind the salt. Water vapor from the boiling water could be captured and cooled. The water vapor would condense and change back to liquid water.

Summary

- A physical change in matter is a change in one or more of matter's physical properties. In a physical change, matter may change its size, shape, or state, but its chemical properties do not change.

- Because the chemical properties of matter remain the same in a physical change, a physical change is often easy to reverse.

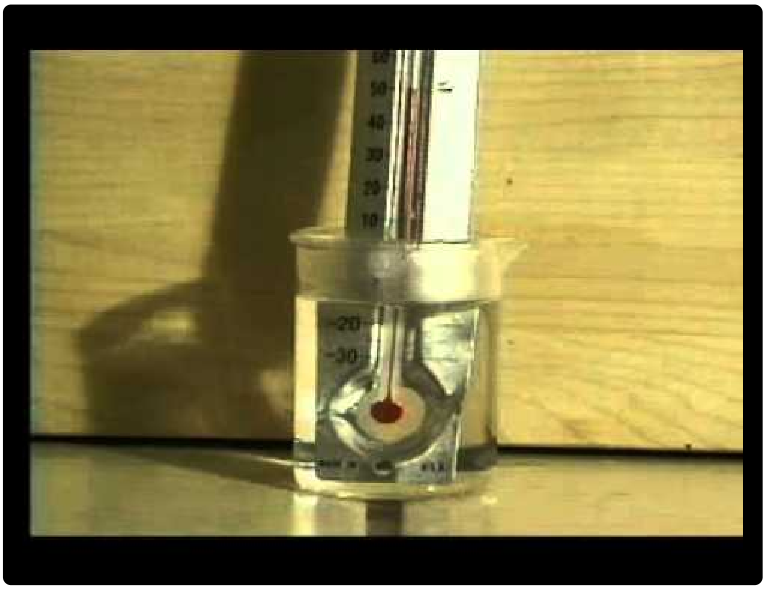
Review

1. Define physical change.
2. What are some examples of physical change?
3. The wood in the **Figure** below is being cut with a chainsaw. Is this a physical change? Why or why not?

[Figure 3]

Explore More

Watch the video about physical changes at the following URL. Then answer the questions below.



https://flexbooks.ck12.org/flx/render/embeddedobject/54900

1. Describe an example of temperature causing a change in the size of matter.
2. How is temperature related to changes in the state of matter?

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2.9 Chemical Change

FlexBooks® 2.0 > American HS Physical Science > Chemical Change

Last Modified: Sep 06, 2018

[Figure 1]

Communities often use fireworks to celebrate important occasions. Fireworks certainly create awesome sights and sounds! Do you know what causes the brilliant lights and loud booms of a fireworks display? The answer is chemical changes.

What Is a Chemical Change?

A **chemical change** occurs whenever matter changes into an entirely different substance with different chemical properties. A chemical change is also called a chemical reaction. Many complex chemical changes occur to produce the explosions of fireworks. An example of a simpler chemical change is the burning of methane. Methane is the main component of natural gas, which is burned in many home furnaces. During burning, methane combines with oxygen in the air to produce entirely different chemical substances, including the gases carbon dioxide and water vapor.

https://flexbooks.ck12.org/flx/render/embeddedobject/5069

Identifying Chemical Changes

Most chemical changes are not as dramatic as exploding fireworks, so how can you tell whether a chemical change has occurred? There are usually clues. You just need to know what to look for. A chemical change has probably occurred if bubbles are released, there is a change of color, or an odor is produced. Other clues include the release of heat, light, or loud sounds. Examples of chemical changes that produce these clues are shown in the **Figure** below.

(a) Release of bubbles

(b) Color changes

(c) Production of an order

(d) Release of light or heat

(e) Production of loud sounds

[Figure 2]

Q: In addition to iron rusting, what is another example of matter changing color? Do you think this color change is a sign that a new chemical substance has been produced?

A: Another example of matter changing color is a penny changing from reddish brown to greenish brown as it becomes tarnished. The color change indicates that a new chemical substance has been produced. Copper on the surface of the penny has combined with oxygen in the air to produce a different substance called copper oxide.

Q: Besides food spoiling, what is another change that produces an odor? Is this a chemical change?

A: When wood burns, it produces a smoky odor. Burning is a chemical change.

Q: Which signs of chemical change do fireworks produce?

A: Fireworks produce heat, light, and loud sounds. These are all signs of chemical change.

Can Chemical Changes Be Reversed?

Because chemical changes produce new substances, they often cannot be undone. For example, you can't change ashes from burning logs back into wood. Some chemical changes can be reversed, but only by other chemical changes. For example, to undo tarnish on copper pennies, you can place them in vinegar. The acid in the vinegar combines with the copper oxide of the tarnish. This changes the copper oxide back to copper and oxygen, making the pennies reddish brown again. You can try this at home to see how well it works.

Summary

- A chemical change occurs whenever matter changes into an entirely different substance with different chemical properties. Burning is an example of a chemical change.
- Signs of chemical change include the release of bubbles, a change of color, production of an odor, release of heat and light, and production of loud sounds.
- Because chemical changes result in different substances, they often cannot be undone. Some chemical changes can be reversed, but only by other chemical changes.

Review

1. What happens in any chemical change?
2. List three signs that a chemical change has occurred.
3. Give an example of a chemical change. Explain why you think it is a chemical change.
4. Why can chemical changes often not be reversed?

Report Content Errors

2.10 States of Matter

FlexBooks® 2.0 > American HS Physical Science > States of Matter

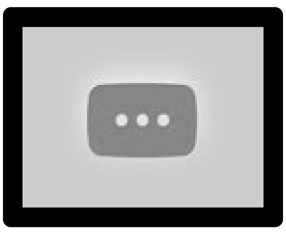
Last Modified: Feb 19, 2021

[Figure 1]

The striking blue walls in this photo are actually the sheer ice walls of a massive glacier. The glacier in the picture is in Argentina, and the bluish water in the foreground is Lake Argentina. The photo represents an important concept in physical science. Can you guess what it is?

Water, Water Everywhere

The photo above represents water in three common states of matter. **States of matter** are different phases in which any given type of matter can exist. There are actually four well-known states of matter: solid, liquid, gas, and plasma. Plasma isn't represented in the iceberg photo, but the other three states of matter are. The iceberg itself consists of water in the solid state, and the lake consists of water in the liquid state.



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Q: Where is water in the gaseous state in the above photo?

A: You can't see the gaseous water, but it's there. It exists as water vapor in the air.

Q: Water is one of the few substances that commonly exist on Earth in more than one state. Many other substances typically exist only in the solid, liquid, or gaseous state. Can you think of examples of matter that usually exists in just one of these three states?

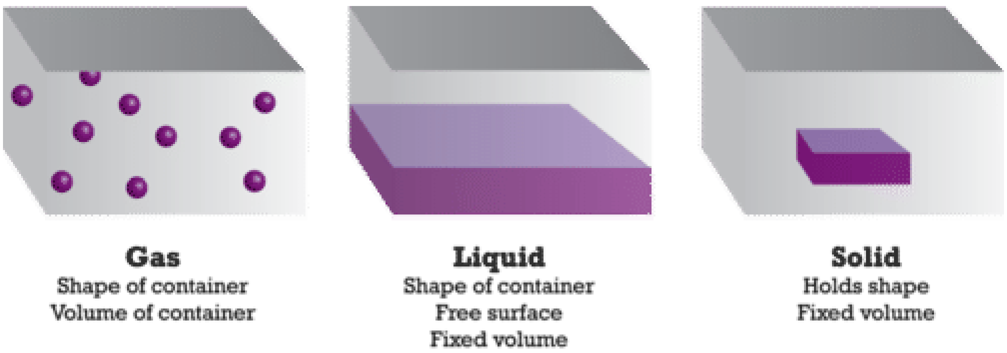
A: Just look around you and you will see many examples of matter that usually exists in the solid state. They include soil, rock, wood, metal, glass, and plastic. Examples of matter that usually exist in the liquid state include cooking oil, gasoline, and mercury, which is the only metal that commonly exists as a liquid. Examples of matter that usually exists in the gaseous state include oxygen and nitrogen, which are the chief gases in Earth's atmosphere.

Phases Are Physical

A given kind of matter has the same chemical makeup and the same chemical properties regardless of its state. That's because state of matter is a physical property. As a result, when matter changes state, it doesn't become a different kind of substance. For example, water is still water whether it exists as ice, liquid water, or water vapor.

Properties of Solids, Liquids, and Gases

The most common states of matter on Earth are solids, liquids, and gases. How do these states of matter differ? Their properties are contrasted in the **Figure** below.

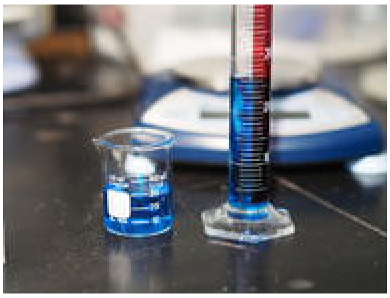


[Figure 2]

Properties of matter in different states.

Q: The **Figure** below shows that a liquid takes the shape of its container. How could you demonstrate this?

A: You could put the same volume of liquid in containers with different shapes. This is illustrated below with a beaker (left) and a graduated cylinder (right). The shape of the liquid in the beaker is short and wide like the beaker, while the shape of the liquid in the graduated cylinder is tall and narrow like that container, but each container holds the same volume of liquid.



[Figure 3]

Q: How could you show that a gas spreads out to take the volume as well as the shape of its container?

A: You could pump air into a bicycle tire. The tire would become firm all over as air molecules spread out to take the shape of the tire and also to occupy the entire volume of the tire.

Summary

- States of matter are different phases in which any given type of matter can exist. There are four well-known states of matter—solid, liquid, gas, and plasma—but only the first three states are common on Earth.
- State of matter is a physical property of matter. A given kind of matter has the same chemical makeup and the same chemical properties, regardless of state.
- Solids have a fixed volume and a fixed shape. Liquids have a fixed volume but take the shape of their container. Gases take both the volume and the shape of their container.

Review

1. Define state of matter.
2. List four states of matter. Which states of matter are most common on Earth?
3. What type of property is state of matter? How could you demonstrate this?
4. Make a table comparing and contrasting solids, liquids, and gases.

Resources

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2.11 Kinetic Theory of Matter

FlexBooks® 2.0 > American HS Physical Science > Kinetic Theory of Matter

Last Modified: Mar 09, 2020

[Figure 1]

This neat row of cola bottles represents matter in three different states—solid, liquid, and gas. The bottles and caps are solids, the cola is a liquid, and carbon dioxide dissolved in the cola is a gas. It gives cola its fizz. Solids, liquids, and gases such as these have different properties. Solids have a fixed shape and a fixed volume. Liquids also have a fixed volume but can change their shape. Gases have neither a fixed shape nor a fixed volume. What explains these differences in states of matter? The answer has to do with energy.

Moving Matter

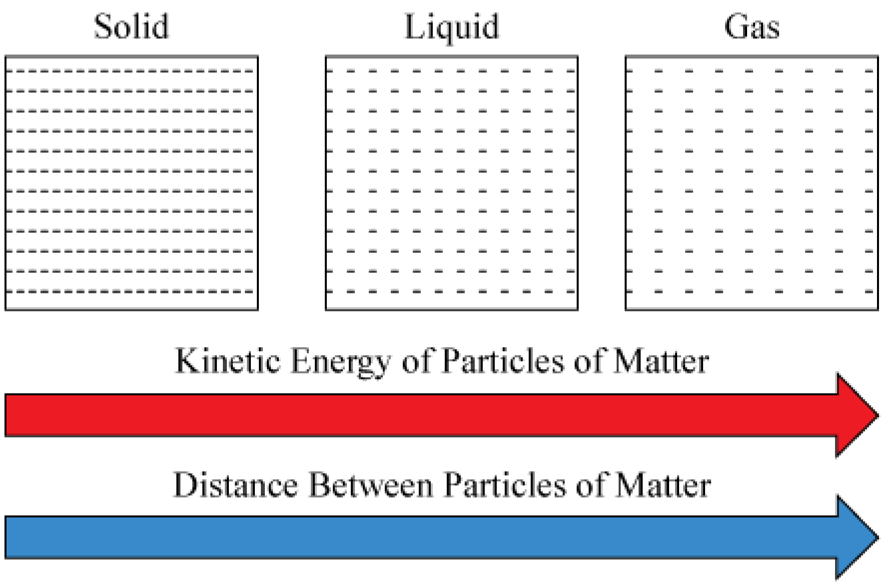
Energy is the ability to cause changes in matter. For example, your body uses chemical energy when you lift your arm or take a step. In both cases, energy is used to move matter—you. Any matter that is moving has energy just because it's moving. The energy of moving matter is called kinetic energy. Scientists think that the particles of all matter are in constant motion. In other words, the particles of matter have kinetic energy. The theory that all matter consists of constantly moving particles is called the **kinetic theory of matter**.

Kinetic Energy and States of Matter

Differences in kinetic energy explain why matter exists in different states. Particles of matter are attracted to each other, so they tend to pull together. The particles can move apart only if they have enough kinetic energy to overcome this force of attraction. It's like a tug of war between opposing sides, with the force of attraction between particles on one side and the kinetic energy of individual particles on the other side. The outcome of the "war" determines the state of matter.

- If particles do not have enough kinetic energy to overcome the force of attraction between them, matter exists as a solid. The particles are packed closely together and held rigidly in place. All they can do is vibrate. This explains why solids have a fixed volume and a fixed shape.
- If particles have enough kinetic energy to partly overcome the force of attraction between them, matter exists as a liquid. The particles can slide past one another but not pull apart completely. This explains why liquids can change shape but have a fixed volume.
- If particles have enough kinetic energy to completely overcome the force of attraction between them, matter exists as a gas. The particles can pull apart and spread out. This explains why gases have neither a fixed volume nor a fixed shape.

Look at the **Figure** below. It sums up visually the relationship between kinetic energy and state of matter.



[Figure 2]

Q: How could you use a bottle of cola to demonstrate these relationships between kinetic energy and state of matter?

A: You could shake a bottle of cola and then open it. Shaking causes carbon dioxide to come out of the cola solution and change to a gas. The gas fizzes out of the bottle and spreads into the surrounding air, showing that its particles have enough kinetic energy to spread apart. Then you could tilt the open bottle and pour out a small amount of the cola on a table, where it will form a puddle. This shows that particles of the liquid have enough kinetic energy to slide over each other but not enough to pull apart completely. If you do nothing to the solid glass of the cola bottle, it will remain the same size and shape. Its particles do not have enough energy to move apart or even to slide over each other.

Summary

- According to the kinetic theory, particles of matter are in constant motion. The energy of motion is called kinetic energy.
- Particles of solids have the least kinetic energy and particles of gases have the most.

Review

1. Use the kinetic molecular theory of matter to describe the motion of particles in ice, liquid water, and water vapor.
2. What is the relationship between the kinetic energy of particles and the forces of attraction between particles?

Explore More

Watch the video below and then answer the questions that follow.

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1. Describe the motion of particles in ice, liquid water, and water vapor.
2. Apply the kinetic theory of matter to explain the differences in your answer to question 1.

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2.12 Conservation of Mass

FlexBooks® 2.0 > American HS Physical Science > Conservation of Mass

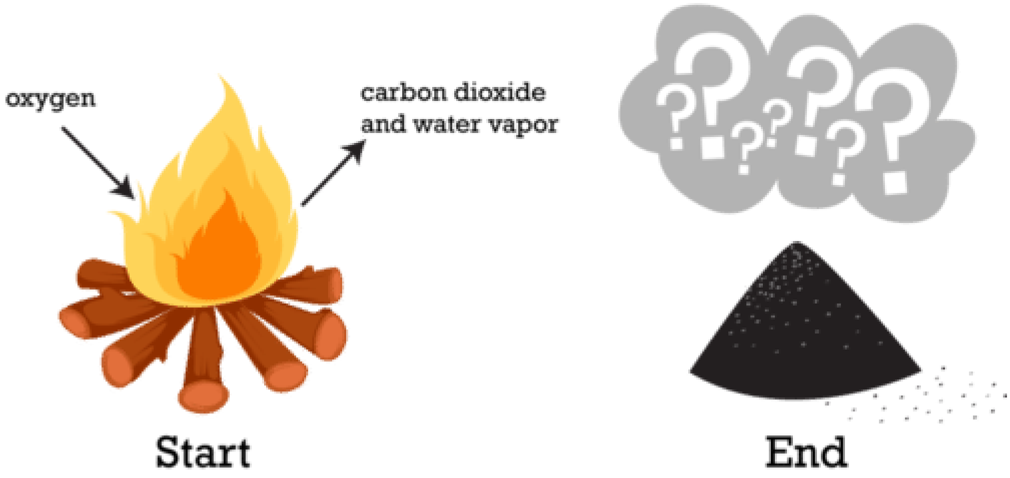
Last Modified: Sep 06, 2018

[Figure 1]

If you build a campfire like this one, you start with a big pile of logs. As the fire burns, the pile of logs slowly shrinks. By the end of the evening, all that's left is a small pile of ashes. What happened to the matter that you started with? Was it destroyed by the fire?

Where's the Matter?

It may seem as though burning destroys matter, but the same amount, or mass, of matter still exists after a campfire as before. Look at the sketch in **Figure** below. It shows that when wood burns, it combines with oxygen and changes not only to ashes but also to carbon dioxide and water vapor. The gases float off into the air, leaving behind just the ashes. Suppose you had measured the mass of the wood before it burned and the mass of the ashes after it burned. Also suppose you had been able to measure the oxygen used by the fire and the gases produced by the fire. What would you find? The total mass of matter after the fire would be the same as the total mass of matter before the fire.



[Figure 2]

Q: What can you infer from this example?

A: You can infer that burning does not destroy matter. It just changes matter into different substances.

Law of Conservation of Mass

This burning campfire example illustrates a very important law in science: the **law of conservation of mass**. This law states that matter cannot be created or destroyed. Even when matter goes through a physical or chemical change, the total mass of matter always remains the same.

Q: How could you show that the mass of matter remains the same when matter changes state?

A: You could find the mass of a quantity of liquid water. Then you could freeze the water and find the mass of the ice. The mass before and after freezing would be the same, showing that mass is conserved when matter changes state.

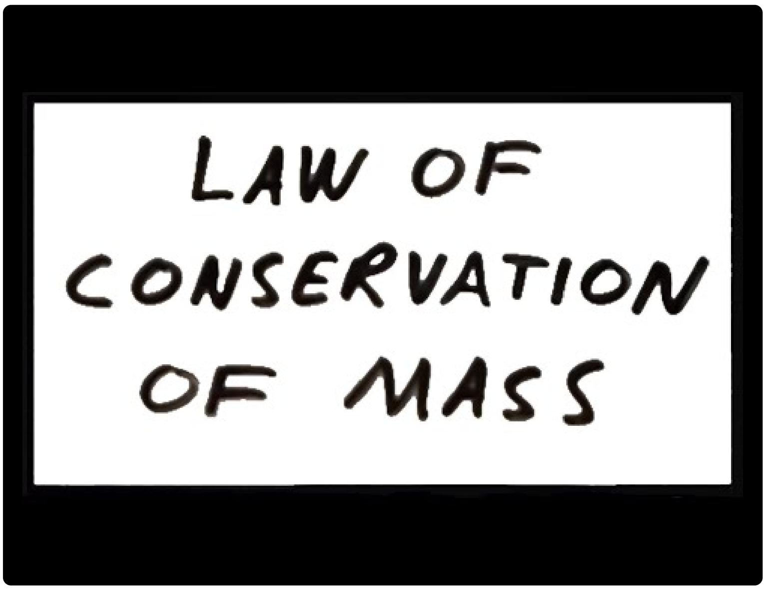
Summary

- Burning and other changes in matter do not destroy matter. The mass of matter is always the same before and after the changes occur.
- The law of conservation of mass states that matter cannot be created or destroyed.

Review

1. What is the law of conservation of mass?
2. Describe an example of the law of conservation of mass.

Resources



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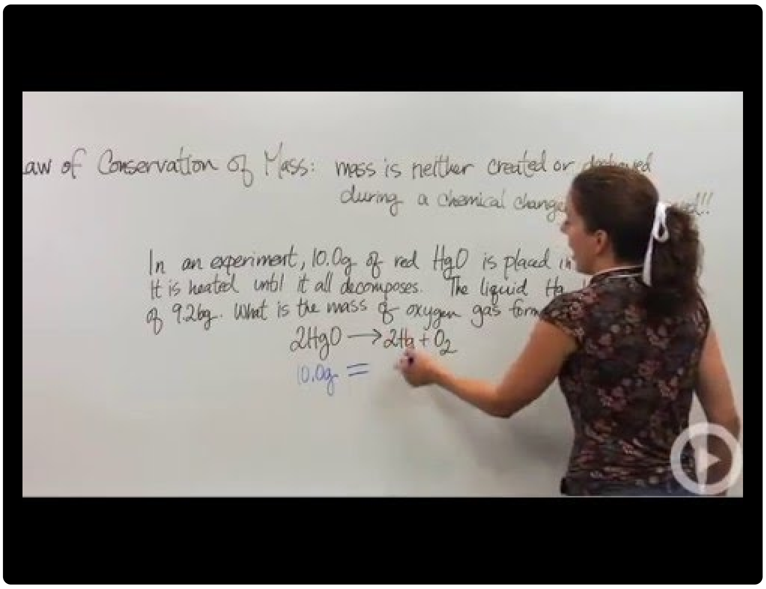

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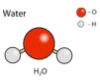	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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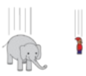	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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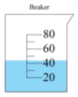
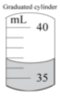
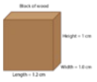
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 3

Atomic Structure

Chapter Outline

3.1 Atom

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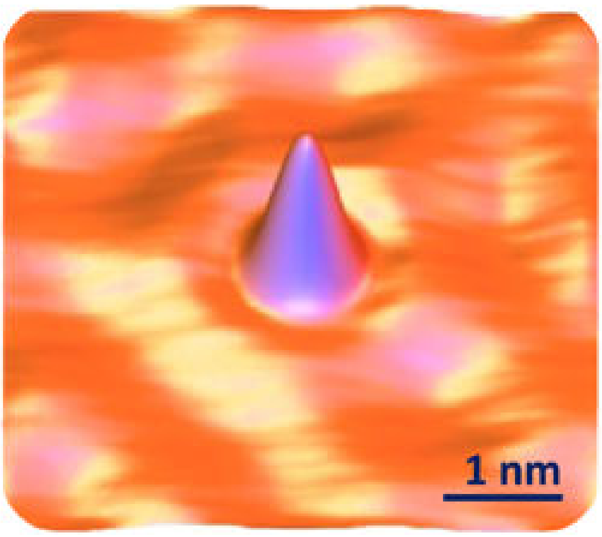


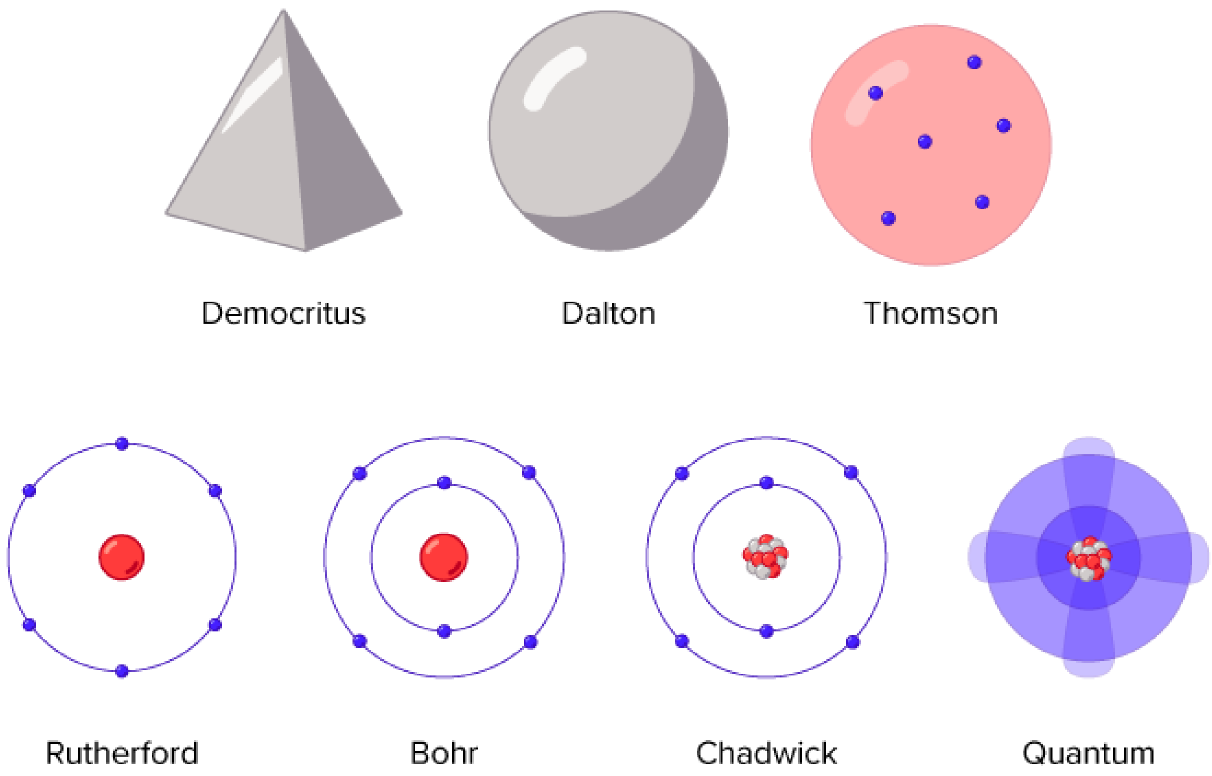
[Figure 1]

What could this hilly blue surface possibly be?

Do you have any idea? The answer is a single atom of the element cobalt. The picture was created using a scanning tunneling microscope. No other microscope can make images of things as tiny as atoms. How small are atoms? You will find out in this lesson.

Discovering the Atom

Atoms are very tiny, so tiny that they could not be seen before scanning tunneling microscopes were invented in 1981. However, the atom and its parts were discovered long before the tunneling microscope was invented. How did scientists discover the atom if they couldn't see it? They made models. A scientific model is a tool constructed by the scientist based on all the known experimental evidence about a particular thing, such as an atom. The first model of the atom goes back to ancient Greece. As time went by and more experiments are performed, models evolve and change to account for new understanding. Explore the timeline below to see how the model of the atom was initially developed and how it has changed over time into what we now have come to accept as the modern model of the atom.



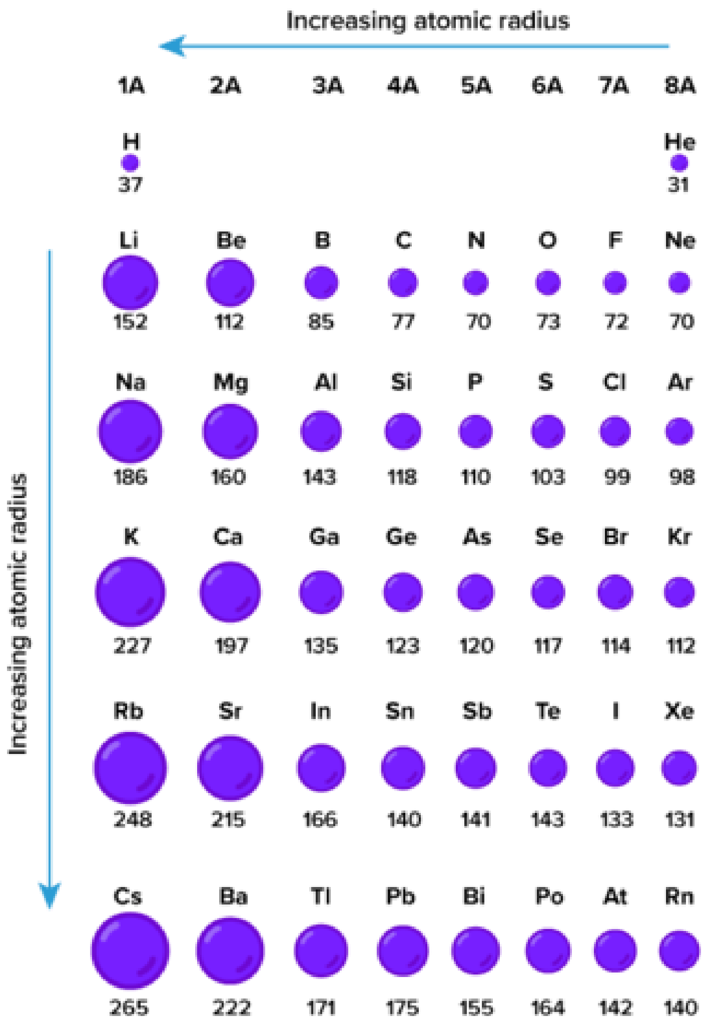
Atoms

Atoms are the building blocks of matter. They are the smallest particles of an element that still have the element's properties. Elements, in turn, are pure substances—such as nickel, hydrogen, and helium—that make up all kinds of matter. All the atoms of a given element are identical in that they have the same number of protons, one of the building blocks of atoms (see below). They are also different from the atoms of all other elements, as atoms of different elements have different numbers of protons.

Size of Atoms

Unlike bricks, atoms are extremely small. The radius of an atom is well under 1 nanometer, which is one-billionth of a meter. If a size that small is hard to imagine, consider this: trillions of atoms would fit inside the period at the end of this sentence. Although all atoms are very small, elements vary in the size of their atoms. The Figure below compares the sizes of atoms of more than 40 different elements. The elements in the figure are represented by chemical symbols, such as H for hydrogen and He for helium. Of course, real atoms are much smaller than the circles representing them in the Figure below.

Atomic size chart



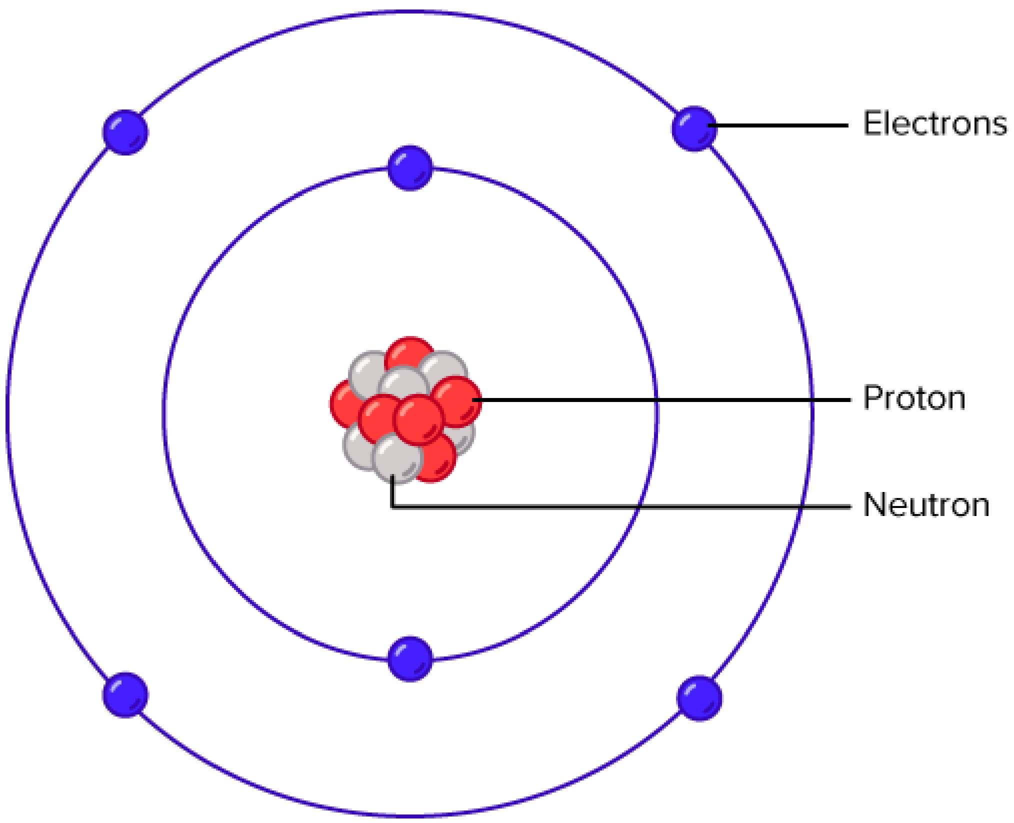
[Figure 2]

Q: Which element in the chart above has the biggest atoms?

A: According to the chart above, the element with the biggest atoms is cesium (Cs).

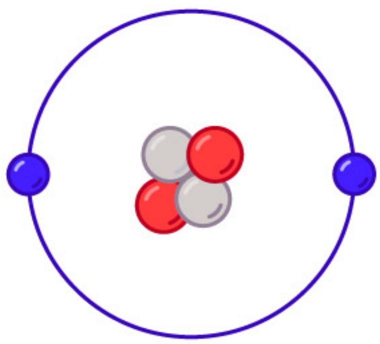
Subatomic Particles

Although atoms are very tiny, they consist of even smaller particles. Three main types of particles that make up all atoms are protons, neutrons, and electrons. The interactive below shows how these particles are arranged in an atom. Click on the subatomic particle to learn more about each type.



The atom shown above represented by the model is carbon, but the particles of all atoms are arranged in the same way. At the center of the atom is a dense area called the nucleus, where all the protons and neutrons are clustered closely together. The electrons constantly move around the nucleus. Helium has two protons and two neutrons in its nucleus and two electrons moving around the nucleus. Atoms of other elements have different numbers of subatomic particles, but the number of protons always equals the number of electrons. This makes atoms neutral in charge because the positive and negative charges "cancel out."
Q: Lithium has three protons, four neutrons, and three electrons. Sketch a model of a lithium atom, similar to the model above for helium.

A: Does your sketch resemble the model in the image below?



[Figure 3]

Q: All atoms of carbon have six protons. How many electrons do carbon atoms have?

A: Carbon atoms must have six electrons to "cancel out" the positive charges of the six protons. That's because atoms are always neutral in electric charge.

Summary

- Atoms are the building blocks of matter.
- They are the smallest particles of an element that still have the element's properties. All atoms are very small, but atoms of different elements vary in size.
- Three main types of particles that make up all atoms are protons, neutrons, and electrons.

Review

1. What is an atom?
2. Which of the following statement(s) are true about the atoms of any element?
   a. The number of protons in an atom of an element is unique to each element.
   b. The number of protons and neutrons in an atom of an element is unique to each element.
   c. A proton is an atom of one element that is identical to a proton in an atom of another element.
   d. The number of protons in an atom of an element is the same for all elements.
3. Which of the following statements explains why atoms are always neutral in charge
   a. They have the same number of protons as the atoms of all other elements.
   b. They have protons that are identical to the protons of all other elements.
   c. They have the same size as the atoms of all other elements.
   d. They have the same number of protons as electrons.

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3.2 Nucleus of the Atom

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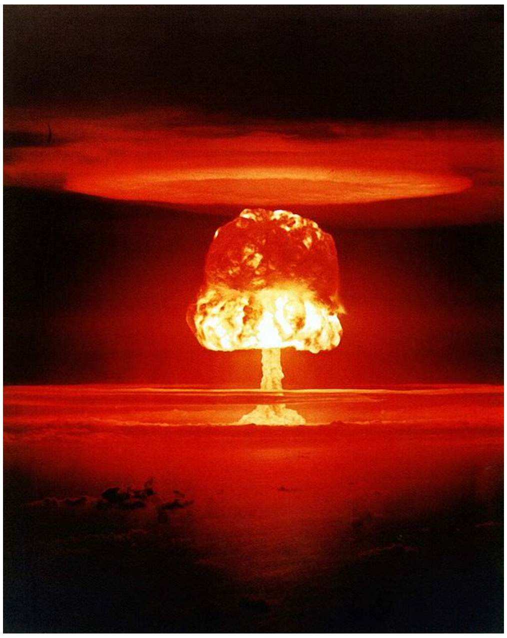
Last Modified: Nov 09, 2018

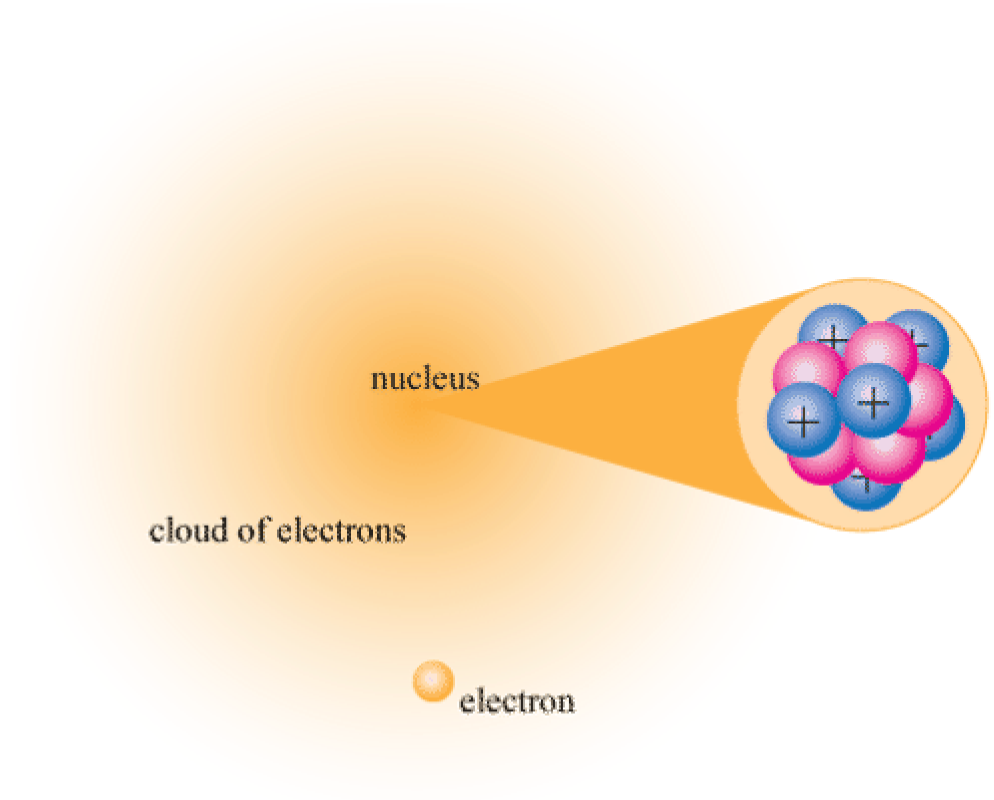


[Figure 1]

An atomic bomb explodes and generates a huge mushroom cloud. The tremendous energy released when the bomb explodes is incredibly destructive. Where does all the energy come from? The answer is the nucleus of the atom.

At the Heart of It All

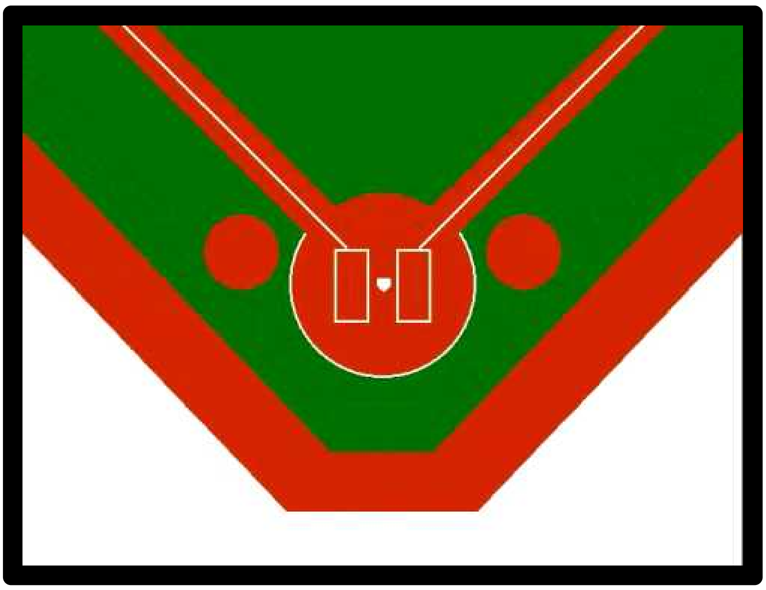
The **nucleus** (plural, nuclei) is a positively charged region at the center of the atom. It consists of two types of subatomic particles packed tightly together. The particles are protons, which have a positive electric charge, and neutrons, which are neutral in electric charge. Outside of the nucleus, an atom is mostly empty space, with orbiting negative particles called electrons whizzing through it. The **Figure** below shows these parts of the atom.



[Figure 2]

Size and Mass of the Nucleus

The nucleus of the atom is extremely small. Its radius is only about 1/100,000 of the total radius of the atom. If an atom were the size of a football stadium, the nucleus would be about the size of a pea!



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Electrons have virtually no mass, but protons and neutrons have a lot of mass for their size. As a result, the nucleus has virtually all the mass of an atom. Given its great mass and tiny size, the nucleus is very dense. If an object the size of a penny had the same density as the nucleus of an atom, its mass would be greater than 30 million tons!

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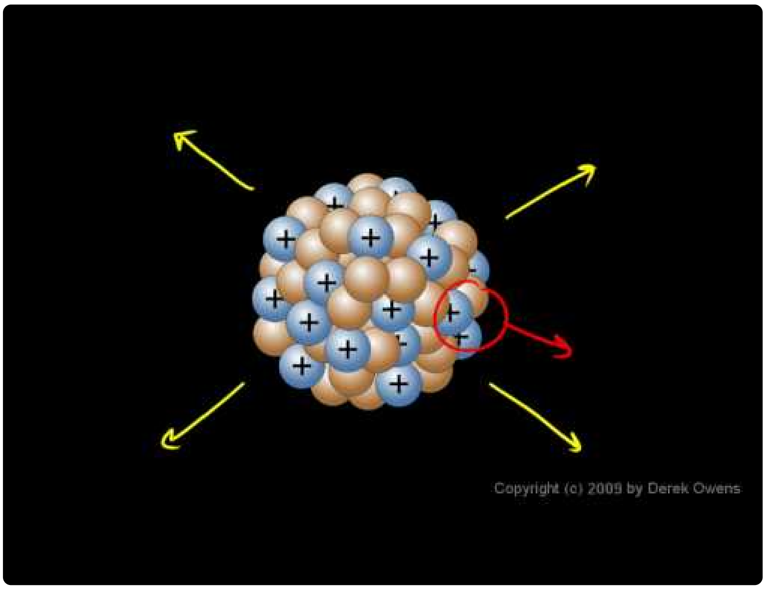
Holding It All Together

Particles with opposite electric charges attract each other. This explains why negative electrons orbit the positive nucleus. Particles with the same electric charge repel each other. This means that the positive protons in the nucleus push apart from one another. So why doesn't the nucleus fly apart? An even stronger force—called the strong nuclear force—holds protons and neutrons together in the nucleus.



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Q: Can you guess why an atomic bomb releases so much energy when it explodes?

A: When an atomic bomb explodes, the nuclei of atoms undergo a process called fission, in which they split apart. This releases the huge amount of energy that was holding together subatomic particles in the nucleus.

Summary

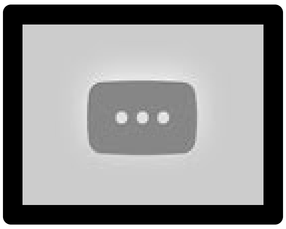
- The nucleus is a small, dense region at the center of the atom. It consists of positive protons and neutral neutrons, so it has an overall positive charge.
- The nucleus is just a tiny part of the atom, but it contains virtually all of the atom's mass.
- The strong nuclear force holds together protons and neutrons in the nucleus and overcomes the electric force of repulsion between protons.

Review

1. Describe the nucleus of the atom.
2. Why is the nucleus positive in charge?
3. Explain why the nucleus is very dense.
4. Outline the forces that act on particles in the nucleus.
5. If you made a three-dimensional model of an atom and its nucleus, how would you represent the atom? How would you represent nucleus? Explain your choices.

Explore More

Watch this short video about how the nucleus was discovered, and then answer the questions below.



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1. Describe the scientific procedure that was used to discover the nucleus.
2. What evidence led scientists to conclude that atoms consist mostly of empty space with a very small, positively charged mass at the center?
3. Reflect on the method used in the experiment. Why was it important to send positive—as opposed to neutral or negative—particles toward the gold foil?

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3.3 Proton

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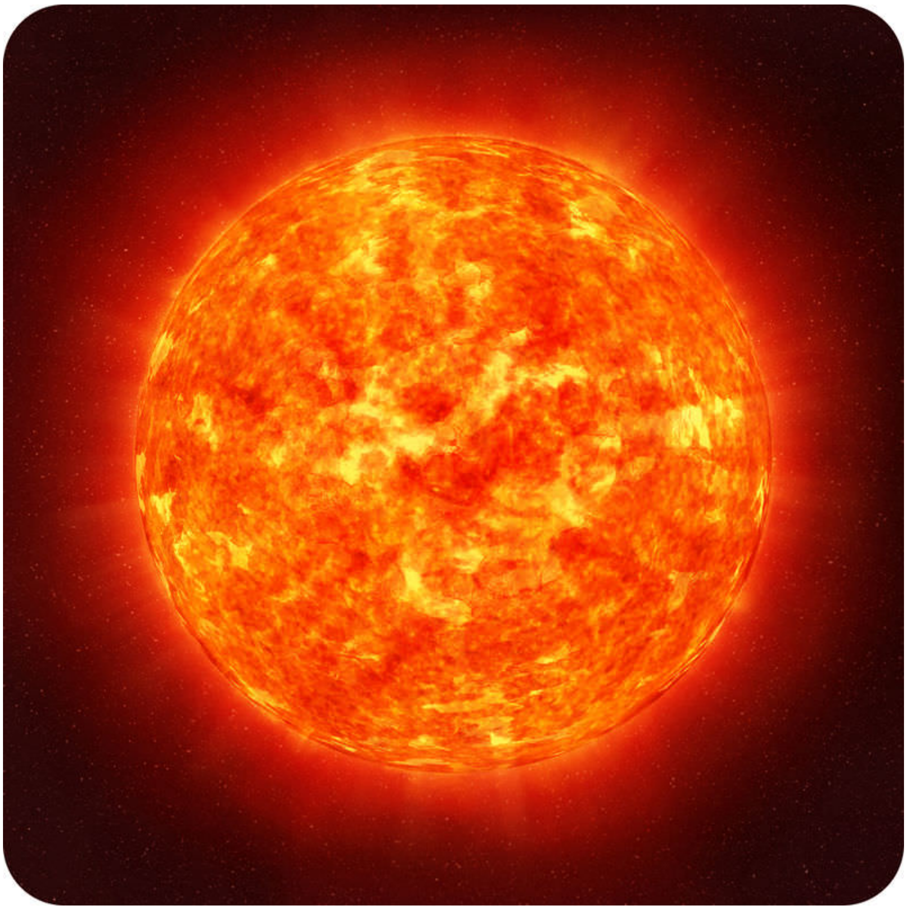
Last Modified: Nov 09, 2018

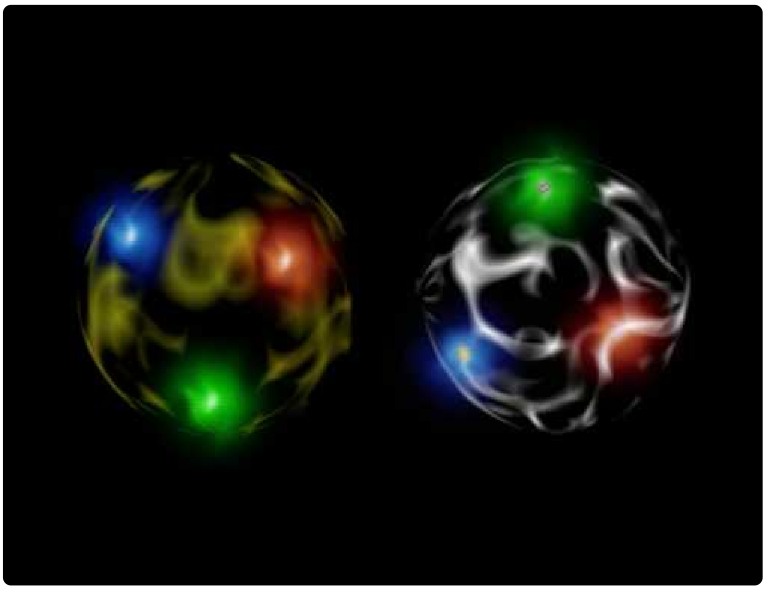


[Figure 1]

This glowing sphere represents the sun, which has a diameter of 1.4×10^9 meters. The sun has a special relationship to another object that is only about 1.7×10^{-17} meters in diameter—the subatomic particle called the proton. How is the gigantic sun related to the extremely tiny proton? Read on to find out.

What Is a Proton?

A **proton** is one of three main particles that make up the atom. The other two particles are the neutron and electron. Protons are found in the nucleus of the atom. This is a tiny, dense region at the center of the atom. Protons have a positive electrical charge of one (+1) and a mass of 1 atomic mass unit (amu), which is about 1.67×10^{-27} kilograms. Together with neutrons, they make up virtually all of the mass of an atom.



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Q: How do you think the sun is related to protons?

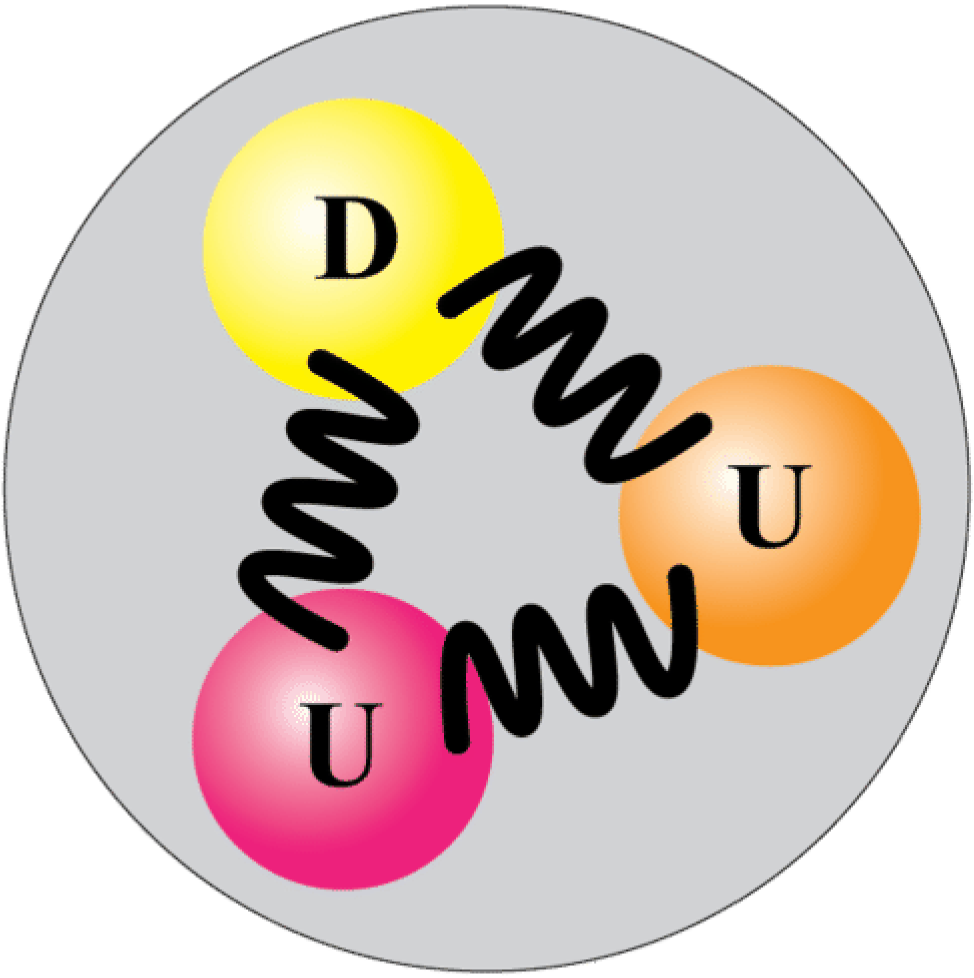
A: The sun's tremendous energy is the result of proton interactions. In the sun, as well as in other stars, protons from hydrogen atoms combine, or fuse, to form nuclei of helium atoms. This fusion reaction releases a huge amount of energy and takes place in nature only at the extremely high temperatures of stars such as the sun.

Identical Protons, Different Elements

All protons are identical. For example, hydrogen protons are exactly the same as protons of helium and all other elements, or pure substances. However, atoms of different elements have different numbers of protons. In fact, atoms of any given element have a unique number of protons that is different from the numbers of protons of all other elements. For example, a hydrogen atom has just one proton, whereas a helium atom has two protons. The number of protons in an atom determines the electrical charge of the nucleus. The nucleus also contains neutrons, but they are neutral in charge. The one proton in a hydrogen nucleus, for example, gives it a charge of +1, and the two protons in a helium nucleus give it a charge of +2.

What Do Protons Contain?

Protons are made of fundamental particles called quarks and gluons. As you can see in the **Figure** below, a proton contains three quarks (colored circles) and three streams of gluons (wavy white lines). Two of the quarks are called up quarks (u), and the third quark is called a down quark (d). The gluons carry the strong nuclear force between quarks, binding them together. This force is needed to overcome the electric force of repulsion between positive protons. Although protons were discovered almost 100 years ago, the quarks and gluons inside them were discovered much more recently. Scientists are still learning more about these fundamental particles.



[Figure 2]

Summary

- A proton one of three main particles that make up the atom. It is found in the nucleus. It has an electrical charge of one +1 and a mass of 1 atomic mass unit (amu).
- Atoms of any given element have a unique number of protons that is different from the numbers of protons of all other elements.
- Protons consist of fundamental particles called quarks and gluons. Gluons carry the strong nuclear force between quarks, binding them together.

Review

1. Describe protons.
2. What is the relationship between protons and elements?

3. Atoms, which are always neutral in electric charge, contain electrons as well as protons and neutrons. An electron has an electrical charge of -1. If an atom has three electrons, infer how many protons it has.
4. Identify the fundamental particles that make up a proton.

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3.4 Neutron

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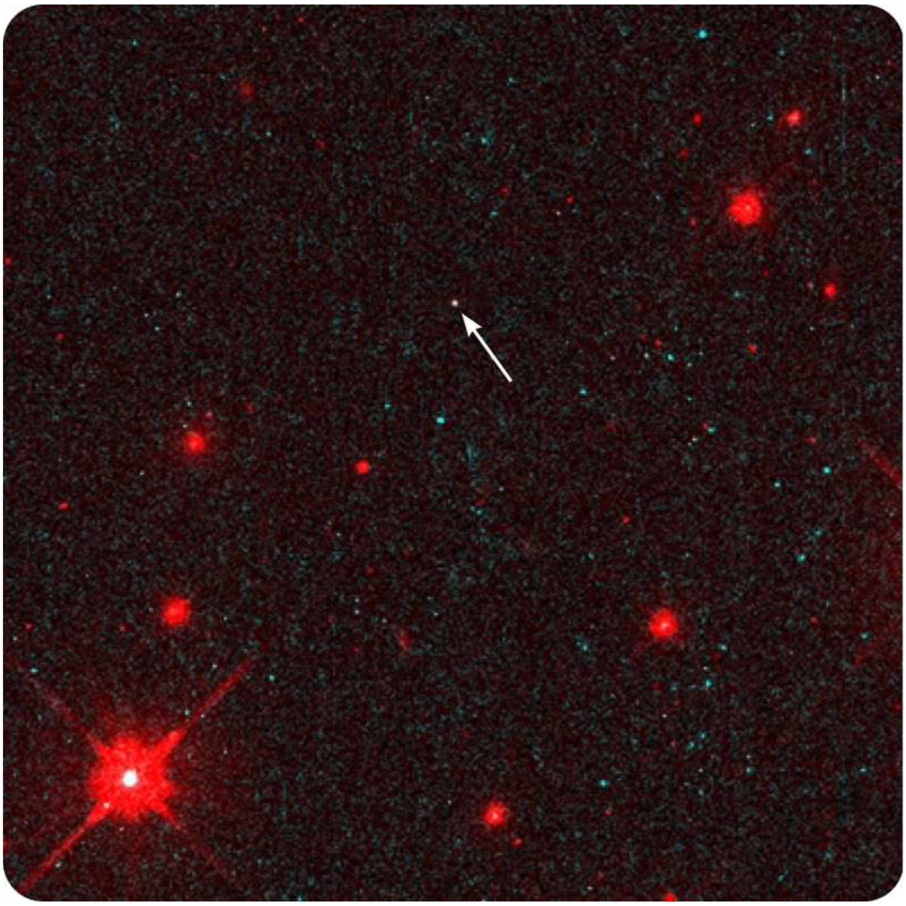
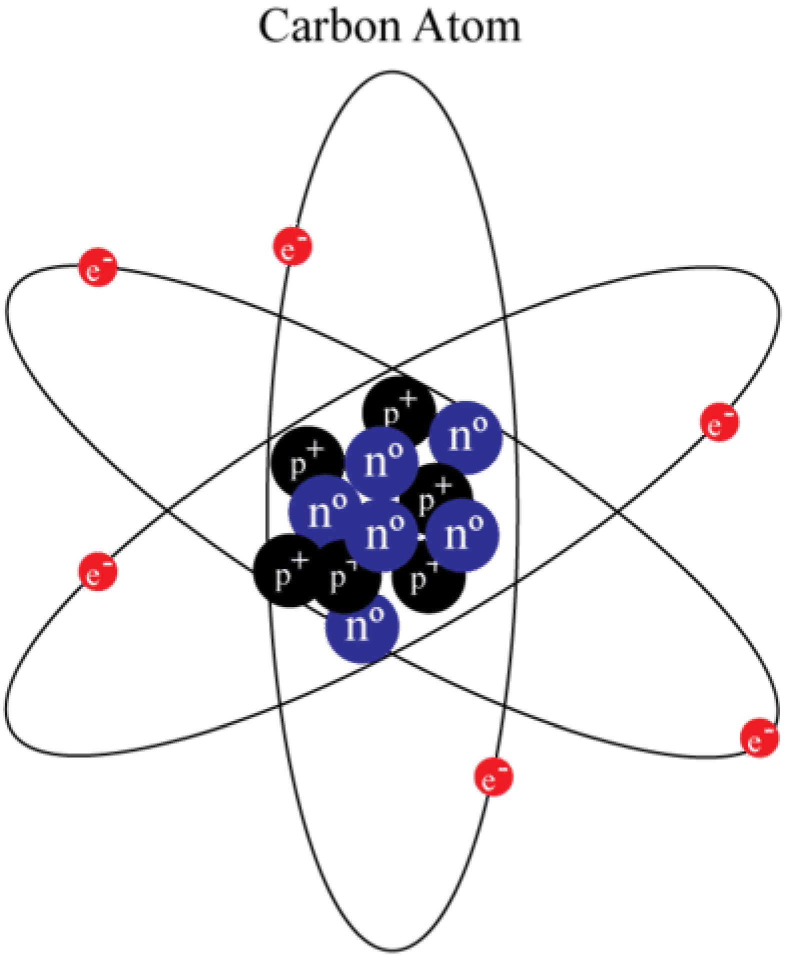


[Figure 1]

The arrow in this photo is pointing to a star that doesn't look like much compared with some of the other stars in the picture. It's certainly much smaller than most other stars. In fact, it's only about 20 kilometers in diameter. Compare that with the 1.4-million-kilometer diameter of our own sun. Despite its small size, however, this star has greater mass than the sun, making it incredibly dense. It also has tremendous gravity. In fact, gravity on its surface is about 2×10^{11} times the gravity we feel on Earth! What type of star is it? It's called a neutron star. That's because it consists solely of neutrons.

What Is a Neutron?

A **neutron** is one of three main particles that make up the atom. The other two particles are the proton and electron. Atoms of all elements—except for most atoms of hydrogen—have neutrons in their nucleus. The nucleus is the small, dense region at the center of an atom where protons are also found. Atoms generally have about the same number of neutrons as protons. For example, all carbon atoms have six protons and most also have six neutrons. A model of a carbon atom is shown in the **Figure** below



[Figure 2]

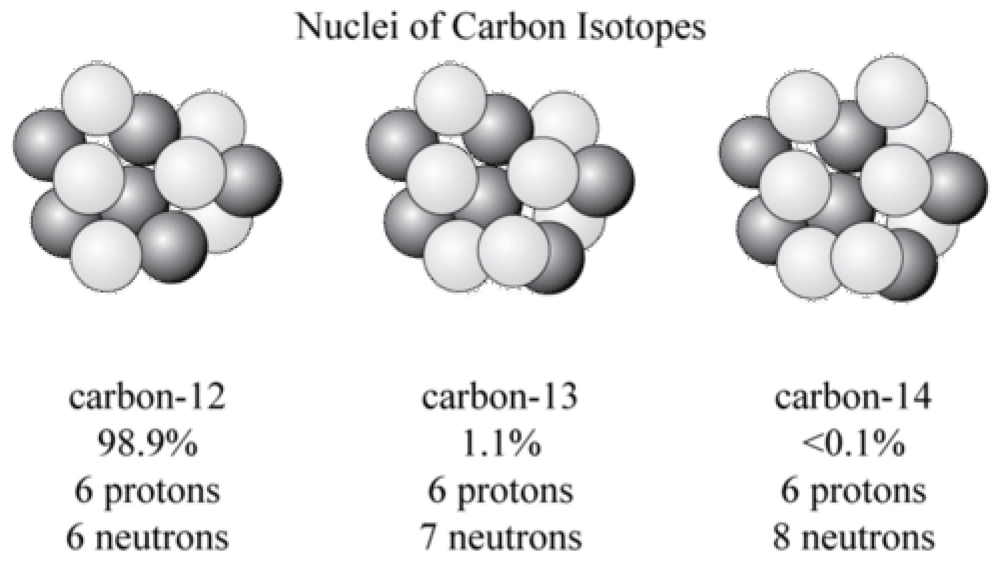
Properties of Neutrons

Unlike protons and electrons, which are electrically charged, neutrons have no charge. In other words, they are electrically neutral. That's why the neutrons in the diagram above are labeled n^0. The zero stands for "zero charge." The mass of a neutron is slightly greater than the mass of a proton, which is 1 atomic mass unit (amu). (An atomic mass unit equals about 1.67×10^{-27} kilograms.) A neutron also has about the same diameter as a proton, or 1.7×10^{-17} meters.

Same Element, Different Numbers of Neutrons

All the atoms of a given element have the same number of protons and electrons. The number of neutrons, however, may vary for atoms of the same element. For example, almost 99 percent of carbon atoms have six neutrons, but the rest have either seven or eight neutrons. Atoms of an element that differ in their numbers of neutrons are called isotopes.

The nuclei of these isotopes of carbon are shown in the **Figure** below. The isotope called carbon-14 is used to find the ages of fossils.



[Figure 3]

Q: Notice the names of the carbon isotopes in the diagram. Based on this example, infer how isotopes of an element are named.

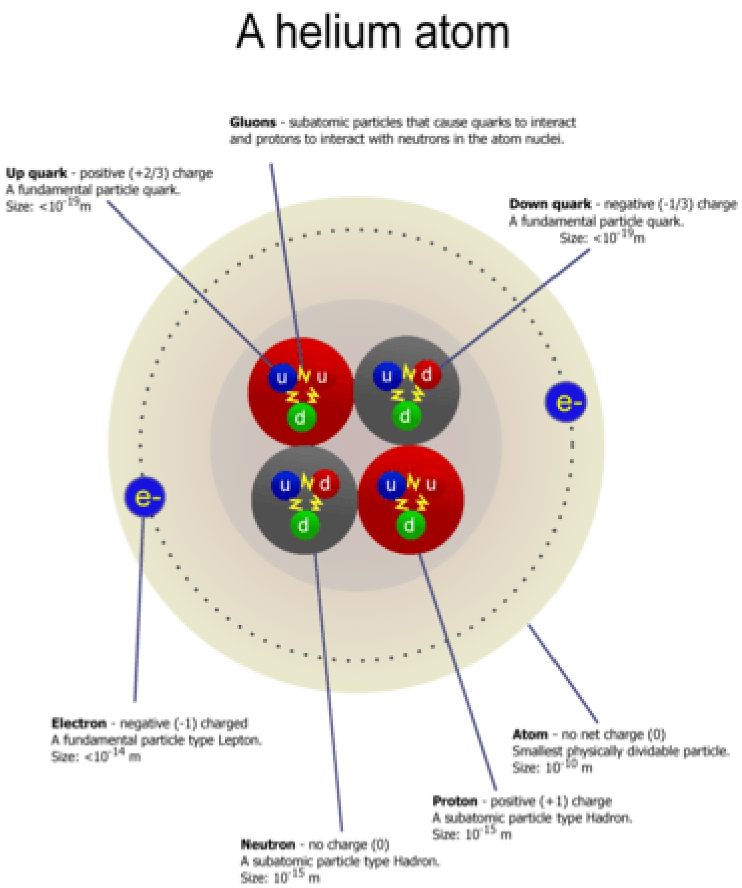
A: Isotopes of an element are named for their total number of protons and neutrons.

Q: The element oxygen has 8 protons. How many protons and neutrons are there in oxygen-17?

A: Oxygen-17—like all atoms of oxygen—has 8 protons. Its name provides the clue that it has a total of 17 protons and neutrons. Therefore, it must have 9 neutrons (8 + 9 = 17).

Particles in Neutrons

Neutrons consist of fundamental particles known as quarks and gluons. Each neutron contains three quarks, as shown in the diagram below. Two of the quarks are called down quarks (d) and the third quark is called an up quark (u). Gluons (represented by wavy yellow lines in the diagram) are fundamental particles that are given off or absorbed by quarks. They carry the strong nuclear force that holds together quarks in a neutron.



[Figure 4]

Summary

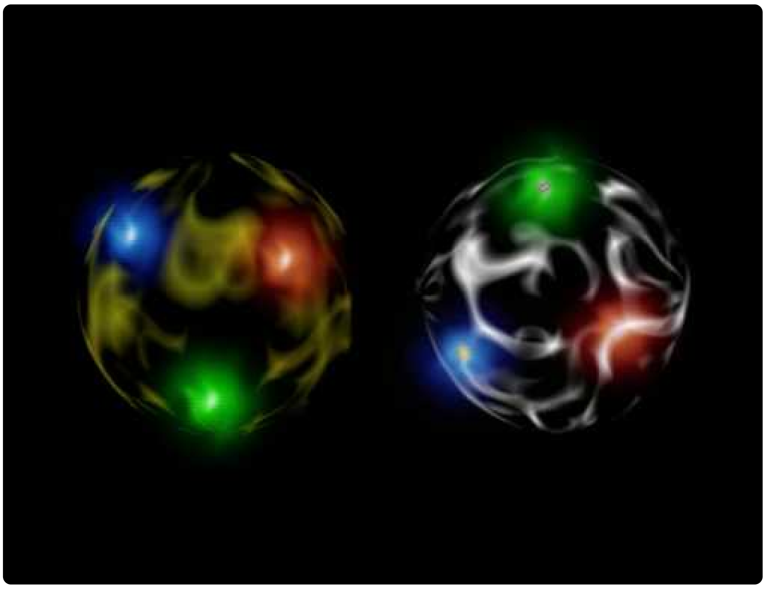
- A neutron is one of three main particles that make up the atom. It is found in the nucleus and is neutral in electric charge. It has about the same mass and diameter as a proton. Neutrons are found in all atoms except for most atoms of hydrogen.
- All the atoms of a given element have the same number of protons and electrons, but they may vary in their numbers of neutrons. Atoms of the same element that differ in their numbers of neutrons are called isotopes.
- Neutrons consist of fundamental particles known as quarks and gluons. Gluons carry the strong nuclear force that binds together the quarks in a neutron.

Review

1. What is a neutron?
2. Compare and contrast neutrons and protons.
3. Explain how isotopes of an element differ from one another. Give an example.

4. Identify the fundamental particles that make up a neutron.

Resources



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3.5 Electron

FlexBooks® 2.0 > American HS Physical Science > Electron

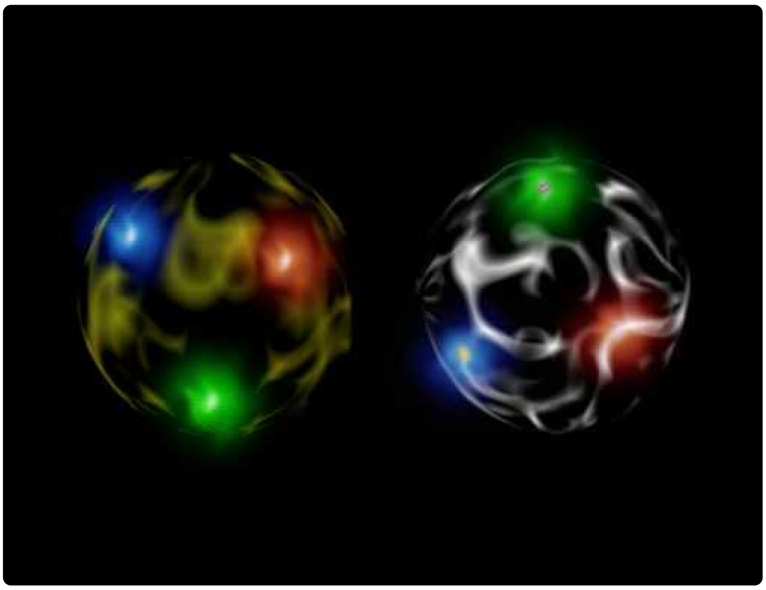
Last Modified: Nov 09, 2018

[Figure 1]

Watch out! Lightning is extremely dangerous. A single bolt of lightning can carry a billion volts of electricity. That's enough energy to light a 100-watt light bulb—for three months! As impressive as it is, lightning is nothing more than a sudden flow of extremely tiny particles. What are the particles that flow in a lightning bolt? The answer is electrons.

What Are Electrons?

Electrons are one of three main types of particles that make up atoms. The other two types are protons and neutrons. Unlike protons and neutrons, which consist of smaller, simpler particles, electrons are fundamental particles that do not consist of smaller particles. They are a type of fundamental particles called leptons. All leptons have an electric charge of -1 or 0.



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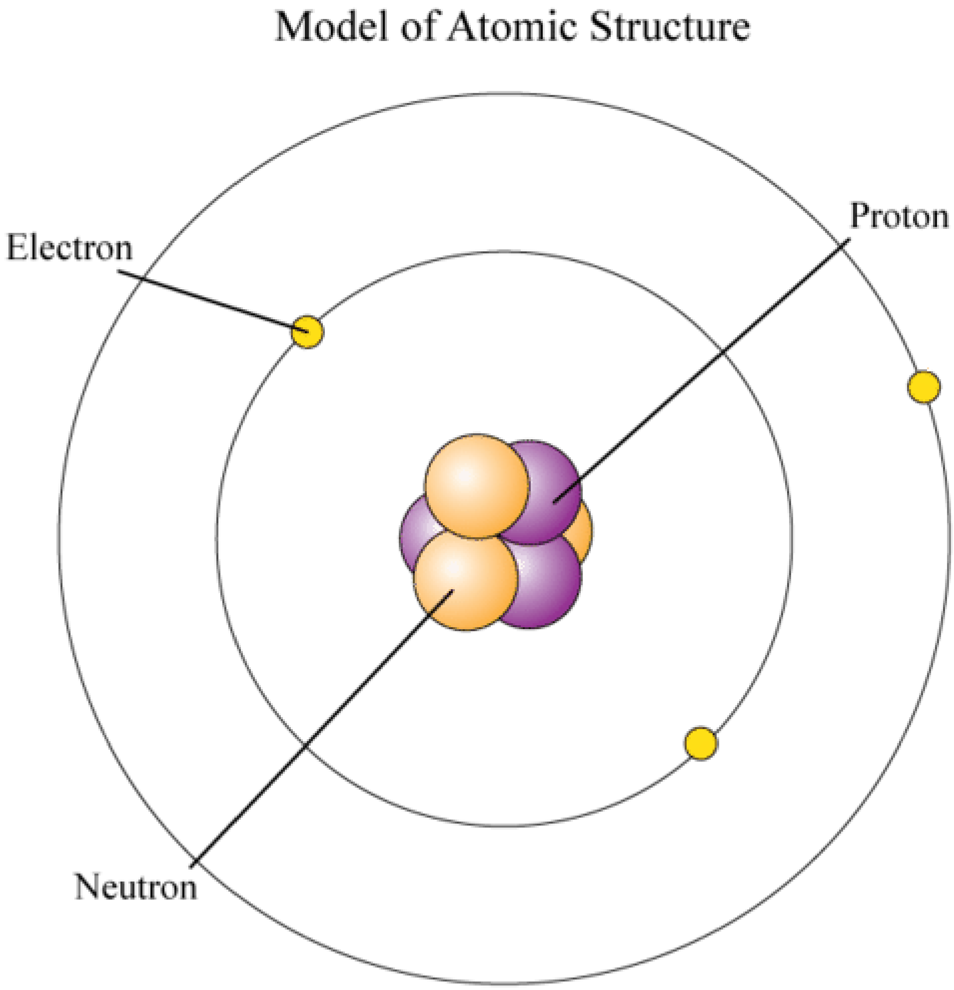
Properties of Electrons

Electrons are extremely small. The mass of an electron is only about 1/2000 the mass of a proton or neutron, so electrons contribute virtually nothing to the total mass of an atom. Electrons have an electric charge of -1, which is equal but opposite to the charge of proton, which is +1. All atoms have the same number of electrons as protons, so the positive and negative charges "cancel out," making atoms electrically neutral.

Where Are Electrons?

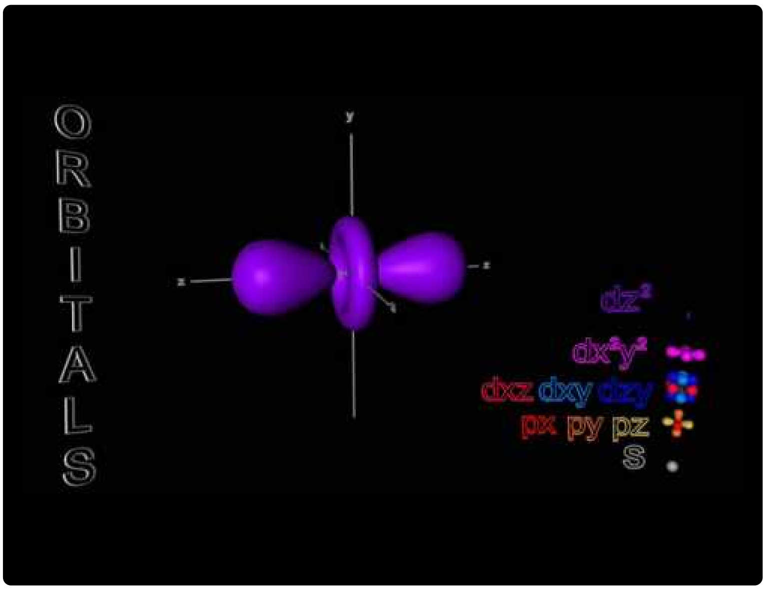
Unlike protons and neutrons, which are located inside the nucleus at the center of the atom, electrons are found outside the nucleus. Because opposite electric charges attract each other, negative electrons are attracted to the positive nucleus. This force of attraction keeps electrons constantly moving through the otherwise empty space around the nucleus. The **Figure** shown below is a common way to represent the structure of an atom. It shows the electron as a particle orbiting the nucleus, similar to the way that planets orbit the sun.



[Figure 2]

Orbitals

The atomic model above is useful for some purposes, but it's too simple when it comes to the location of electrons. In reality, it's impossible to say what path an electron will follow. Instead, it's only possible to describe the chances of finding an electron in a certain region around the nucleus. The region where an electron is most likely to be is called an orbital. Each orbital can have at most two electrons. Some orbitals, called S orbitals, are shaped like spheres, with the nucleus in the center. An S orbital is pictured in **Figure** below. Where the dots are denser, the chance of finding an electron is greater. Also pictured in **Figure** below is a P orbital. P orbitals are shaped like dumbbells, with the nucleus in the pinched part of the dumbbell.



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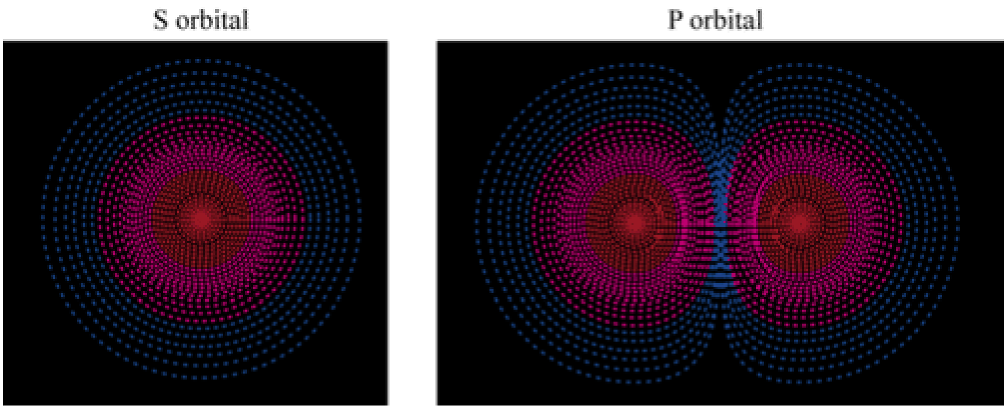


[Figure 3]

Q: How many electrons can there be in each type of orbital shown above?

A: There can be a maximum of two electrons in any orbital, regardless of its shape.

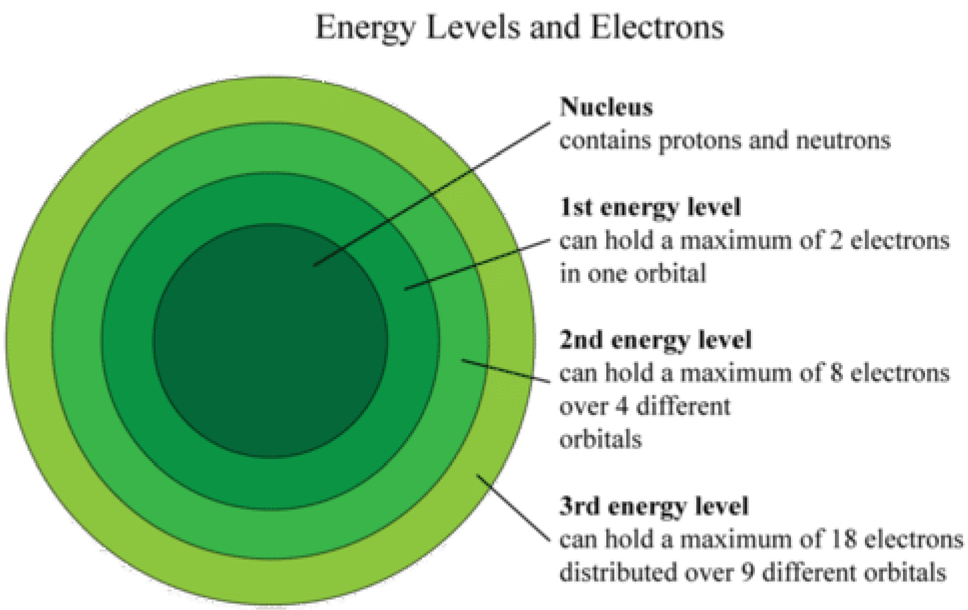
Q: Where is the nucleus in each orbital?

A: The nucleus is at the center of each orbital. It is in the middle of the sphere in the S orbital and in the pinched part of the P orbital.

What's Your Energy Level?

Electrons are located at fixed distances from the nucleus, called energy levels. You can see the first three energy levels in the **Figure** below. The diagram also shows the maximum possible number of electrons at each energy level.

- Electrons at lower energy levels, which are closer to the nucleus, have less energy. At the lowest energy level, which has the least energy, there is just one orbital, so this energy level has a maximum of two electrons.
- Only when a lower energy level is full are electrons added to the next higher energy level. Electrons at higher energy levels, which are farther from the nucleus, have more energy. They also have more orbitals and greater possible numbers of electrons.
- Electrons at the outermost energy level of an atom are called valence electrons. They determine many of the properties of an element. That's because these electrons are involved in chemical reactions with other atoms. Atoms may share or transfer valence electrons. Shared electrons bind atoms together to form chemical compounds.



[Figure 4]

Q: If an atom has 12 electrons, how will they be distributed in energy levels?

A: The atom will have two electrons at the first energy level, eight at the second energy level, and the remaining two at the third energy level.

Q: Sometimes, an electron jumps from one energy level to another. How do you think this happens?

A: To change energy levels, an electron must either gain or lose energy. That's because electrons at higher energy levels have more energy than electrons at lower energy levels.

Summary

- Electrons are one of three main types of particles that make up the atom. They are extremely small and have an electric charge of -1. All atoms have the same number of electrons as protons.

- Negative electrons are attracted to the positive nucleus. This force of attraction keeps electrons constantly moving around the nucleus. The region where an electron is most likely to be found is called an orbital.
- Electrons are located at fixed distances from the nucleus, called energy levels. Electrons at lower energy levels have less energy than electrons at higher energy levels

Review

1. What are electrons?
2. Compare and contrast electrons and protons.
3. Sketch a model of a beryllium atom, which has four protons, five neutrons, and four electrons. Your model should include the placement of electrons at the appropriate energy levels.
4. What are valence electrons? Why are they so important? How many valence electrons does a beryllium atom have (see question 3)?

Explore More

Use the resource below to answer the questions that follow.

https://flexbooks.ck12.org/flx/render/embeddedobject/176798

1. Who discovered electrons? When were they discovered?
2. Outline how electrons were discovered.
3. What was the significance of the discovery of electrons?

4. Where did Thomson think electrons were located in the atom? How does this differ from the modern view of electrons presented above?

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3.6 Atomic Forces

FlexBooks® 2.0 > American HS Physical Science > Atomic Forces

Last Modified: Apr 17, 2019

[Figure 1]

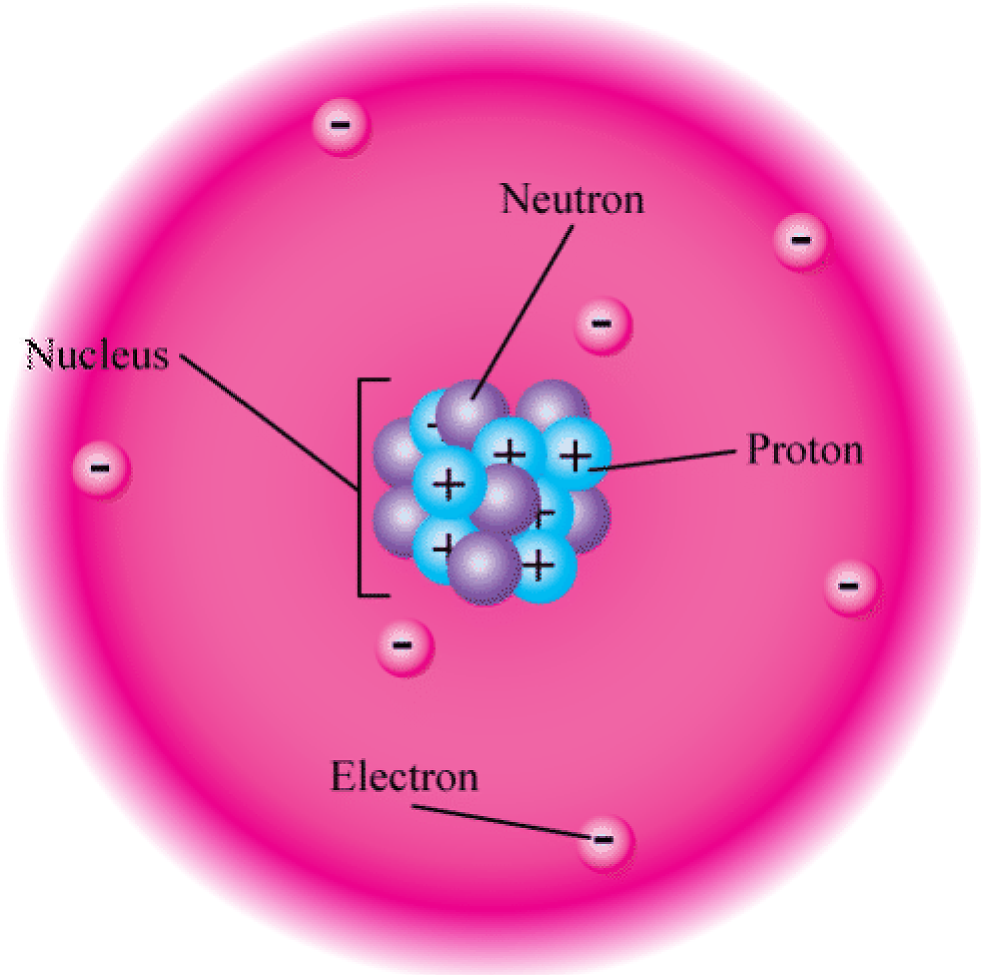
You've probably used items like those pictured here. What do all of them have in common? They are all used to hold things together. However, they do so in different ways. Like these different kinds of fasteners, there are different kinds of "fasteners" that hold together the subatomic particles inside atoms. The "fasteners" are called forces, and there are three different kinds of them at work inside the atom: electromagnetic force, strong nuclear force, and weak nuclear force.

Electromagnetic Force

Electromagnetic force is a force of attraction or repulsion between all electrically charged particles. This force is transferred between charged particles of matter by fundamental force-carrying particles called photons. Because of electromagnetic force, particles with opposite charges attract each other and particles with the same charge repel each other.

Inside the atom, two types of subatomic particles have electric charge: electrons, which have an electric charge of -1, and protons, which have an opposite but equal electric charge of +1. The model of an atom in the **Figure** below shows both types of charged particles. Protons are found inside the nucleus at the center of the atom, and they give the nucleus a positive charge. (There are also neutrons in the nucleus, but they have no electric charge.)

Negative electrons stay in the area surrounding the positive nucleus because of the electromagnetic force of attraction between them.



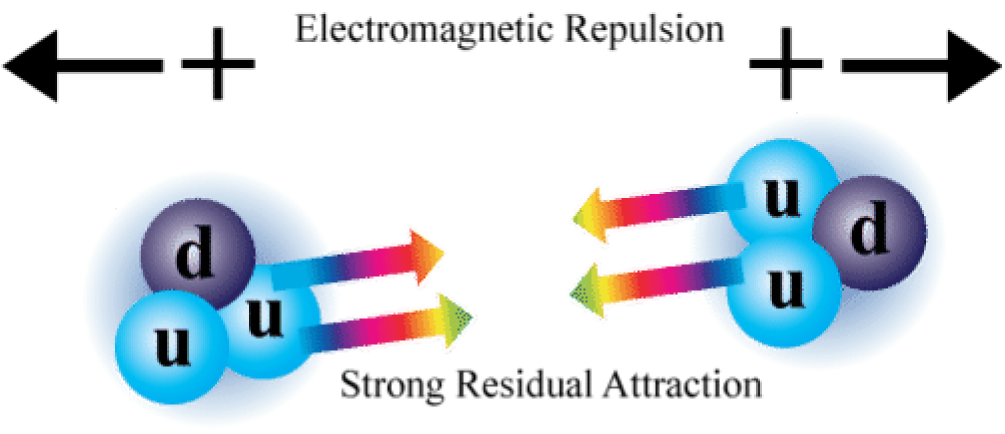
[Figure 2]

Q: Why do you think protons cluster together in the nucleus of the atom instead of repelling each other because of their like charges?

A: The electromagnetic force of repulsion between positively charged protons is overcome by a stronger force, called the strong nuclear force.

Strong Nuclear Force

The strong nuclear force is a force of attraction between fundamental particles called quarks, which have a type of charge called color charge. The strong nuclear force is transferred between quarks by fundamental force-carrying particles called gluons. Both protons and neutrons consist of quarks. The exchange of gluons holds quarks together within a proton or neutron. Excess, or residual, strong force holds together protons and neutrons in the nucleus. The strong nuclear force is strong enough to overcome the electromagnetic force of repulsion pushing protons apart. Both forces are represented in the **Figure** below.



[Figure 3]

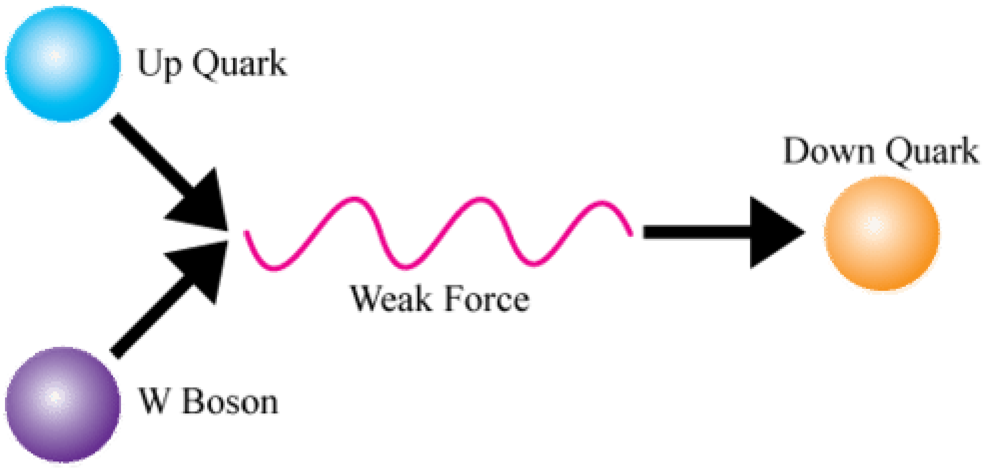
The types of quarks found in protons and neutrons are called up quarks (u) and down quarks (d). Each proton consists of two up quarks and one down quark (uud), and each neutron consists of one up quark and two down quarks (udd). This diagram represents two protons.

The strong nuclear force works only over very short distances. As a result, it isn't effective if the nucleus gets too big. As more protons are added to the nucleus, the electromagnetic force of repulsion between them gets stronger, while the strong nuclear force of attraction between them gets weaker. This puts an upper limit on the number of protons an atom can have and remain stable. If atoms have more than 83 protons, the electromagnetic repulsion between them is greater than the strong nuclear force of attraction between them. This makes the nucleus unstable, or radioactive, so it breaks down. The following video discusses the strong nuclear force and its role in the atom.

https://flexbooks.ck12.org/flx/render/embeddedobject/54897

Weak Nuclear Force

The weak nuclear force is transferred by the exchange of force-carrying fundamental particles called W and Z bosons. This force is also a very short-range force that works only within the nucleus of the atom. It is much weaker than the strong force or electromagnetic force that are also at work inside the atom. Unlike these other two forces, the weak nuclear force does not bind subatomic particles together in an atom. Instead, it changes subatomic particles from one type to another. The **Figure** below shows one way this can happen. In this figure, an up quark in a proton is changed by the weak force to a down quark. This changes the proton (uud) to a neutron (udd).

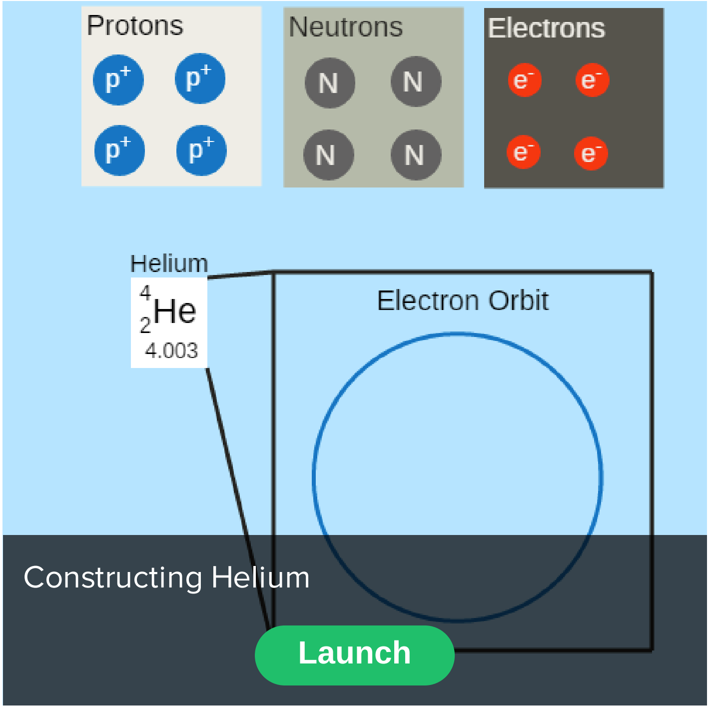


[Figure 4]

Q: If the weak force causes a proton to change to a neutron, how does this change the atom?

A: The resulting atom represents a different element. That's because each element has a unique number of protons. For example, all atoms of helium have two protons. If one of the protons in a helium atom changes to a neutron, the resulting atom would have just one proton, so the atom would no longer be a helium atom. Instead it would be a hydrogen atom, because all hydrogen atoms have a single proton.

Launch the PLIX Interactive below to build a helium atom. Be sure to use the mass number and atomic number included in the periodic symbol of helium to help you determine the correct number of protons, neutrons and electrons that make up a helium atom:



https://flexbooks.ck12.org/assessment/tools/geometry-tool/fullscreen.html?qID=544038b6da2cfe1d8b78669a

Summary

- The electromagnetic force of attraction between negative electrons and positive protons in the nucleus keeps electrons in the area surrounding the nucleus.
- The electromagnetic force of repulsion between positive protons in the nucleus is overcome by the strong nuclear force between protons and neutrons. This force holds the nucleus together.
- The weak nuclear force changes subatomic particles from one type to another. When protons change to neutrons, this changes atoms of one element to atoms of a different element.

Review

1. Which subatomic particles are affected by electromagnetic force? How does this force affect them?
2. What is the strong nuclear force? How does it hold the nucleus together?
3. How does the weak nuclear force differ from the other fundamental forces inside the atom? How can it change an atom of one element to an atom of a different element?

Report Content Errors

3.7 Atomic Number and Mass Number

FlexBooks® 2.0 > American HS Physical Science > Atomic Number and Mass Number

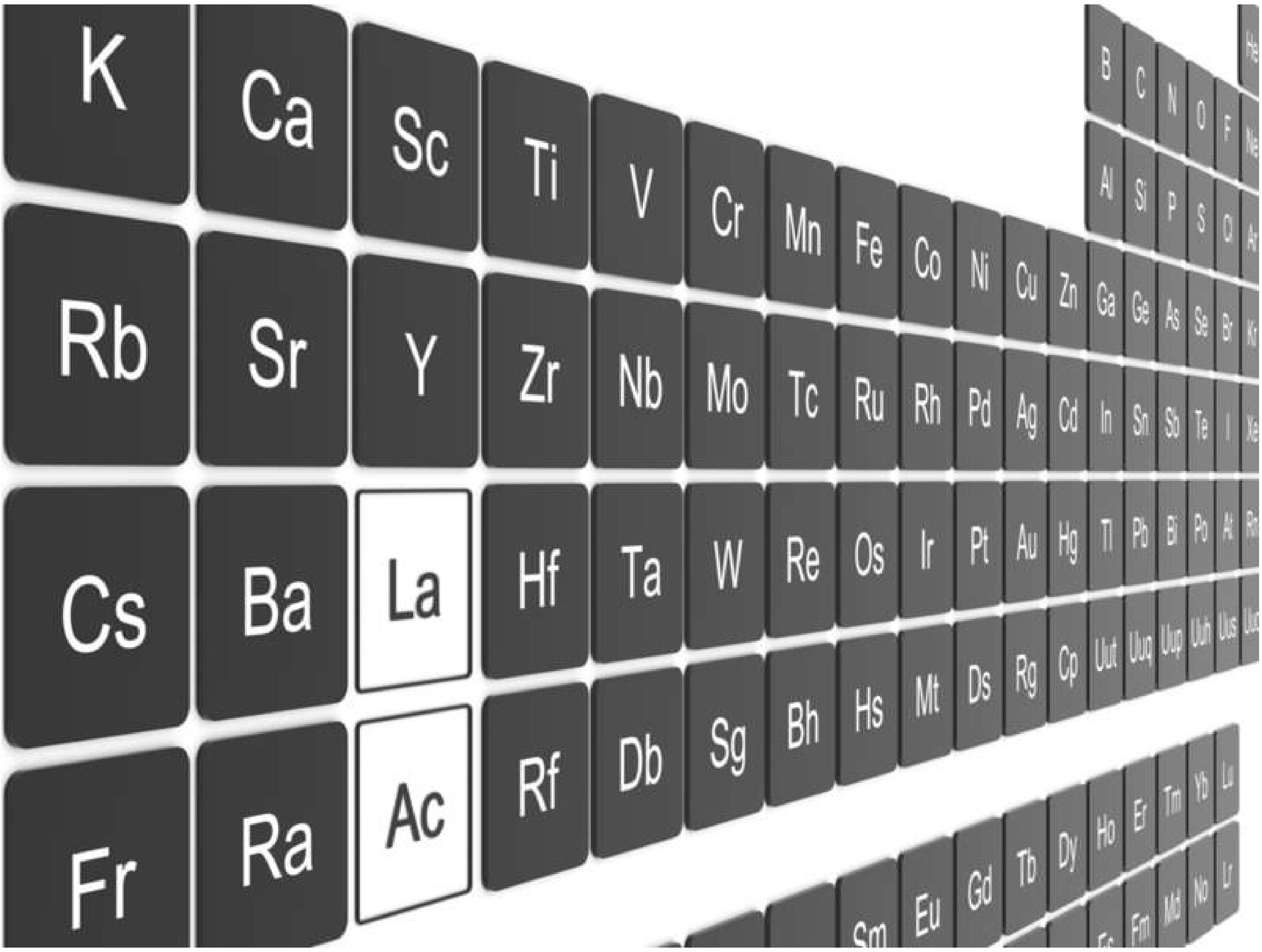
Last Modified: Jul 04, 2019

[Figure 1]

Athletes wearing the same-colored jerseys are all on the same team. In addition, each player's jersey has a unique number to distinguish him from his teammates. Imagine how confusing it would be if members of both teams wore the same-colored jerseys or all the members of a team had the same number on their jerseys. How could you tell the athletes apart?

Telling Atoms Apart

It's often useful to have ways to signify different people or objects like athletes on teams. The same is true of atoms. It's important to be able to distinguish atoms of one element from atoms of other elements. Elements are pure substances that make up all other matter, so each one is given a unique name. The names of elements are also represented by unique one- or two-letter symbols, such as H for hydrogen, C for carbon, and He for helium. You can see other examples in the **Figure** below.



[Figure 2]

Q: The table shown above is called the periodic table of the elements. Each symbol stands for a different element. What do you think the symbol K stands for?

A: The symbol K stands for the element potassium. The symbol comes from the Latin name for potassium, which is *kalium*.

The symbols in the table above would be more useful if they revealed more information about the atoms they represent. For example, it would be useful to know the numbers of protons and neutrons in the atoms. That's where atomic number and mass number come in.

Atomic Number

The number of protons in an atom is called its **atomic number**. This number is very important because it is unique for atoms of a given element. All atoms of an element have the same number of protons, and every element has a different number of protons in its atoms. For example, all helium atoms have two protons, and no other elements have atoms with two protons. In the case of helium, the atomic number is 2. The atomic number of an element is usually written in front of and slightly below the element's symbol, like in the **Figure** below for helium.

[Figure 3]

Atoms are neutral in electrical charge because they have the same number of negative electrons as positive protons. Therefore, the atomic number of an atom also tells you how many electrons the atom has. This, in turn, determines many of the atom's properties.

Mass Number

There is another number in the box above for helium. That number is the **mass number**, which is the mass of the atom in a unit called the **atomic mass unit (amu)**. One atomic mass unit is the mass of a proton, or about 1.67×10^{-27} kilograms, which is an extremely small mass.

A neutron has just a tiny bit more mass than a proton, so its mass is often assumed to be one atomic mass unit as well. Because electrons have virtually no mass, just about all the mass of an atom is in its protons and neutrons. Therefore, the total number of protons and neutrons in an atom determines its mass in atomic mass units.

Consider helium again. Most helium atoms have two neutrons in addition to two protons. Therefore the mass of most helium atoms is 4 atomic mass units (2 amu for the protons + 2 amu for the neutrons). However, some helium atoms have more or less than two neutrons. Atoms with the same number of protons but different numbers of neutrons are called isotopes. Because the number of neutrons can vary for a given element, the mass numbers of different atoms of an element may also vary. For example, some helium atoms have three neutrons instead of two. Therefore, they have a different mass number than the one given in the box above.

Q: What is the mass number of a helium atom that has three neutrons?

A: The mass number is the number of protons plus the number of neutrons. For helium atoms with three neutrons, the mass number is 2 (protons) + 3 (neutrons) = 5.

Q: How would you represent this isotope of helium to show its atomic number and mass number?

A: You would represent it by the element's symbol and both numbers, with the mass number on top and the atomic number on the bottom:

$$^{5}_{2}\mathrm{He}$$

Summary

- Elements are pure substances that make up all matter, so each one is given a unique name. The names of elements are also represented by unique one-, two-, or three- letter symbols.
- The number of protons in an atom is called its atomic number. This is also unique for each element.
- An atom's mass number is its mass in atomic mass units (amu), which is about equal to the total number of protons and neutrons in the atom. Different isotopes of an element have different mass numbers because they have different numbers of neutrons.

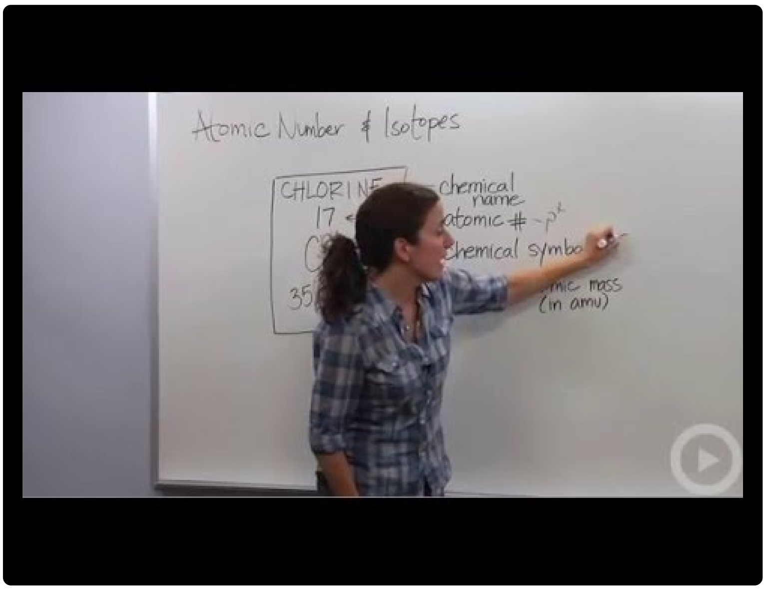
Review

1. What is the atomic number of an atom? Why is this number important?
2. Describe the atomic mass unit. What does it represent and what does it equal?
3. The symbol below represents an isotope of helium. How many protons and neutrons does it have?

$$^{3}_{2}\mathrm{He}$$

1. All carbon atoms have six protons. Most also have six neutrons, but some have seven or eight neutrons. What is the mass number of a carbon isotope that has seven neutrons?

Resources



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3.8 Ion

FlexBooks® 2.0 > American HS Physical Science > Ion

Last Modified: Apr 14, 2020

[Figure 1]

The incredible green lights in this cold northern sky consist of charged particles known as ions. Their swirling pattern is caused by the pull of Earth's magnetic field. Called the northern lights, this phenomenon of nature shows that ions respond to a magnetic field. Do you know what ions are? Read on to find out.

Atoms Are Neutral

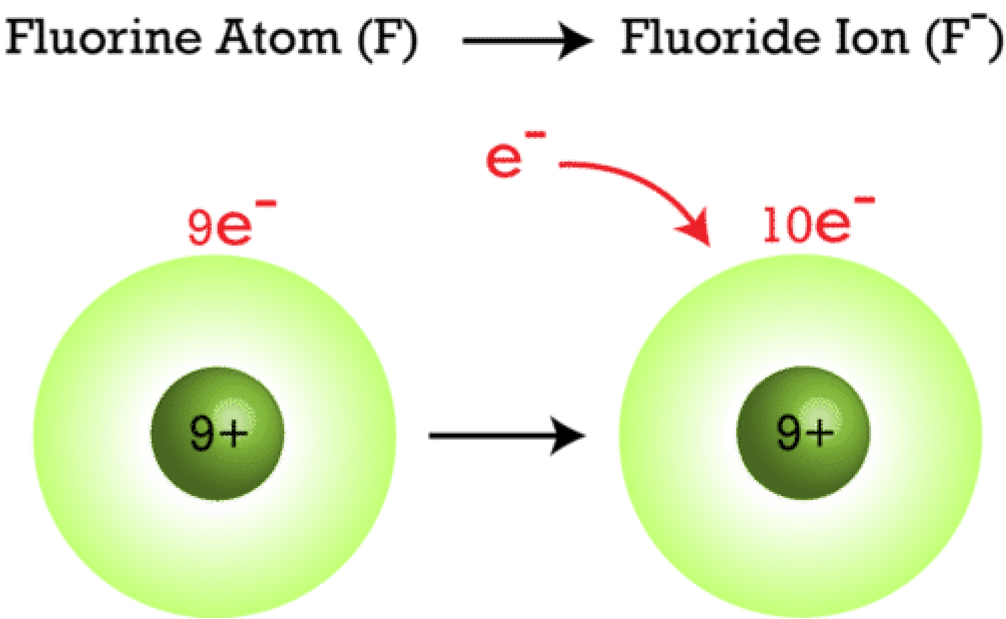
The northern lights aren't caused by atoms, because atoms are not charged particles. An atom always has the same number of electrons as protons. Electrons have an electric charge of -1 and protons have an electric charge of +1. Therefore, the charges of an atom's electrons and protons "cancel out." This explains why atoms are neutral in electric charge.

Q: What would happen to an atom's charge if it were to gain extra electrons?

A: If an atom were to gain extra electrons, it would have more electrons than protons. This would give it a negative charge, so it would no longer be neutral.

Atoms to Ions

Atoms cannot only gain extra electrons. They can also lose electrons. In either case, they become **ions**. Ions are atoms that have a positive or negative charge because they have unequal numbers of protons and electrons. If atoms lose electrons, they become positive ions, or cations. If atoms gain electrons, they become negative ions, or anions. Consider the example of fluorine (see **Figure** below). A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride ion with an electric charge of -1.



[Figure 2]

Names and Symbols

Like fluoride, other negative ions usually have names ending in *–ide*. Positive ions, on the other hand, are just given the element name followed by the word *ion*. For example, when a sodium atom loses an electron, it becomes a positive sodium ion. The charge of an ion is indicated by a plus (+) or minus sign (-), which is written to the right of and just above the ion's chemical symbol. For example, the fluoride ion is represented by the symbol F^-, and the sodium ion is represented by the symbol Na^+. If the charge is greater than one, a number is used to indicate it. For example, iron (Fe) may lose two electrons to form an ion with a charge of plus two. This ion would be represented by the symbol Fe^{2+}. This and some other common ions are listed with their symbols in the **Table** below.

Some Common Ions

Cations		Anions	
Name of Ion	**Chemical Symbol**	**Name of Ion**	**Chemical Symbol**
Calcium ion	Ca^{2+}	Chloride	Cl^{-}
Hydrogen ion	H^{+}	Fluoride	F^{-}
Iron(II) ion	Fe^{2+}	Bromide	Br^{-}
Iron(III) ion	Fe^{3+}	Oxide	O^{2-}

Q: How does the iron(III) ion differ from the iron(II) ion?

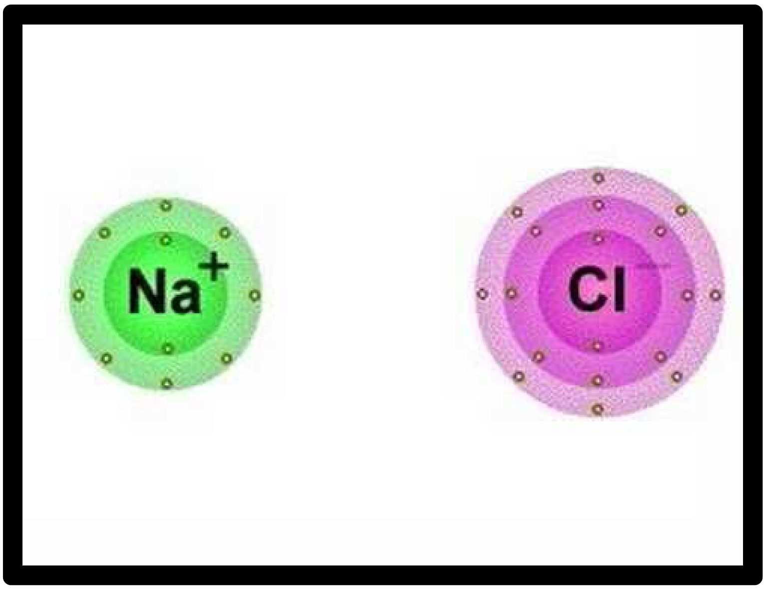
A: The iron(III) ion has a charge of +3, so it has one less electron than the iron(II) ion, which has a charge of +2.

Q: What is the charge of an oxide ion? How does its number of electrons compare to its number of protons?

A: An oxide ion has a charge of -2. It has two more electrons than protons.

How Ions Form

The process in which an atom becomes an ion is called ionization. It may occur when atoms are exposed to high levels of radiation. The radiation may give their outer electrons enough energy to escape from the attraction of the positive nucleus. However, most ions form when atoms transfer electrons to or from other atoms or molecules. For example, sodium atoms may transfer electrons to chlorine atoms. This forms positive sodium ions (Na^{+}) and negative chloride ions (Cl^{-}).



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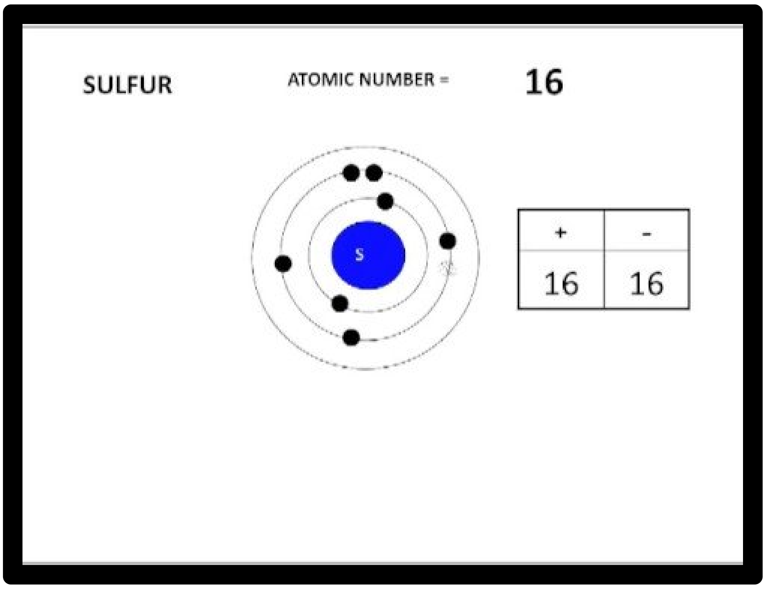
Q: Why do you think atoms lose electrons to, or gain electrons from, other atoms?

A: Atoms form ions by losing or gaining electrons because it makes them more stable and this state takes less energy to maintain. The most stable state for an atom is to have its outermost energy level filled with the maximum possible number of electrons. In the case of metals such as lithium, with just one electron in the outermost energy level, a more stable state can be achieved by losing that one outer electron. In the case of nonmetals such as fluorine, which has seven electrons in the outermost energy level, a more stable state can be achieved by gaining one electron and filling up the outer energy level.



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Properties of Ions

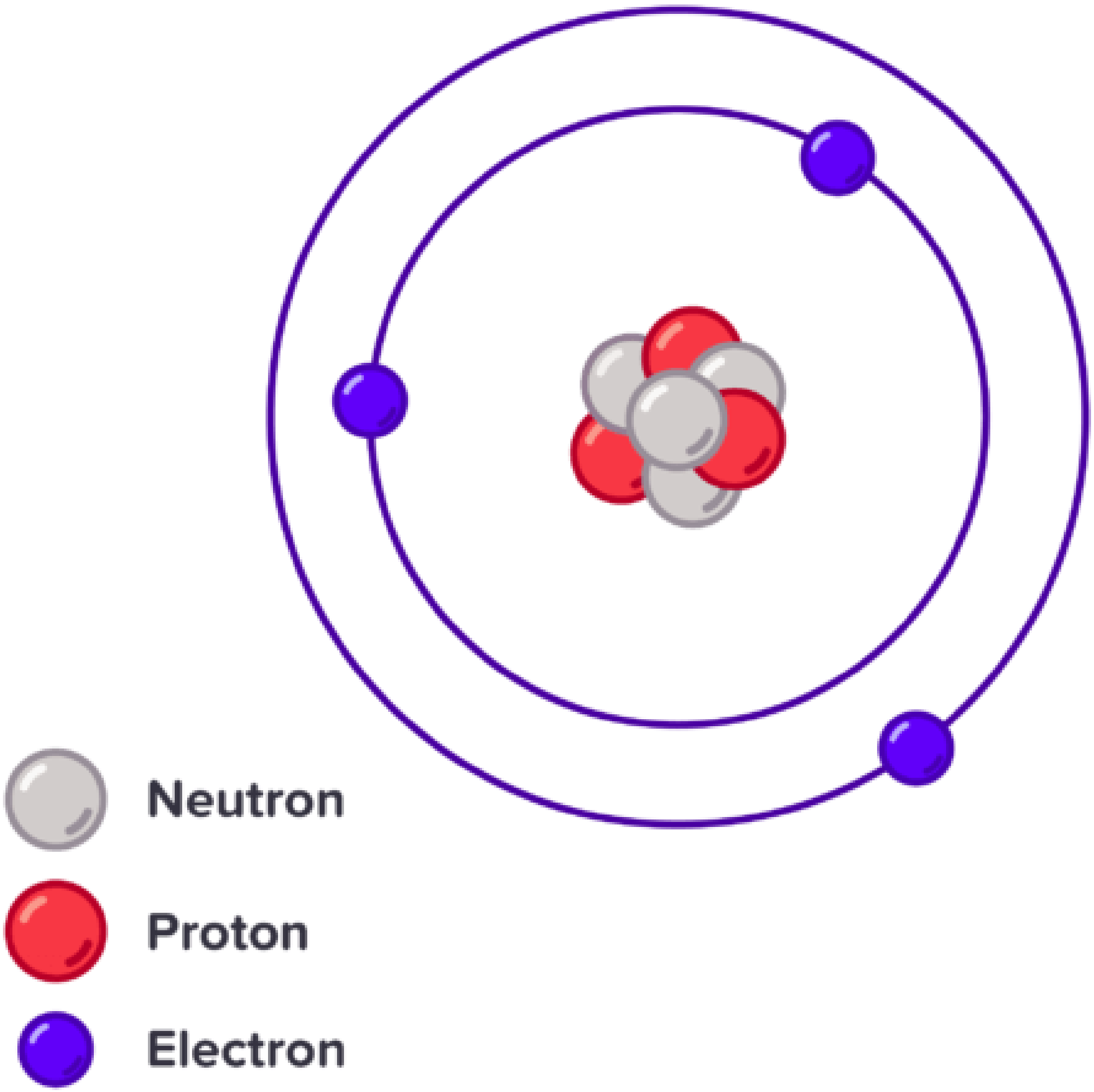
Ions are highly reactive, especially as gases. They usually react with ions of opposite charge to form neutral compounds. For example, positive sodium ions and negative chloride ions react to form the neutral compound sodium chloride, commonly known as table salt. This occurs because oppositely charged ions attract each other. Ions with the same charge, on the other hand, repel each other. Ions are also deflected by a magnetic field, as you saw in the opening image of the northern lights.

Summary

- Atoms have equal numbers of positive protons and negative electrons, so they are neutral in electric charge.
- Atoms can gain or lose electrons and become ions, which are atoms that have a positive or negative charge because they have unequal numbers of protons and electrons.
- The process in which an atom becomes an ion is called ionization. It may occur when atoms are exposed to high levels of radiation or when atoms transfer electrons to or from other atoms.
- Ions are reactive, attracted or repulsed by other charged particles, and deflected by a magnetic field.

Review

1. Why are atoms neutral in electric charge?
2. Define ion.
3. Compare and contrast cations and anions, and give an example of each.
4. Describe how ions form.
5. List properties of ions.
6. The model in the illustration below represents an atom of lithium (Li). If the lithium atom becomes an ion, which type of ion will it be, a cation or an anion? What will be the electric charge of this ion? What will the ion be named? What symbol will be used to represent it?



[Figure 3]

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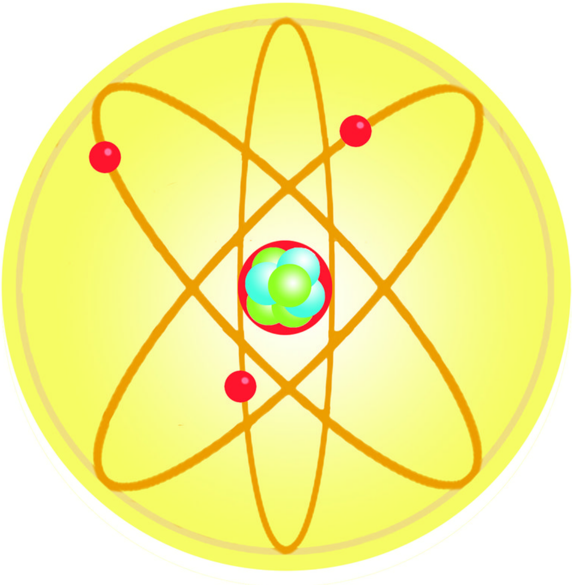
3.9 Dalton's Atomic Theory

FlexBooks® 2.0 > American HS Physical Science > Dalton's Atomic Theory

Last Modified: Nov 09, 2018



[Figure 1]

You probably know what this sketch represents. It's a model of an atom, one of the miniscule particles that make up all matter. The idea that matter consists of extremely tiny particles called atoms was first introduced about 2500 years ago by a Greek philosopher named Democritus. However, other philosophers considered Democritus' idea ridiculous, and it was more or less forgotten for more than 2000 years.

Reintroducing the Atom

Around 1800, the English chemist John Dalton brought back Democritus' ancient idea of the atom. You can see a picture of Dalton below. Dalton grew up in a working-class family. As an adult, he made a living by teaching and just did research in his spare time. Nonetheless, from his research he developed one of the most important theories in all of science. Based on his research results, he was able to demonstrate that atoms actually do exist, something that Democritus had only guessed.

[Figure 2]

Dalton's Experiments

Dalton did many experiments that provided evidence for the existence of atoms. For example:

- He investigated pressure and other properties of gases, from which he inferred that gases must consist of tiny, individual particles that are in constant, random motion.
- He researched the properties of compounds, which are substances that consist of more than one element. He showed that a given compound is always comprised of the same elements in the same whole-number ratio and that different compounds consist of different elements or ratios. This can happen, Dalton reasoned, only if elements are made of separate, discrete particles that cannot be subdivided.

Atomic Theory

From his research, Dalton developed a theory about atoms. Dalton's atomic theory consists of three basic ideas:

- All substances are made of atoms. Atoms are the smallest particles of matter. They cannot be divided into smaller particles, created, or destroyed.
- All atoms of the same element are alike and have the same mass. Atoms of different elements are different and have different masses.
- Atoms join together to form compounds, and a given compound always consists of the same kinds of atoms in the same proportions.

Dalton's atomic theory was accepted by many scientists almost immediately. Most of it is still accepted today. However, scientists now know that atoms are not the smallest particles of matter. Atoms consist of several types of smaller particles, including protons, neutrons, and electrons.

The Billiard Ball Model

Because Dalton thought atoms were the smallest particles of matter, he envisioned them as solid, hard spheres, like billiard (pool) balls, so he used wooden balls to model them. Three of his model atoms are pictured in the **Figure** below. Do you see the holes in the balls? Dalton added these so the model atoms could be joined together with hooks and used to model compounds.

[Figure 3]

Q: When scientists discovered smaller particles inside the atom, they realized that Dalton's atomic models were too simple. How do modern atomic models differ from Dalton's models?

A: Modern atomic models, like the one pictured at the top of this article, usually represent subatomic particles, including electrons, protons, and neutrons.

Summary

- Around 1800, the English chemist John Dalton reintroduced the idea of the atom, which was first introduced by the ancient Greek philosopher named Democritus.
- Dalton did many experiments with gases and compounds that provided evidence for the existence of atoms.
- Dalton developed an atomic theory that is still mostly accepted today. It is one of the most important theories in all of science.
- Dalton thought individual atoms were solid, hard spheres, so he modeled them with wooden balls.

Review

1. Who was John Dalton?
2. What evidence did Dalton use to argue for the existence of atoms?
3. State Dalton's atomic theory.
4. Explain how Dalton modeled atoms and compounds.

Resources

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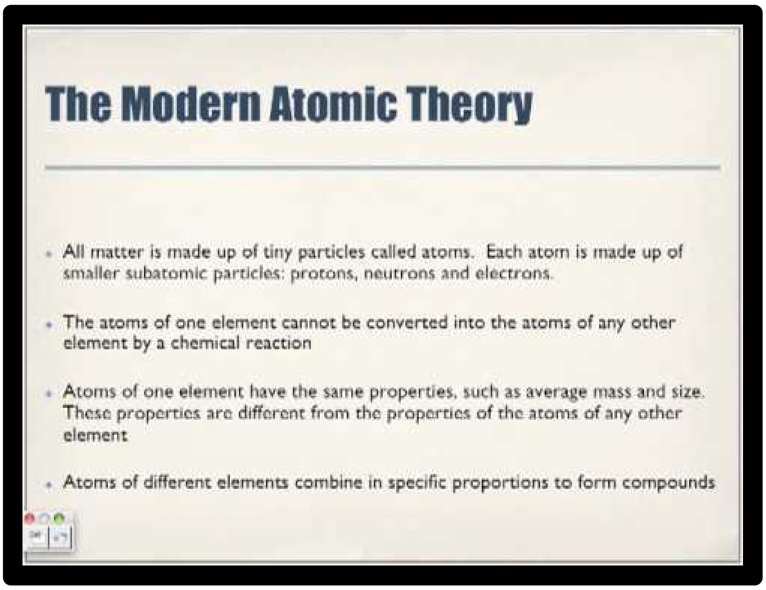

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3.10 Thomson's Atomic Model

FlexBooks® 2.0 > American HS Physical Science > Thomson's Atomic Model

Last Modified: Nov 09, 2018

[Figure 1]

You probably know that the wires strung between these high towers carry electricity. But do you know what electricity is? It actually consists of a constant stream of tiny particles called electrons. Electrons are negatively charged fundamental particles inside atoms. Atoms were discovered around 1800, but almost 100 years went by before electrons were discovered.

Thomson Discovers Electrons

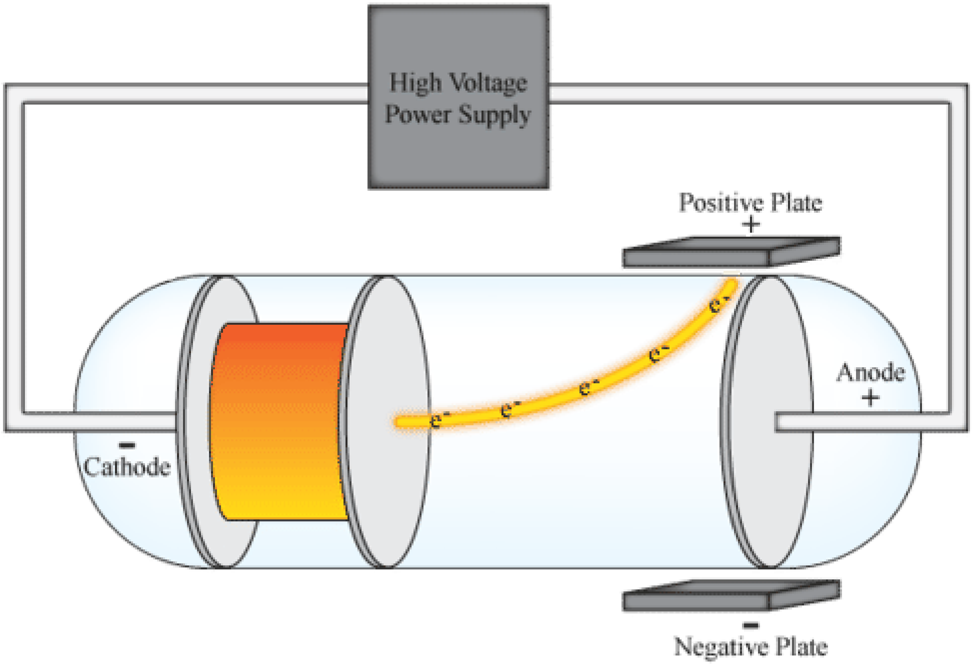
John Dalton discovered atoms in 1804. He thought they were the smallest particles of matter, which could not be broken down into smaller particles. He envisioned them as solid, hard spheres. It wasn't until 1897 that a scientist named Joseph John (J. J.) Thomson discovered that there are smaller particles within the atom. Thomson was born in England and studied at Cambridge University, where he later became a professor. In 1906, he won the Nobel Prize in physics for his research on how gases conduct electricity. This research also led to his discovery of the electron. You can see a picture of Thomson below.

[Figure 2]

Thomson's Experiments

In his research, Thomson passed current through a cathode ray tube, similar to the one seen in the **Figure** below. A cathode ray tube is a glass tube from which virtually all of the air has been removed. It contains a piece of metal called an electrode at each end. One electrode is negatively charged and known as a cathode. The other electrode is positively charged and known as an anode. When high-voltage electric current is applied to the end plates, a cathode ray travels from the cathode to the anode.

What is a cathode ray? That's what Thomson wanted to know. Is it just a ray of energy that travels in waves like a ray of light? That was one popular hypothesis at the time. Or was a cathode ray a stream of moving particles? That was the other popular hypothesis. Thomson tested these ideas by placing negative and positive plates along the sides of the cathode ray tube to see how the cathode ray would be affected. The cathode ray appeared to be repelled by the negative plate and attracted by the positive plate. This meant that the ray was negative in charge and that is must consist of particles that have mass. He called the particles "corpuscles," but they were later renamed electrons.



[Figure 3]

Thomson also measured the mass of the particles he had identified. He did this by determining how much the cathode rays were bent when he varied the voltage. He found that the mass of the particles was 2000 times smaller than the mass of the smallest atom, the hydrogen atom. In short, Thomson had discovered the existence of particles smaller than atoms. This disproved Dalton's claim that atoms are the smallest particles of matter. From his discovery, Thomson also inferred that electrons are fundamental particles within atoms.

Q: Atoms are neutral in electric charge. How can they be neutral if they contain negatively charged electrons?

A: Atoms also contain positively charged particles that cancel out the negative charge of the electrons. However, these positive particles weren't discovered until a couple of decades after Thomson discovered electrons.

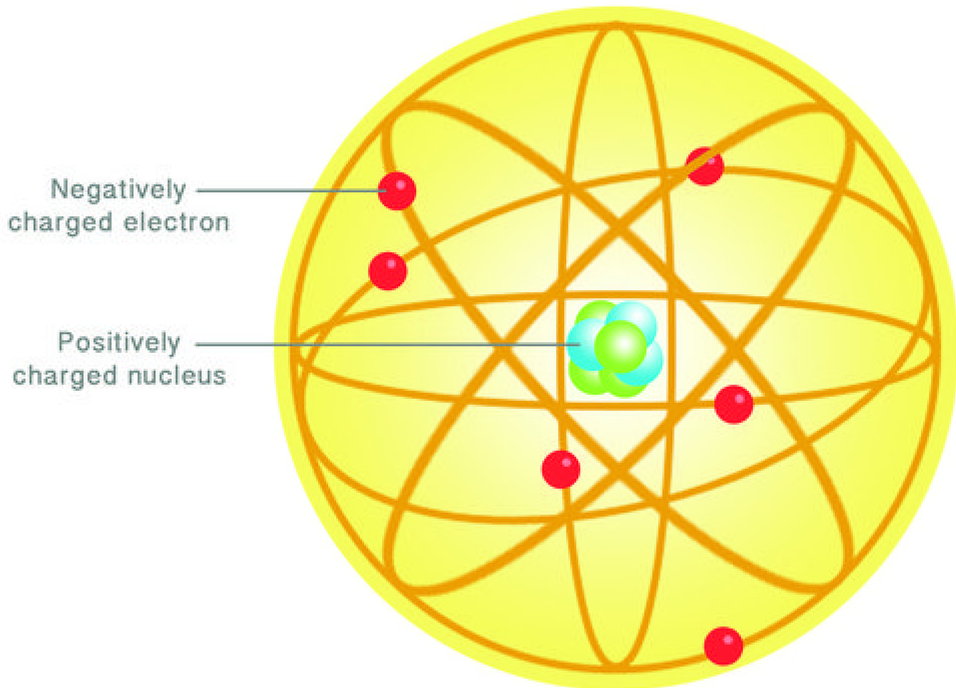
The Plum Pudding Model

Thomson also knew that atoms are neutral in electric charge, so he asked the same question: How can atoms contain negative particles and still be neutral? He hypothesized that the rest of the atom must be positively charged in order to cancel out the negative charge of the electrons. He envisioned the atom as being similar to a plum pudding, like the one pictured in the **Figure** below—mostly positive in charge (the pudding) with negative electrons (the plums) scattered through it.

[Figure 4]

Q: How is our modern understanding of atomic structure different from Thomson's plum pudding model?

A: Today we know that all of the positive charge in an atom is concentrated in a tiny central area called the nucleus, with the electrons swirling through empty space around it, as in the **Figure** below. The nucleus was discovered just a few years after Thomson discovered the electron, so the plum pudding model was soon rejected.



[Figure 5]

Summary

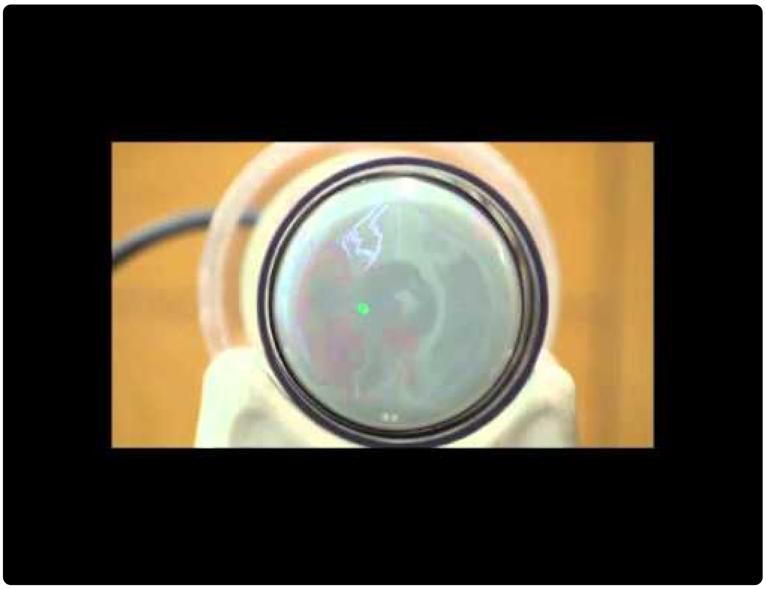
- In 1897, J. J. Thomson discovered the first subatomic particle, the electron, while researching cathode rays.
- To explain the neutrality of atoms, Thomson proposed a model of the atom in which negative electrons are scattered throughout a sphere of positive charge. He called his atom the plum pudding model.

Review

1. Who was J. J. Thomson?
2. Explain how Thomson discovered negatively charged particles smaller than atoms.
3. Thomson compared his idea of atomic structure to a plum pudding. Invent an original analogy for Thomson's plum pudding model of the atom.
4. Why was Thomson's model soon rejected?

Explore More

Watch this detailed presentation about J. J. Thomson's discovery of the electron, and then answer the question below.



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1. Thomson not only discovered that a cathode ray consists of flowing negatively charged particles that are smaller than atoms. He also made the logical leap that these particles help make up atoms. What reasoning did Thomson use to make this inference?

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3.11 Rutherford's Atomic Model

FlexBooks® 2.0 > American HS Physical Science > Rutherford's Atomic Model

Last Modified: Sep 06, 2018

[Figure 1]

Thom is shooting baskets. He's trying to hit the backboard so the ball will bounce off it and into the basket. If only the backboard was bigger! It would be a lot easier to hit. If the ball misses the backboard, it will just keep going and Thom will have to run after it. Believe it or not, the research that led to the discovery of the nucleus of the atom was a little like shooting baskets.

Narrowing Down the Nucleus

In 1804, almost a century before the nucleus was discovered, the English scientist John Dalton provided evidence for the existence of the atom. Dalton thought that atoms were the smallest particles of matter, which couldn't be divided into smaller particles. He modeled atoms with solid wooden balls. In 1897, another English scientist, named J. J. Thomson, discovered the electron. It was first subatomic particle to be identified. Because atoms are neutral in electric charge, Thomson assumed that atoms must also contain areas of positive charge to cancel out the negatively charged electrons. He thought that an atom was like a plum pudding, consisting mostly of positively charged matter with negative electrons scattered through it.

The nucleus of the atom was discovered next. It was discovered in 1911 by a scientist from New Zealand named Ernest Rutherford, who is pictured in **Figure** below. Through his clever research, Rutherford showed that the positive charge of an atom is confined to a tiny massive region at the center of the atom, rather than being spread evenly throughout the "pudding" of the atom as Thomson had suggested.

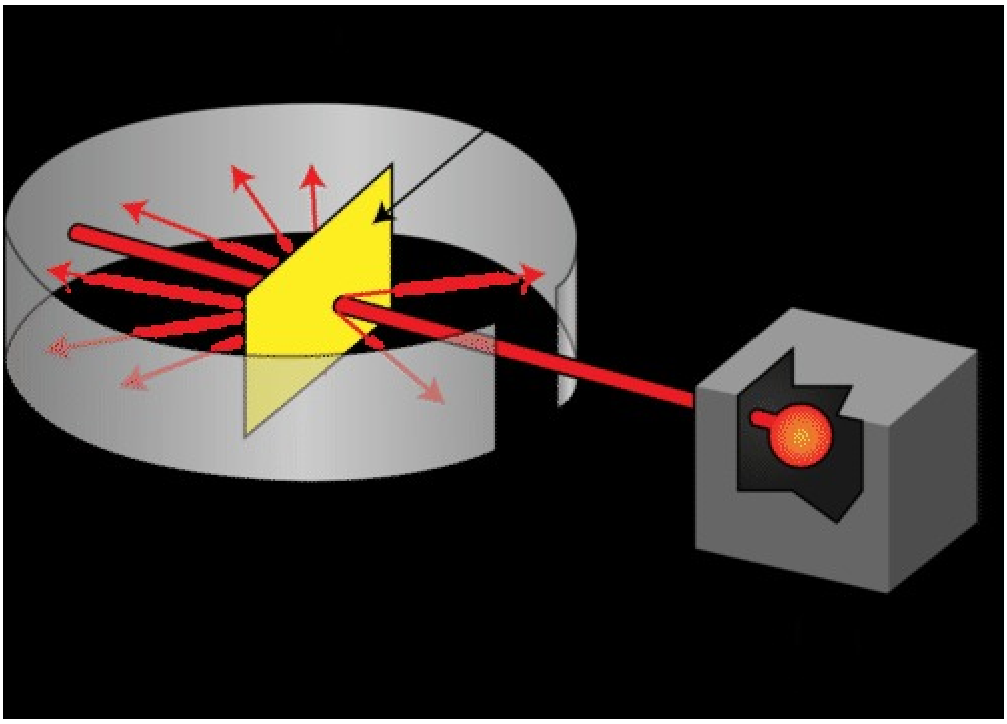
[Figure 2]

Go for the Gold!

The way Rutherford discovered the atomic nucleus is a good example of the role of creativity in science. His quest actually began in 1899 when he discovered that some elements give off positively charged particles that can penetrate just about anything. He called these particles alpha (α) particles (we now know they were helium nuclei). Like all good scientists, Rutherford was curious. He wondered how he could use alpha particles to learn about the structure of the atom. He decided to aim a beam of alpha particles at a sheet of very thin gold foil. He chose gold because it can be pounded into sheets that are only 0.00004 cm thick. Surrounding the sheet of gold foil, he placed a screen that glowed when alpha particles struck it. It would be used to detect the alpha particles after they passed through the foil. A small slit in the screen allowed the beam of alpha particles to reach the foil from the particle emitter. You can see the setup for Rutherford's experiment in the **Figure** below.

Q: What would you expect to happen when the alpha particles strike the gold foil?

A: The alpha particles would penetrate the gold foil. Alpha particles are positive, so they might be repelled by any areas of positive charge inside the gold atoms.



[Figure 3]

Assuming a plum pudding model of the atom, Rutherford predicted that the areas of positive charge in the gold atoms would deflect, or bend, the path of all the alpha particles as they passed through. You can see what really happened in the **Figure** above. Most of the alpha particles passed straight through the gold foil as though it wasn't there. The particles seemed to be passing through empty space. Only a few of the alpha particles were deflected from their straight path, as Rutherford had predicted. Surprisingly, a tiny percentage of the particles bounced back from the foil like a basketball bouncing off a backboard!

Q: What can you infer from these observations?

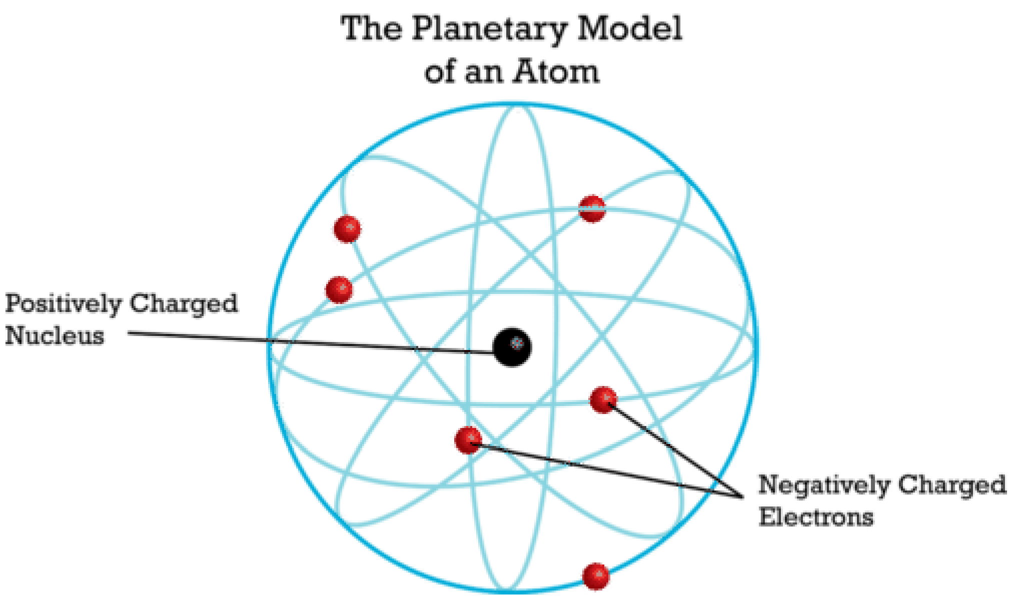
A: You can infer that most of the alpha particles were not repelled by any positive charge, whereas a few were repelled by a strong positive charge.

The Nucleus Takes Center Stage

Rutherford made the same inferences. He concluded that all of the positive charge and virtually all of the mass of an atom are concentrated in one tiny area and the rest of the atom is mostly empty space. Rutherford called the area of concentrated positive charge the nucleus. He predicted—and soon discovered—that the nucleus contains positively charged particles, which he named protons. Rutherford also predicted the existence of neutral nuclear particles called neutrons, but he failed to find them. However, his student James Chadwick discovered them several years later.

The Planetary Model

Rutherford's discoveries meant that Thomson's plum pudding model was incorrect. Positive charge is not spread evenly throughout an atom. Instead, it is all concentrated in the tiny nucleus. The rest of the atom is empty space except for the electrons scattered through it. In Rutherford's model of the atom, which is shown in the **Figure** below, the electrons move around the massive nucleus like planets orbiting the sun. That's why his model is called the planetary model. Rutherford didn't know exactly where or how electrons orbit the nucleus. That research would be undertaken by later scientists, beginning with Niels Bohr in 1913. New and improved atomic models would also be developed. Nonetheless, Rutherford's model is still often used to represent the atom.



[Figure 4]

Summary

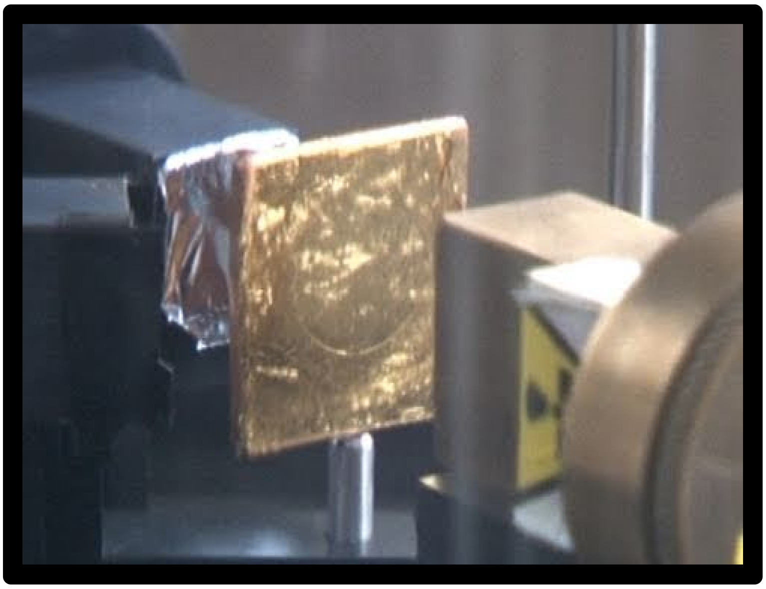
- Ernest Rutherford discovered the nucleus of the atom in 1911. He sent a beam of alpha particles toward gold foil and observed the way the particles were deflected by the gold atoms. From his results, he concluded that all of the positive charge and virtually all of the mass of an atom are concentrated in one tiny area, called the nucleus, and the rest of the atom is mostly empty space.
- In Rutherford's planetary model of the atom, the electrons move through empty space around the tiny positive nucleus like planets orbiting the sun.

Review

1. How did Ernest Rutherford discover the nucleus of the atom?
2. Place Rutherford's discovery in the broader history of the atom.
3. Describe how you could make a three-dimensional version of Rutherford's planetary model of the atom.

Explore More

Watch this video about Rutherford's gold foil experiment, and then answer the questions below.



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1. How did Rutherford observe alpha particles in his experiment? In the modern version of Rutherford's experiment, which is shown in the video, how are alpha particles observed? Which way do you think is more accurate?
2. Based on the animation in the video, draw a sketch showing what happens to alpha particles as they pass through gold atoms.
3. How has Rutherford's gold foil experiment been adopted by modern researchers?

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3.12 Bohr's Atomic Model

FlexBooks® 2.0 > American HS Physical Science > Bohr's Atomic Model

Last Modified: Feb 19, 2021

[Figure 1]

Look at the people in the picture. Do you see how they are standing on different rungs of the ladder? When you stand on a ladder, you can stand on one rung or another, but you can never stand in between two rungs. A ladder can be used to model parts of an atom. Do you know how?

Modeling the Atom

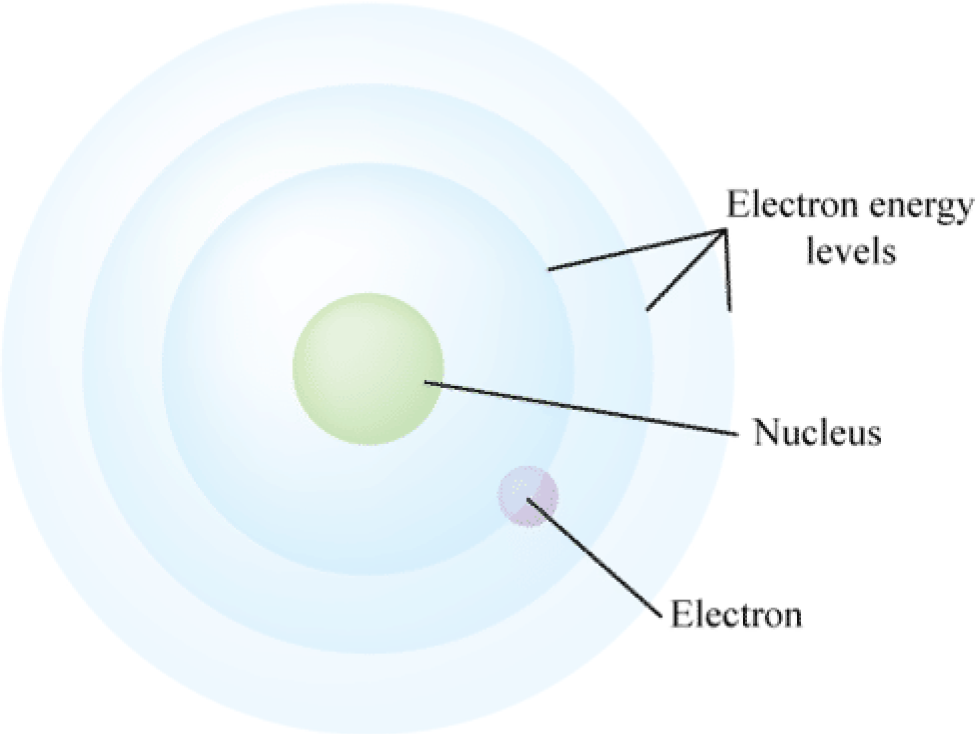
The existence of the atom was first demonstrated around 1800 by John Dalton. Then, close to a century went by before J.J. Thomson discovered the first subatomic particle, the negatively charged electron. Because atoms are neutral in charge, Thomson thought that they must consist of a sphere of positive charge with electrons scattered through it. In 1910, Ernest Rutherford showed that this idea was incorrect. He demonstrated that all of the positive charge of an atom is actually concentrated in a tiny central region called the nucleus. Rutherford surmised that electrons move around the nucleus like planets around the sun. Rutherford's idea of atomic structure was an improvement on Thomson's model, but it wasn't the last word. Rutherford focused on the nucleus and didn't really clarify where the electrons were in the empty space surrounding the nucleus.

The next major advance in atomic history occurred in 1913, when the Danish scientist Niels Bohr published a description of a more detailed model of the atom. His model identified more clearly where electrons could be found. Although later scientists would develop more refined atomic models, Bohr's model was basically correct and much of it is still accepted today. It is also a very useful model because it explains the properties of different elements. Bohr received the 1922 Nobel prize in physics for his contribution to our understanding of the structure of the atom. You can see a picture of Bohr below.

[Figure 2]

On the Level

As a young man, Bohr worked in Rutherford's lab in England. Because Rutherford's model was weak on the position of the electrons, Bohr focused on them. He hypothesized that electrons can move around the nucleus only at fixed distances from the nucleus based on the amount of energy they have. He called these fixed distances energy levels, or electron shells. He thought of them as concentric spheres, with the nucleus at the center of each sphere. In other words, the shells consisted of sphere within sphere within sphere. Furthermore, electrons with less energy would be found at lower energy levels, closer to the nucleus. Those with more energy would be found at higher energy levels, farther from the nucleus. Bohr also hypothesized that if an electron absorbed just the right amount of energy, it would jump to the next higher energy level. Conversely, if it lost the same amount of energy, it would jump back to its original energy level. However, an electron could never exist in between two energy levels. These ideas are illustrated in the **Figure** below.



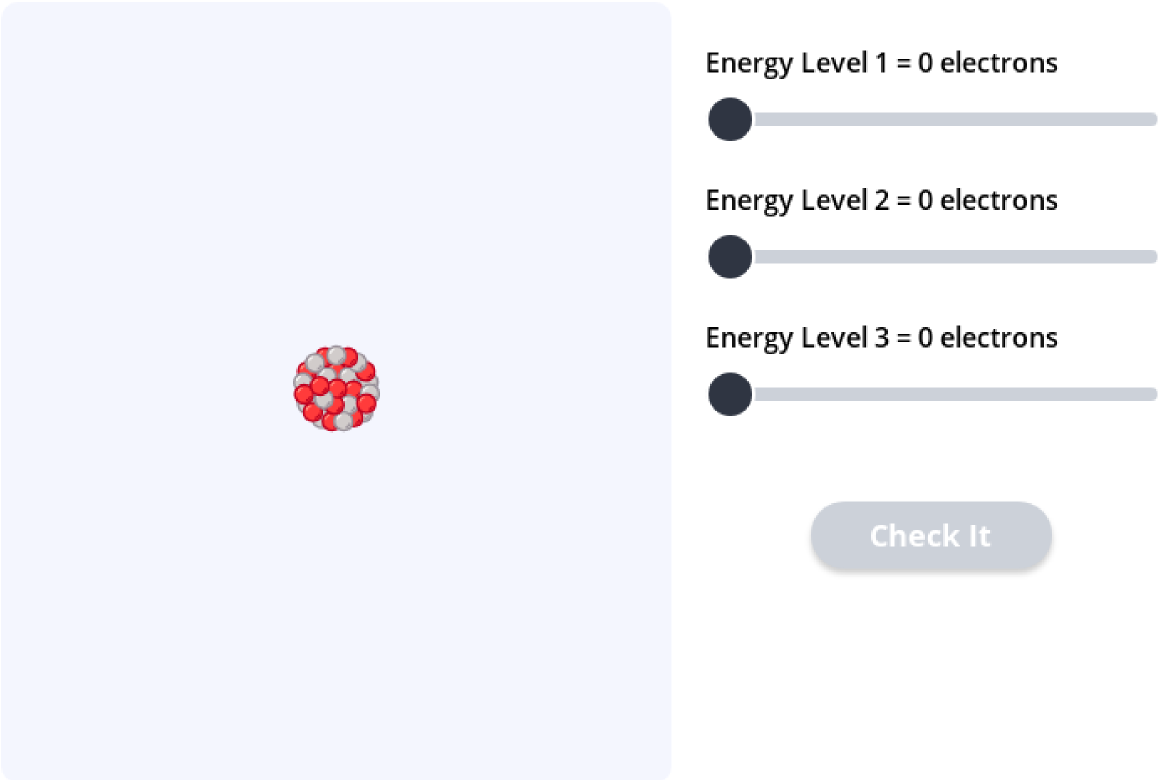
[Figure 3]

This is a two-dimensional model of a three-dimensional atom. The concentric circles actually represent concentric spheres.

Q: How is an atom like a ladder?

A: Energy levels in an atom are like the rungs of a ladder. Just as you can stand only on the rungs and not in between them, electrons can orbit the nucleus only at fixed distances from the nucleus and not in between them.

Can you complete Bohr's model for a silicon atom?



Energy by the Spoonful

Bohr's model of the atom is actually a combination of two different ideas: Rutherford's atomic model of electrons orbiting the nucleus and German scientist Max Planck's idea of a quantum, which Planck published in 1901. A **quantum** (plural, quanta) is the minimum amount of energy that can be absorbed or released by matter. It is a discrete, or distinct, amount of energy. If energy were water and you wanted to add it to matter in the form of a drinking glass, you couldn't simply pour the water continuously into the glass. Instead, you could add it only in small fixed quantities, for example, by the teaspoonful. Bohr reasoned that if electrons can absorb or lose only fixed quantities of energy, then they must vary in their energy by these fixed amounts. Thus, they can occupy only fixed energy levels around the nucleus that correspond to quantum increases in energy.

Q: The idea that energy is transferred only in discrete units, or quanta, was revolutionary when Max Planck first proposed it in 1901. However, what scientists already knew about matter may have made it easier for them to accept the idea of energy quanta. Can you explain?

A: Scientists already knew that matter exists in discrete units called atoms. This idea had been demonstrated by John Dalton around 1800. Knowing this may have made it easier for scientists to accept the idea that energy exists in discrete units as well.

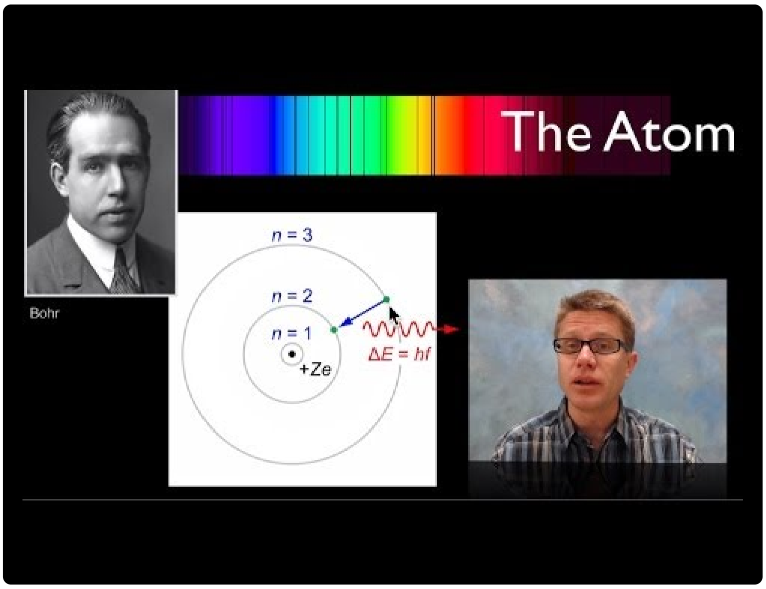
Summary

- In Bohr's atomic model, electrons move around the nucleus only at fixed distances from the nucleus based on the amount of energy they have. The fixed distances where electrons may orbit are called energy levels.
- Bohr arrived at his model by applying Planck's idea of energy quanta to Rutherford's atomic model of electrons orbiting the nucleus.

Review

1. How does Bohr's atomic model build on Rutherford's model?
2. Explain the connection between energy quanta and energy levels.
3. How does Bohr's work demonstrate the importance of communication in science?

Resources



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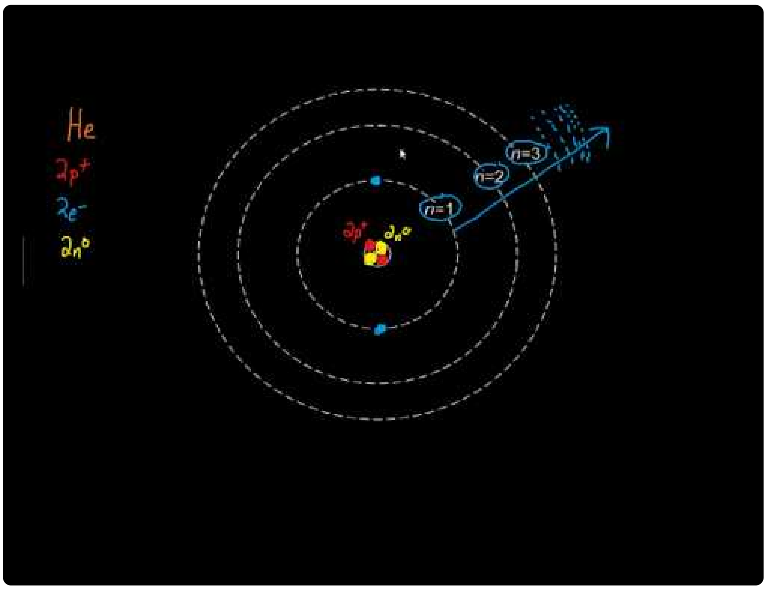

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3.13 Energy Level

FlexBooks® 2.0 > American HS Physical Science > Energy Level

Last Modified: Oct 25, 2021

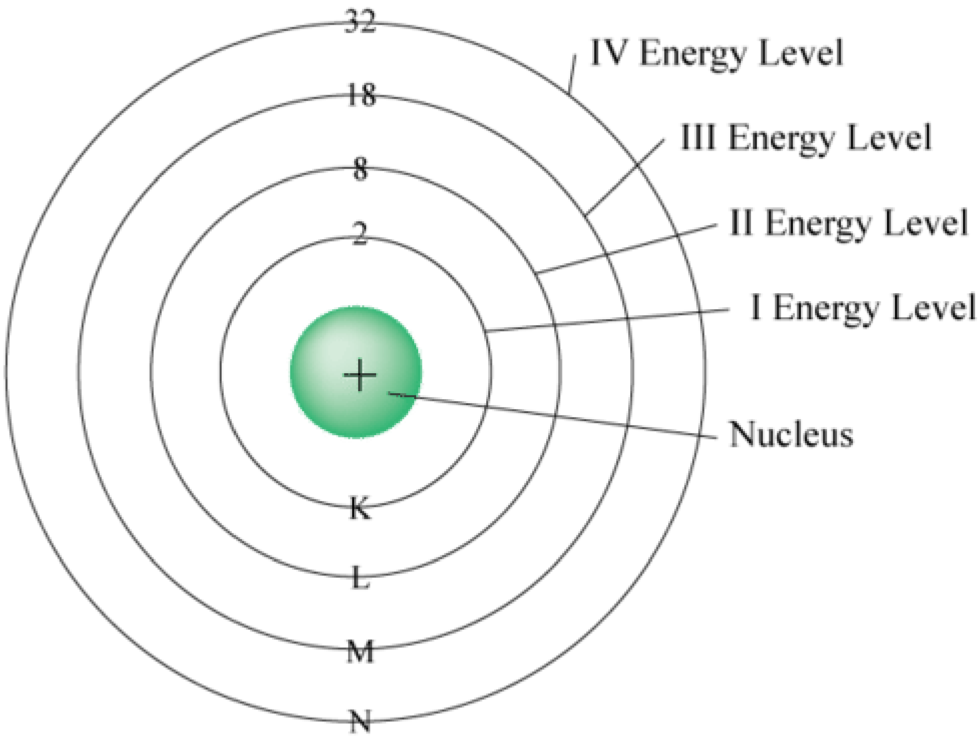
[Figure 1]

Fireworks are a great way to celebrate happy events. Do you know what causes the brilliant, colored lights of fireworks? The lights are bursts of energy given off by atoms in the fireworks. What do you suppose causes these bursts of light? The answer has to do with energy levels of atoms.

What Are Energy Levels?

Energy levels (also called electron shells) are fixed distances from the nucleus of an atom where electrons may be found. Electrons are tiny, negatively charged particles in an atom that move around the positive nucleus at the center. Energy levels are a little like the steps of a staircase. You can stand on one step or another but not in between the steps. The same goes for electrons. They can occupy one energy level or another but not the space between energy levels.

The model in the **Figure** below shows the first four energy levels of an atom. Electrons in energy level I (also called energy level K) have the least amount of energy. As you go farther from the nucleus, electrons at higher levels have more energy, and their energy increases by a fixed, discrete amount. Electrons can jump from a lower to the next higher energy level if they absorb this amount of energy. Conversely, if electrons jump from a higher to a lower energy level, they give off energy, often in the form of light. This explains the fireworks pictured above. When the fireworks explode, electrons gain energy and jump to higher energy levels. When they jump back to their original energy levels, they release the energy as light. Different atoms have different arrangements of electrons, so they give off light of different colors.



[Figure 2]

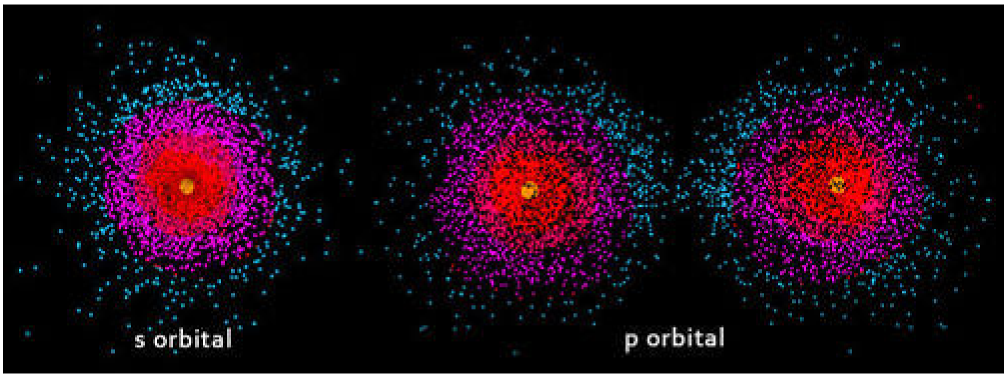
Q: In the atomic model **Figure** above, where would you find electrons that have the most energy?

A: Electrons with the most energy would be found in energy level IV.

Energy Levels and Orbitals

The smallest atoms are hydrogen atoms. They have just one electron. That one electron is in the first energy level. Bigger atoms have more electrons. Electrons are always added to the lowest energy level first until it has the maximum number of electrons possible. Then electrons are added to the next higher energy level until that level is full, and so on.

How many electrons can a given energy level hold? The maximum numbers of electrons possible for the first four energy levels are shown in the **Figure** above. For example, energy level I can hold a maximum of two electrons, and energy level II can hold a maximum of eight electrons. The maximum number depends on the number of orbitals at a given energy level. An orbital is a volume of space within an atom where an electron is most likely to be found. As you can see by the images in the **Figure** below, some orbitals are shaped like spheres (S orbitals) and some are shaped like dumbbells (P orbitals). There are other types of orbitals as well.



[Figure 3]

Regardless of its shape, each orbital can hold a maximum of two electrons. Energy level I has just one orbital, so two electrons will fill this energy level. Energy level II has four orbitals, so it takes eight electrons to fill this energy level.

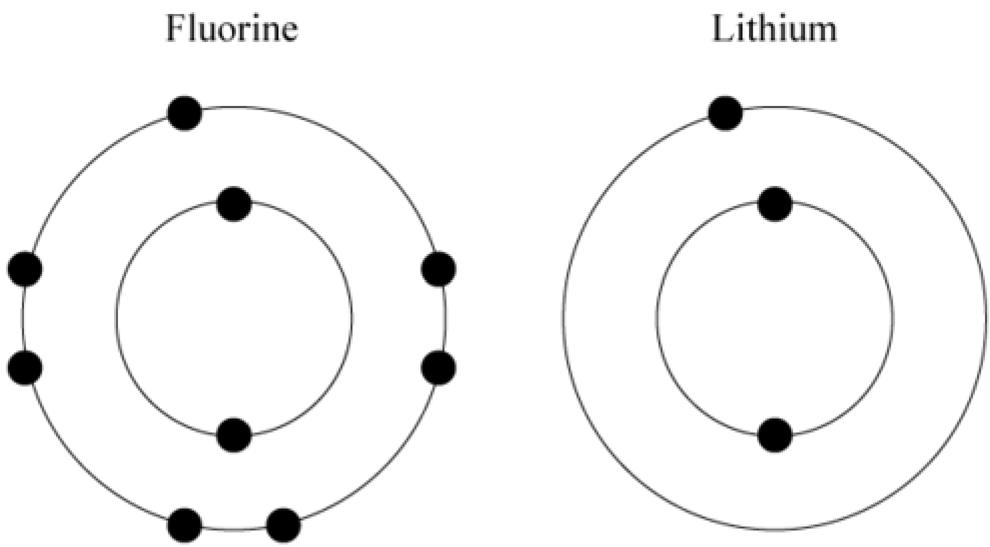
Q: Energy level III can hold a maximum of 18 electrons. How many orbitals does this energy level have?

A: At two electrons per orbital, this energy level must have nine orbitals.

The Outermost Level

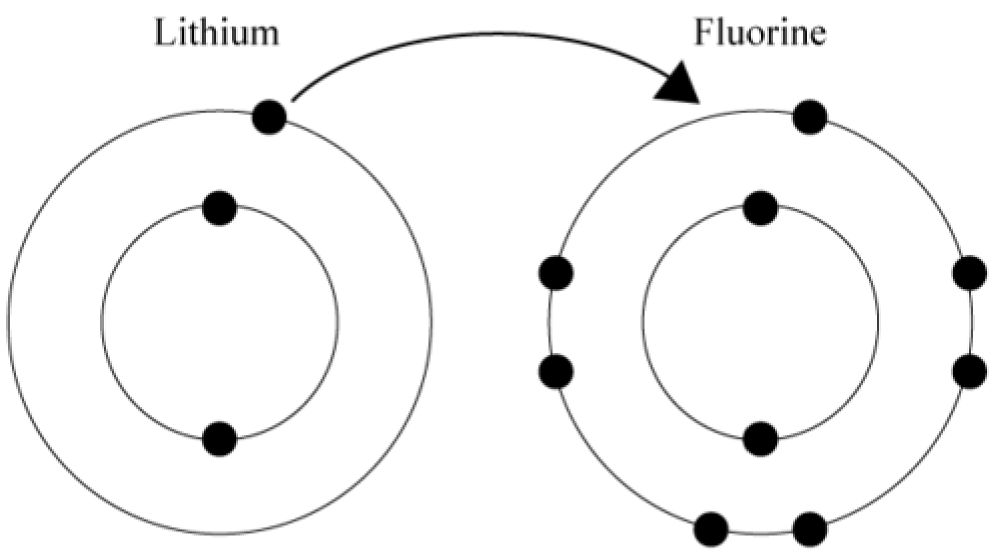
Electrons in the outermost energy level of an atom have a special significance. These electrons are called valence electrons, and they determine many of the properties of an atom. An atom is most stable if its outermost energy level contains as many electrons as it can hold. For example, helium has two electrons, both in the first energy level. This energy level can hold only two electrons, so helium's only energy level is full. This makes helium a very stable element. In other words, its atoms are unlikely to react with other atoms.

Consider the elements fluorine and lithium, modeled in the **Figure** below. Fluorine has seven of eight possible electrons in its outermost energy level, which is energy level II. It would be more stable if it had one more electron because this would fill its outermost energy level. Lithium, on the other hand, has just one of eight possible electrons in its outermost energy level (also energy level II). It would be more stable if it had one less electron because it would have a full outer energy level (now energy level I).



[Figure 4]

Both fluorine and lithium are highly reactive elements because of their number of valence electrons. Fluorine will readily gain one electron and lithium will just as readily give up one electron to become more stable. In fact, lithium and fluorine will react together as shown in the **Figure** below. When the two elements react, lithium transfers its one "extra" electron to fluorine.



[Figure 5]

Q: A neon atom has ten electrons. How many electrons does it have in its outermost energy level? How stable do you think a neon atom is?

A: A neon atom has two electrons in energy level I and its remaining eight electrons in energy level II, which can hold only eight electrons. This means that is outermost energy level is full. Therefore, a neon atom is very stable.

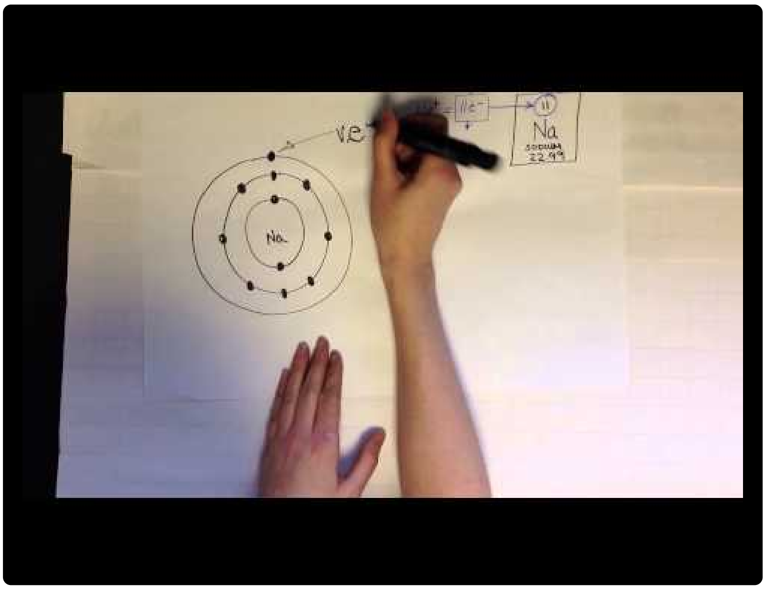
Summary

- Energy levels (also called electron shells) are fixed distances from the nucleus of an atom where electrons may be found. As you go farther from the nucleus, electrons at higher energy levels have more energy.
- Electrons are always added to the lowest energy level first until it has the maximum number of electrons possible, and then electrons are added to the next higher energy level until that level is full, and so on. The maximum number of electrons at a given energy level depends on its number of orbitals. There are at most two electrons per orbital.
- Electrons in the outermost energy level of an atom are called valence electrons. They determine many of the properties of an atom, including how reactive it is.

Review

1. What are energy levels?
2. Relate energy levels to the amount of energy their electrons have.
3. What must happen for an electron to jump to a different energy level?
4. How many electrons can the fourth energy level have? How many orbitals are there at this energy level?
5. An atom of sodium has 11 electrons. Make a sketch of a sodium atom, showing how many electrons it has at each energy level. Infer how reactive sodium atoms are.

Resources



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3.14 Electron Cloud Atomic Model

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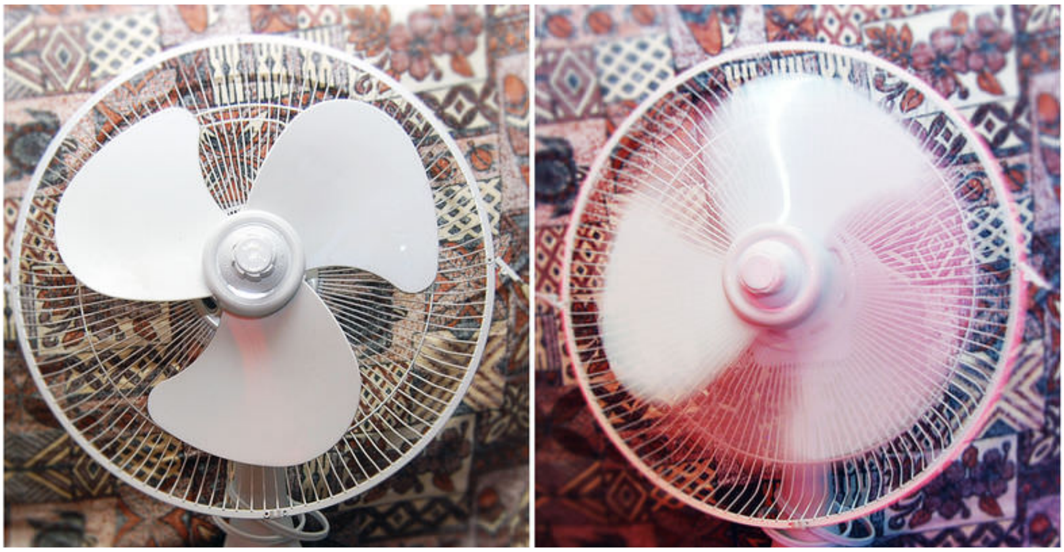
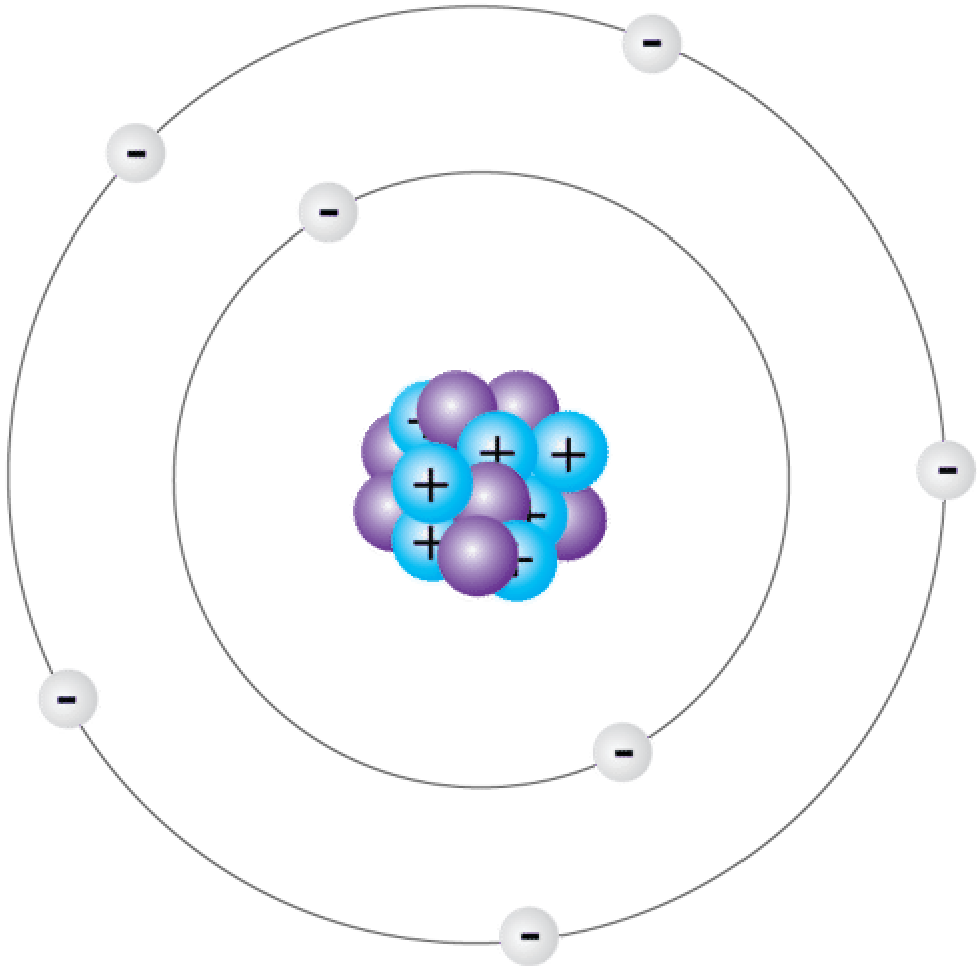


[Figure 1]

The fan pictured here is turned off in the photo on the left and running at high speed in the photo on the right. In the right-hand photo, the blades are moving too fast for you to see the individual blades. You can't tell where any given blade is at any given moment. In some ways, rapidly moving fan blades are similar to electrons moving about the nucleus of an atom. Like fan blades, electrons move very quickly and we can never tell exactly where they are. If that's the case, how can we represent electrons in models of the atom?

Where Are the Electrons?

Up until about 1920, scientists accepted Niels Bohr's model of the atom. In this model, negative electrons circle the positive nucleus at fixed distances from the nucleus, called energy levels. You can see the model in **Figure** below for an atom of the element nitrogen. Bohr's model is useful for understanding properties of elements and their chemical interactions. However, it doesn't explain certain behaviors of electrons, except for those in the simplest atom, the hydrogen atom.



[Figure 2]

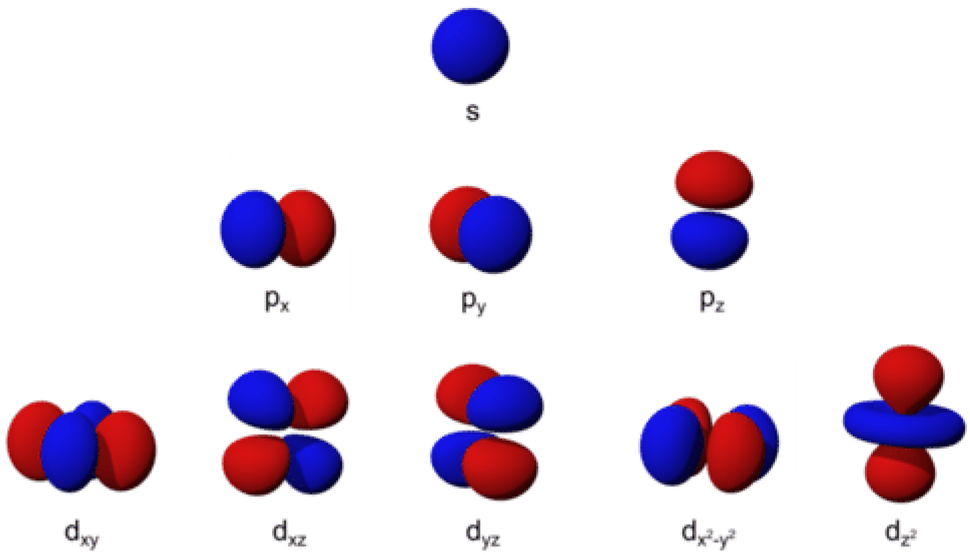
What Are the Chances?

In the mid-1920s, an Austrian scientist named Erwin Schrödinger thought that the problem with Bohr's model was restricting the electrons to specific orbits. He wondered if electrons might behave like light, which scientists already knew had properties of both particles and waves. Schrödinger speculated that electrons might also travel in waves.

Q: How do you pin down the location of an electron in a wave?

A: You can't specify the exact location of an electron. However, Schrödinger showed that you can at least determine where an electron is most likely to be.

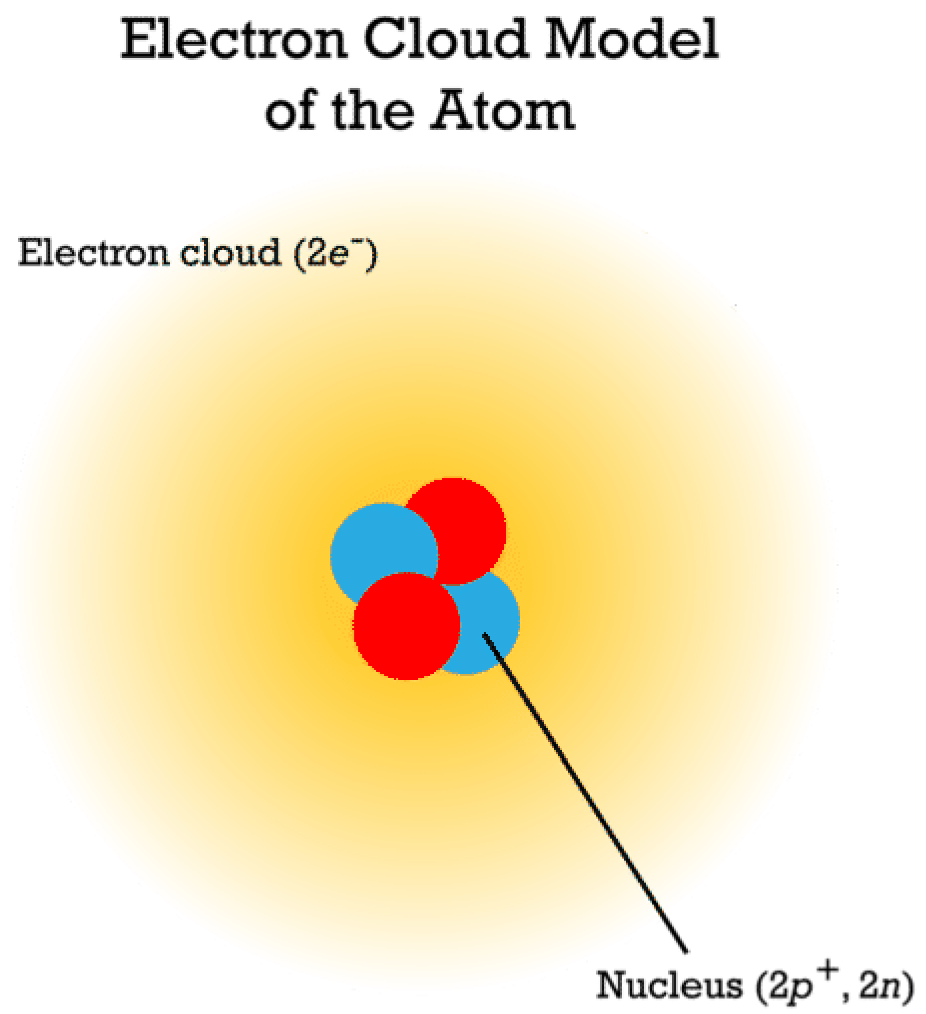
Schrödinger developed an equation that could be used to calculate the chances of an electron being in any given place around the nucleus. Based on his calculations, he identified regions around the nucleus where electrons are most likely to be. He called these regions **orbitals**. As you can see in the **Figure** below, orbitals may be shaped like spheres, dumbbells, or rings. In each case, the nucleus of the atom is at the center of the orbital.



[Figure 3]

A Fuzzy Cloud

Schrödinger's work on orbitals is the basis of the modern model of the atom, which scientists call the quantum mechanical model. The modern model is also commonly called the **electron cloud** model. That's because each orbital around the nucleus of the atom resembles a fuzzy cloud around the nucleus, like the ones shown in the **Figure** below for a helium atom. The densest area of the cloud is where the electrons have the greatest chances of being.



[Figure 4]

Q: In the model pictured in the **Figure** above, where are the two helium electrons most likely to be?

A: The two electrons are most likely to be inside the sphere closest to the nucleus where the cloud is darkest.

Summary

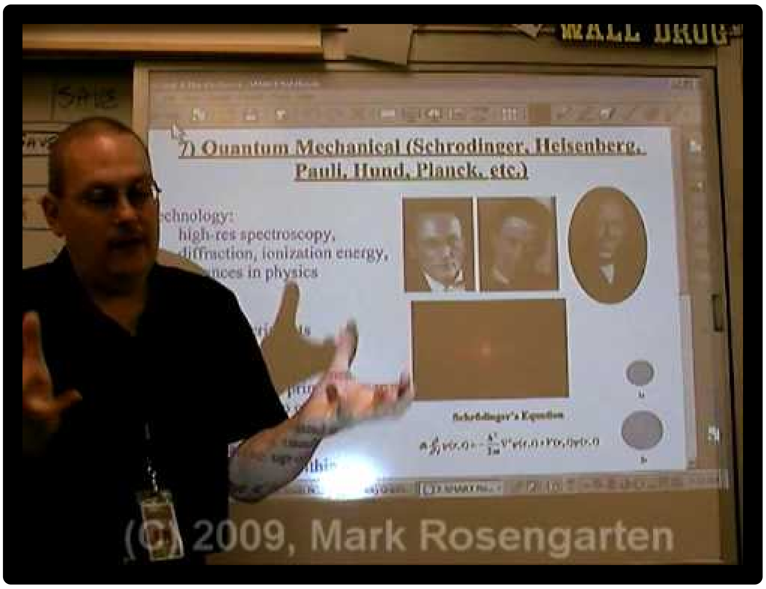
- Bohr's model of the atom, in which electrons circle the nucleus at fixed energy levels, cannot explain all the behaviors of electrons.
- In the 1920s, Erwin Schrödinger proposed that electrons travel in waves, which means their exact positions cannot be determined. He developed an equation to calculate the chances of an electron being in any given place. Using his equation, he identified regions around the nucleus, called orbitals, where electrons are most likely to be.
- Orbitals are the basis of the electron cloud model of the atom. This model is still accepted by scientists today.

Review

1. What is the problem with Bohr's model of the atom?
2. How did Schrödinger resolve this problem?
3. Describe orbitals.
4. Outline the electron cloud model of the atom.

Explore More

Watch the video about the electron cloud model below, and then answer the questions that follow.



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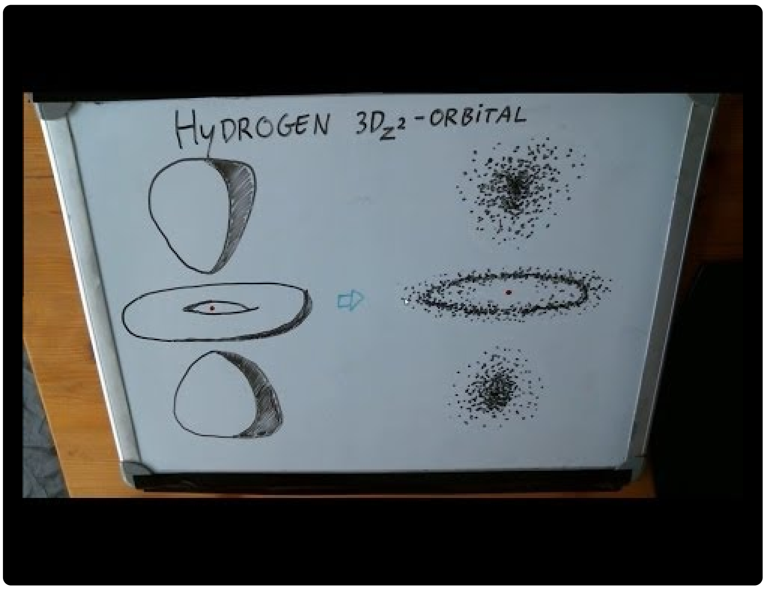
1. What influences the movement of electrons in atoms?
2. What is the Heisenberg uncertainty principle?
3. How is the Heisenberg uncertainty principle related to electron orbitals?

Resources



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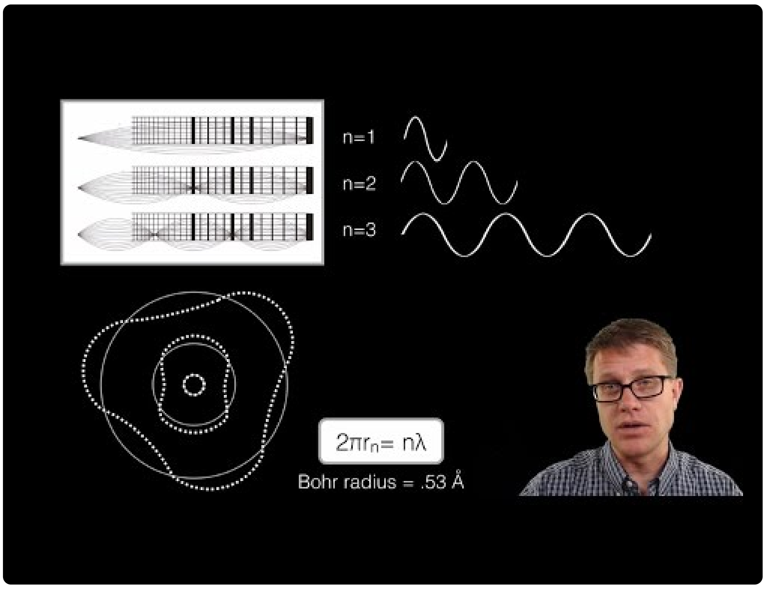

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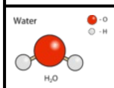	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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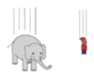	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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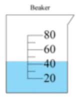
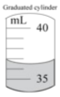
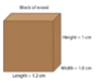
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 4

The Periodic Table

Chapter Outline

4.1 Mendeleev's Periodic Table

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Last Modified: Jul 14, 2021

[Figure 1]

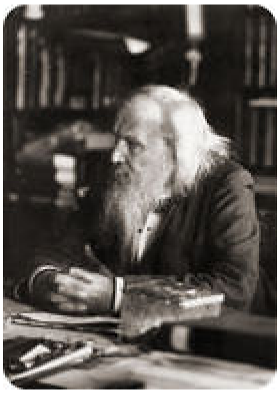
Look at the left-hand photo above. What a messy closet! Do you have a messy closet too? If you do, then you know how hard it can be to find a specific item of clothing. If you don't have a messy closet, just imagine trying to find a particular shirt or pair of jeans in the closet above. It could take a long time, and it would probably make you late for school! Now look at the closet on the right. It's very neat and well organized. With a closet like this, it would be easy to find whatever item you wanted.

Q: What do these two closets have to do with science?

A: They show why it's important to keep things organized, including the elements, which are the pure substances that make up all kinds of matter.

Organizing Elements

For many years, scientists looked for a good way to organize the elements. This became increasingly important as more and more elements were discovered. An ingenious method of organizing elements was developed in 1869 by a Russian scientist named Dmitri Mendeleev, who is pictured below. Mendeleev's method of organizing elements was later revised, but it served as a basis for the method that is still used today.



[Figure 2]

Mendeleev was a teacher as well as a chemist. He was writing a chemistry textbook and wanted to find a way to organize the 63 known elements so it would be easier for students to learn about them. He made a set of cards of the elements, similar to a deck of playing cards. On each card, he wrote the name of a different element, its atomic mass, and other known properties. Mendeleev arranged and rearranged the cards in many different ways, looking for a pattern. He finally found it when he placed the elements in order by increasing atomic mass.

Q: What is atomic mass? Why might it be a good basis for organizing elements?

A: Atomic mass is the mass of one atom of an element. It is about equal to the mass of the protons plus the neutrons in an atom. It is a good basis for organizing elements because each element has a unique number of protons and atomic mass is an indirect way of organizing elements by number of protons.

Groups and Periods

You can see how Mendeleev organized the elements in the **Figure** below. From left to right across each row, elements are arranged by increasing atomic mass. Mendeleev discovered that if he placed eight elements in each row and then continued on to the next row, the columns of the table would contain elements with similar properties. He called the columns **groups**. They are sometimes called families, because elements within a group are similar but not identical to one another, like people in a family.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

[Figure 3]

Mendeleev's table of the elements is called a **periodic table** because of its repeating pattern. Anything that keeps repeating is referred to as periodic. Other examples of things that are periodic include the monthly phases of the moon and the daily cycle of night and day. The term *period* refers to the interval between repetitions. For example, the moon's phases repeat every four weeks. In a periodic table of the elements, the **periods** are the rows of the table. In Mendeleev's table, each period contains eight elements, and then the pattern repeats in the next row.

Filling in the Blanks

Did you notice the blanks in Mendeleev's table? They are spaces that Mendeleev left blank for elements that had not yet been discovered when he created his table. He predicted that these missing elements would eventually be discovered. Based on their position in the table, he even predicted their properties. For example, he predicted a missing element in row 5 of group III. He also predicted that the missing element would have an atomic mass of 68 and be a relatively soft metal like other elements in this group. Scientists searched for the missing element, and they found it just a few years later. They named the new element gallium. Scientists searched for the other missing elements in Mendeleev's table and eventually found all of them.

An important measure of a good model is its ability to make accurate predictions. This makes it a useful model. Clearly, Mendeleev's periodic table was a useful model. It helped scientists discover new elements and made sense of those that were already known.

Summary

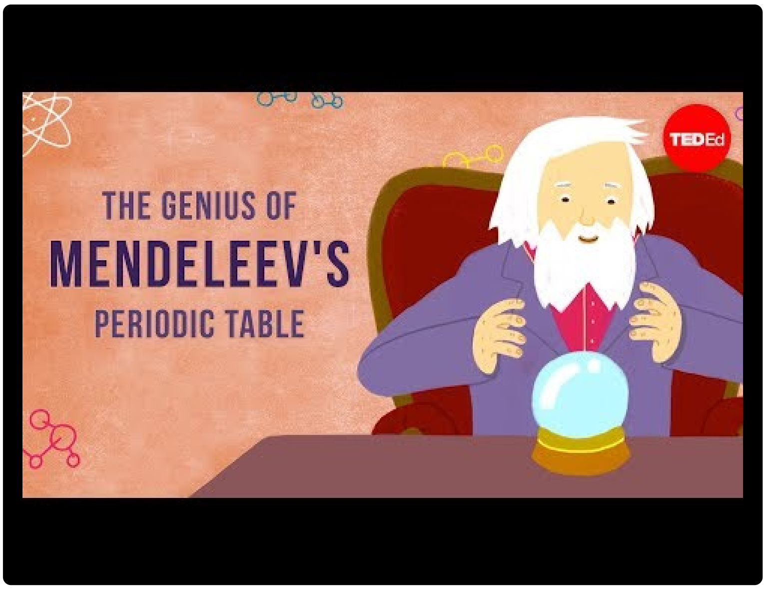
- In 1869, Dmitri Mendeleev developed a method for organizing elements based on their atomic mass. His method was later revised, but it served as a basis for the method used today.

- Mendeleev created a periodic table of all the elements that were known at the time. The rows of the table, called periods, each contained eight elements that increased in atomic mass from left to right. The columns of the table, called groups, contained elements with similar properties.
- Mendeleev's periodic table was a good model because it could be used to predict unknown elements and their properties. All of these missing elements were eventually discovered.

Review

1. How did Mendeleev develop his periodic table of the elements?
2. What are the groups in Mendeleev's table?
3. Describe the periods in Mendeleev's table.
4. Why was Mendeleev's periodic table a good model?

Resources



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4.2 Valence Electrons

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Last Modified: Oct 20, 2020

[Figure 1]

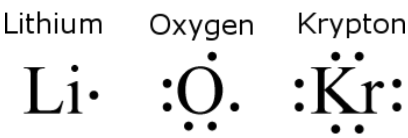
Did you ever play the card game called "Go fish"? Players try to form groups of cards of the same value, such as four sevens, with the cards they are dealt or by getting cards from other players or the deck. This give and take of cards is a simple analogy for the way atoms give and take valence electrons in chemical reactions.

What Are Valence Electrons?

Valence electrons are the electrons in the outer energy level of an atom that can participate in interactions with other atoms. Valence electrons are generally the electrons that are farthest from the nucleus. As a result, they may be attracted as much or more by the nucleus of another atom than they are by their own nucleus.

Electron Dot Diagrams

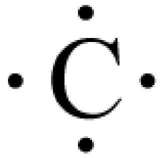
Because valence electrons are so important, atoms are often represented by simple diagrams that show only their valence electrons. These are called electron dot diagrams, and three are shown below. In this type of diagram, an element's chemical symbol is surrounded by dots that represent the valence electrons. Typically, the dots are drawn as if there is a square surrounding the element symbol with up to two dots per side. An element never has more than eight valence electrons, so there can't be more than eight dots per atom.



[Figure 2]

Q: Carbon (C) has four valence electrons. What does an electron dot diagram for this element look like?

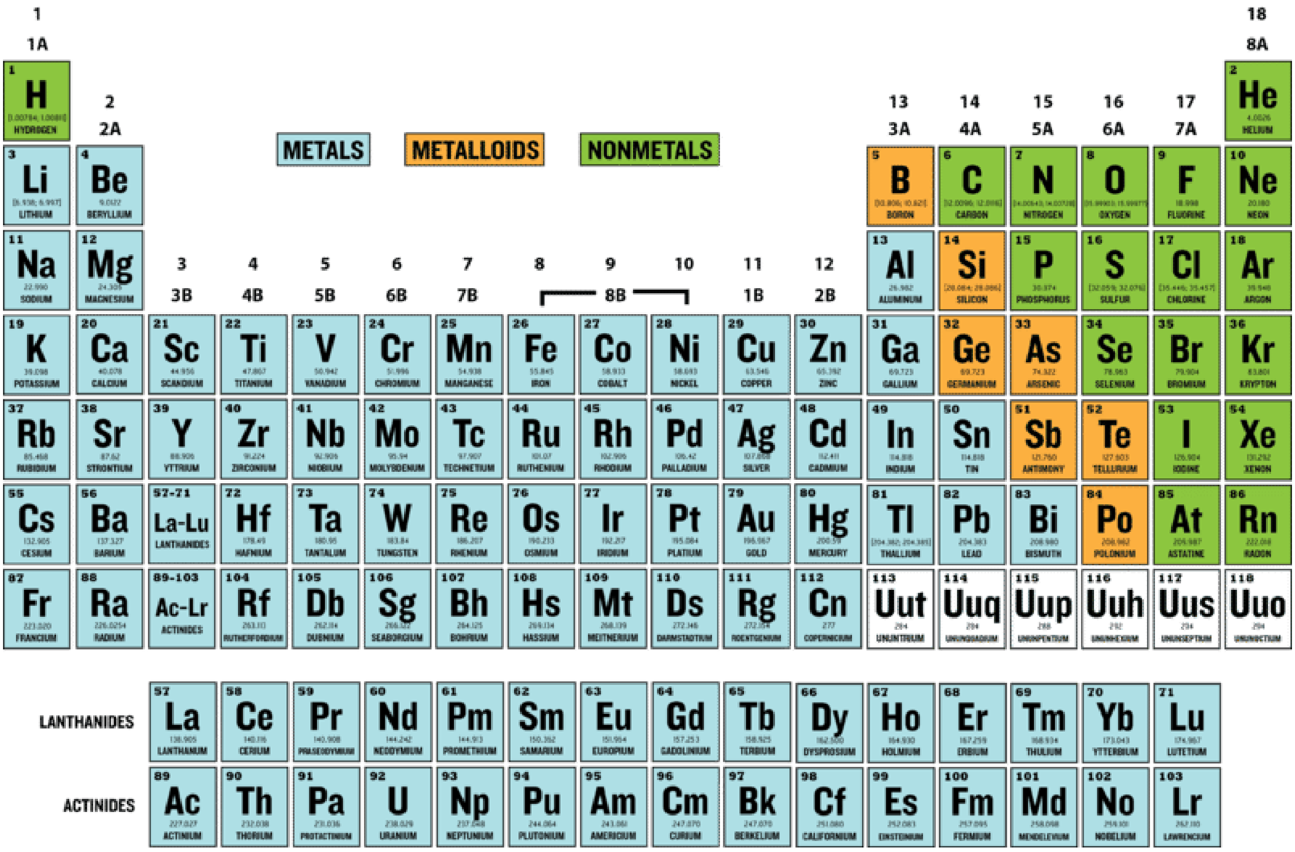
A: An electron dot diagram for carbon looks like this:



[Figure 3]

Valence Electrons and the Periodic Table

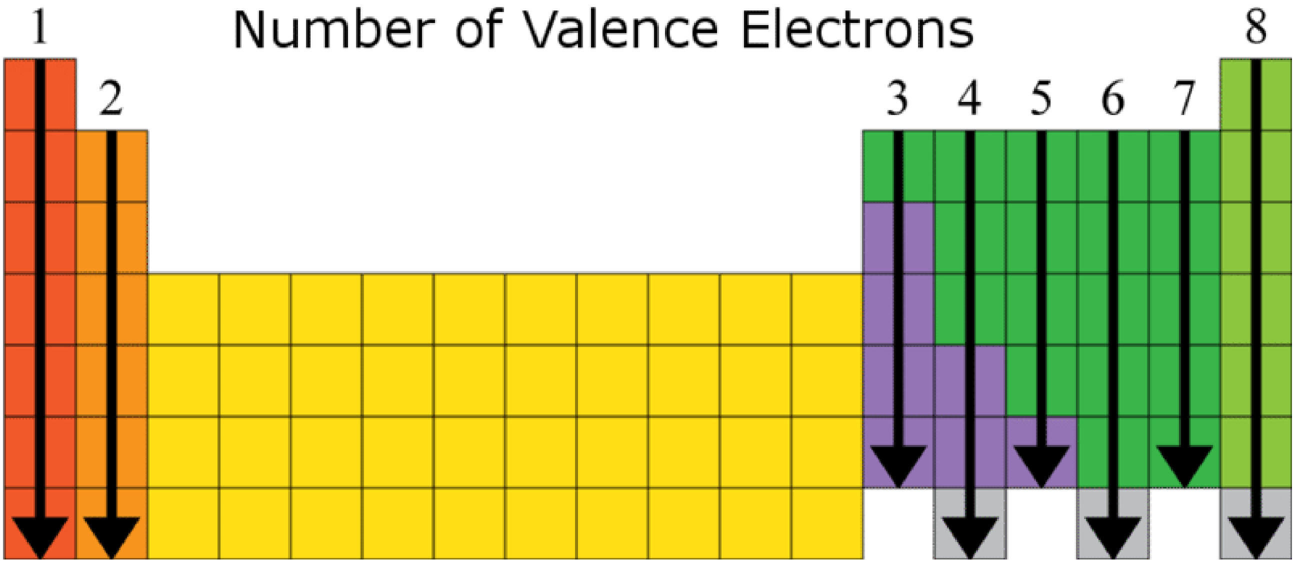
The number of valence electrons in an atom is reflected by its position in the periodic table of the elements (see the periodic table in the **Figure** below). Across each row, or period, of the periodic table, the number of valence electrons in groups 1–2 and 13–18 increases by one from one element to the next. Within each column, or group, of the table, all the elements have the same number of valence electrons. This explains why all the elements in the same group have very similar chemical properties.



[Figure 4]

For elements in groups 1–2 and 13–18, the number of valence electrons is easy to tell directly from the periodic table. This is illustrated in the simplified periodic table in the

Figure below. It shows just the numbers of valence electrons in each of these groups. For elements in groups 3–12, determining the number of valence electrons is more complicated.



[Figure 5]

Q: Based on both periodic tables above (**Figures** above and above), what are examples of elements that have just one valence electron? What are examples of elements that have eight valence electrons? How many valence electrons does oxygen (O) have?

A: Any element in group 1 has just one valence electron. Examples include hydrogen (H), lithium (Li), and sodium (Na). Any element in group 18 has eight valence electrons (except for helium, which has a total of just two electrons). Examples include neon (Ne), argon (Ar), and krypton (Kr). Oxygen, like all the other elements in group 16, has six valence electrons.

Valence Electrons and Reactivity

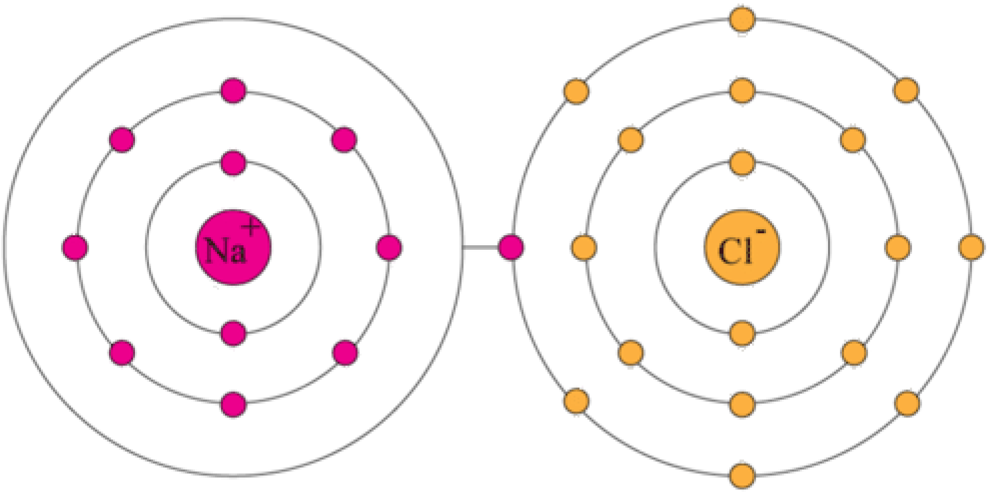
The table salt pictured in the **Figure** below contains two elements that are so reactive they are rarely found alone in nature. Instead, they undergo chemical reactions with other elements and form compounds. Table salt is the compound named sodium chloride (NaCl). It forms when an atom of sodium (Na) gives up an electron and an atom of chlorine (Cl) accepts it. When this happens, sodium becomes a positively charged ion (Na^+), and chlorine becomes a negatively charged ion (Cl^-). The two ions are attracted to each and join a matrix of interlocking sodium and chloride ions, forming a crystal of salt.

[Figure 6]

Table salt (sodium chloride).

Q: Why does sodium give up an electron?

A: An atom of a group 1 element such as sodium has just one valence electron. It is "eager" to give up this electron in order to have a full outer energy level, because this will give it the most stable arrangement of electrons. You can see how this happens in the **Figure** below. Group 2 elements with two valence electrons are almost as reactive as elements in group 1 for the same reason.



[Figure 7]

Q: Why does chlorine accept the electron from sodium?

A: An atom of a group 17 element such as chlorine has seven valence electrons. It is "eager" to gain an extra electron to fill its outer energy level and gain stability. Group 16 elements with six valence electrons are almost as reactive for the same reason.

Atoms of group 18 elements have eight valence electrons (or two in the case of helium). These elements already have a full outer energy level, so they are very stable. As a result, they rarely if ever react with other elements. Elements in other groups vary in their reactivity but are generally less reactive than elements in groups 1, 2, 16, or 17.

Q: Find calcium (Ca) in the periodic table (see **Figure** above). Based on its position in the table, how reactive do you think calcium is? Name another element with which calcium might react.

A: Calcium is a group 2 element with two valence electrons. Therefore, it is very reactive and gives up electrons in chemical reactions. It is likely to react with an element with six valence electrons that "wants" to gain two electrons. This would be an element in group 6, such as oxygen.

Valence Electrons and Electricity

Valence electrons also determine how well—if at all—the atoms of an element conduct electricity. The copper wires in the cable in the **Figure** below are coated with plastic. Copper is an excellent conductor of electricity, so it is used for wires that carry electric current. Plastic contains mainly carbon, which cannot conduct electricity, so it is used as insulation on the wires.

[Figure 8]

Q: Why do copper and carbon differ in their ability to conduct electricity?

A: Atoms of metals such as copper easily give up valence electrons. Their electrons can move freely and carry electric current. Atoms of nonmetals such as the carbon, on the other hand, hold onto their electrons. Their electrons can't move freely and carry current.

A few elements, called metalloids, can conduct electricity, but not as well as metals. Examples include silicon and germanium in group 14. Both become better conductors at higher temperatures. These elements are called semiconductors.

Q: How many valence electrons do atoms of silicon and germanium have? What happens to their valence electrons when the atoms are exposed to an electric field?

A: Atoms of these two elements have four valence electrons. When the atoms are exposed to an electric field, the valence electrons move away from the atoms and allow current to flow.

Summary

- Valence electrons are the electrons in the outer energy level of an atom that can participate in interactions with other atoms.
- Electron dot diagrams that show only the valence electrons present in an atom.
- The number of valence electrons in atoms may cause them to be unreactive or highly reactive. For those atoms that are reactive, the number of valence electrons also determines whether they tend to give up or gain electrons in chemical reactions.
- Metals, which easily give up electrons, can conduct electricity. Nonmetals, which attract electrons, generally cannot. Metalloids such as silicon and germanium can conduct electricity but not as well as metals.

Review

1. What are valence electrons?
2. Draw an electron dot diagram for an atom of nitrogen (N).
3. Which of the following statements about valence electrons and the periodic table is true?
   a. The number of valence electrons decreases from left to right across each period.
   b. The number of valence electrons increases from top to bottom within each group.
   c. All of the elements in group 9 have nine valence electrons.
   d. Elements with the most valence electrons are in group 18.
4. Which element would you expect to be more reactive: phosphorus (P) or fluorine (F)? Explain your answer.
5. Why can’t nonmetals conduct electricity?

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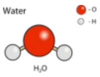	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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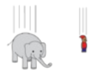
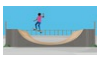
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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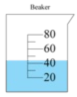
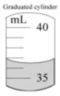
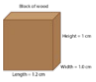
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 5

Chemical Interactions

Chapter Outline

5.1 Chemical Bond

FlexBooks® 2.0 > American HS Physical Science > Chemical Bond

Last Modified: Jul 13, 2021

[Figure 1]

Did you ever make cupcakes from scratch? You mix together flour, sugar, eggs, and other ingredients to make the batter, put the batter into cupcake papers, and then put them into the oven to bake. The cupcakes that come out of the oven after baking are different from any of the individual ingredients that went into the batter. Like the ingredients that join together to make cupcakes, atoms of different elements can join together to form entirely different substances called compounds. In cupcakes, the eggs and other wet ingredients cause the dry ingredients to stick together. What causes elements to stick together in compounds? The answer is chemical bonds.

What Is a Chemical Bond?

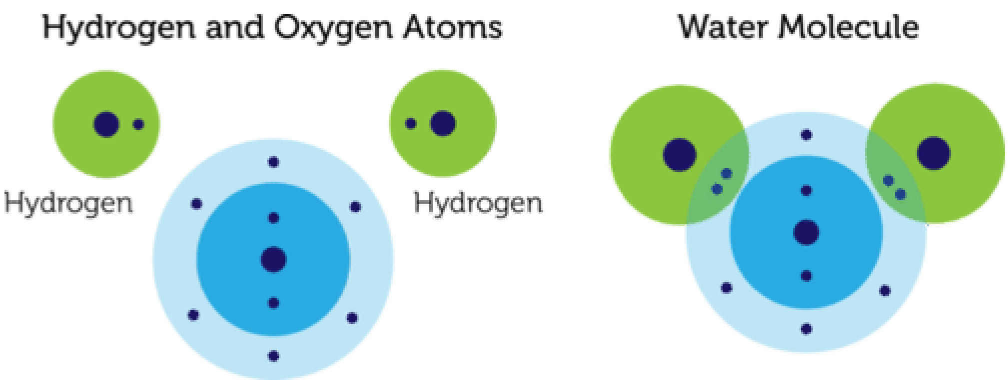
A **chemical bond** is a force of attraction between atoms or ions. Bonds form when atoms share or transfer valence electrons. Valence electrons are the electrons in the outer energy level of an atom that may be involved in chemical interactions. Valence electrons are the basis of all chemical bonds.

Q: Why do you think that chemical bonds form?

A: Chemical bonds form because they give atoms a more stable arrangement of electrons.

Why Bonds Form

To understand why chemical bonds form, consider the common compound known as water, or H_2O. It consists of two hydrogen (H) atoms and one oxygen (O) atom. As you can see in the on the left side of the **Figure** below, each hydrogen atom has just one electron, which is also its sole valence electron. The oxygen atom has six valence electrons. These are the electrons in the outer energy level of the oxygen atom.

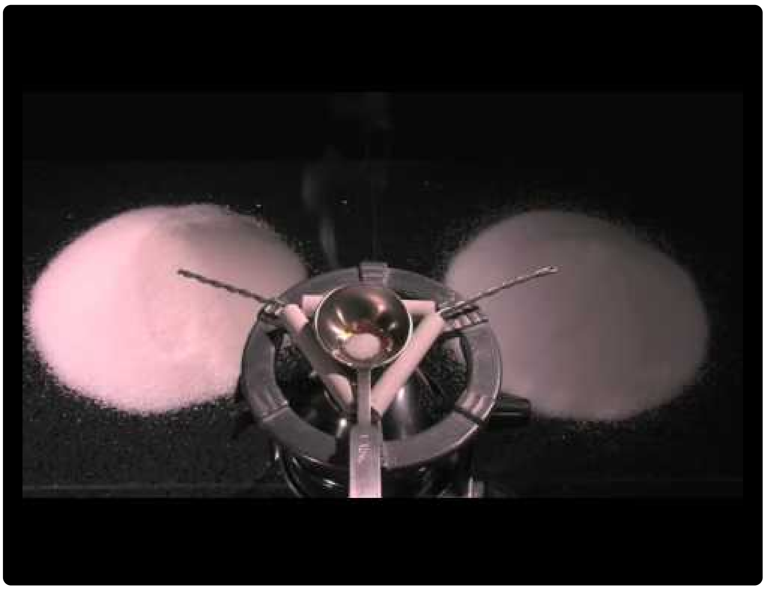


[Figure 2]

In the water molecule on the right in the **Figure** above, each hydrogen atom shares a pair of electrons with the oxygen atom. By sharing electrons, each atom has electrons available to fill its sole or outer energy level. The hydrogen atoms each have a pair of shared electrons, so their first and only energy level is full. The oxygen atom has a total of eight valence electrons, so its outer energy level is full. A full outer energy level is the most stable possible arrangement of electrons. It explains why elements form chemical bonds with each other.

Types of Chemical Bonds

Not all chemical bonds form in the same way as the bonds in water. There are actually three different types of chemical bonds, called covalent, ionic, and metallic bonds. Each type of bond is described below.



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- A covalent bond is the force of attraction that holds together two nonmetal atoms that share a pair of electrons. One electron is provided by each atom, and the pair of electrons is attracted to the positive nuclei of both atoms. The water molecule represented in the **Figure** above contains covalent bonds.
- An ionic bond is the force of attraction that holds together oppositely charged ions. Ionic bonds form crystals instead of molecules. Table salt contains ionic bonds.
- A metallic bond is the force of attraction between a positive metal ion and the valence electrons that surround it—both its own valence electrons and those of other ions of the same metal. The ions and electrons form a lattice-like structure. Only metals, such as the copper pictured in the **Figure** below, form metallic bonds.

[Figure 3]

Metallic bonds explain many of the properties of metals. This coil of wire is made of the metal copper. Like other metals, copper is shiny, can be formed into wires, and conducts electricity.

Summary

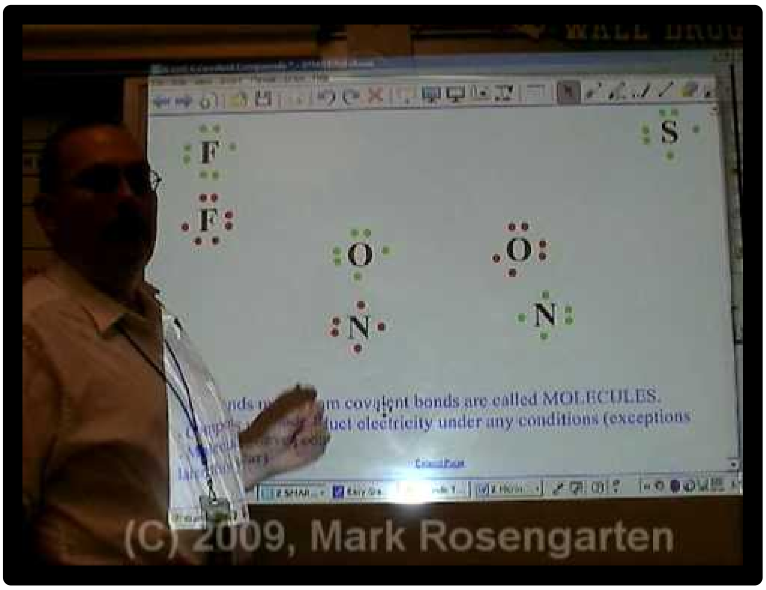
- A chemical bond is a force of attraction between atoms or ions. Bonds form when atoms share or transfer valence electrons.
- Atoms form chemical bonds to achieve a full outer energy level, which is the most stable arrangement of electrons.
- There are three different types of chemical bonds: covalent, ionic, and metallic bonds.

Review

1. What is a chemical bond?
2. Explain why hydrogen and oxygen atoms are more stable when they form bonds in a water molecule.
3. How do ionic bonds and covalent bonds differ?

Explore More

Watch this video about covalent bonds, and then answer the questions below.



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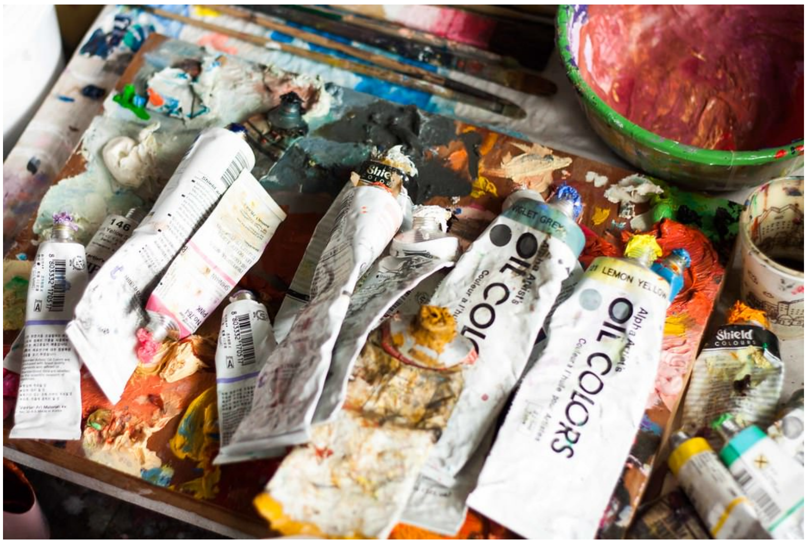
1. Which types of elements can form covalent bonds?
2. How can you tell the number of covalent bonds an element can form?
3. Why does one atom of nitrogen form bonds with three atoms of hydrogen?

5.2 Chemistry of Compounds

FlexBooks® 2.0 > American HS Physical Science > Chemistry of Compounds

Last Modified: Feb 19, 2021



[Figure 1]

Look at all the colors you can make by mixing together just a few colors of paint. In the photo above, the rainbow of colors on the brush formed from just four paint colors: green, yellow, red, and blue. The same thing is true of matter in general. By combining just a few different elements, you can form many different chemical compounds.

What Are Compounds?

A **compound** is a unique substance that forms when two or more elements combine chemically. Compounds form as a result of chemical reactions. The elements in compounds are held together by chemical bonds. A chemical bond is a force of attraction between atoms or ions that share or transfer valence electrons.

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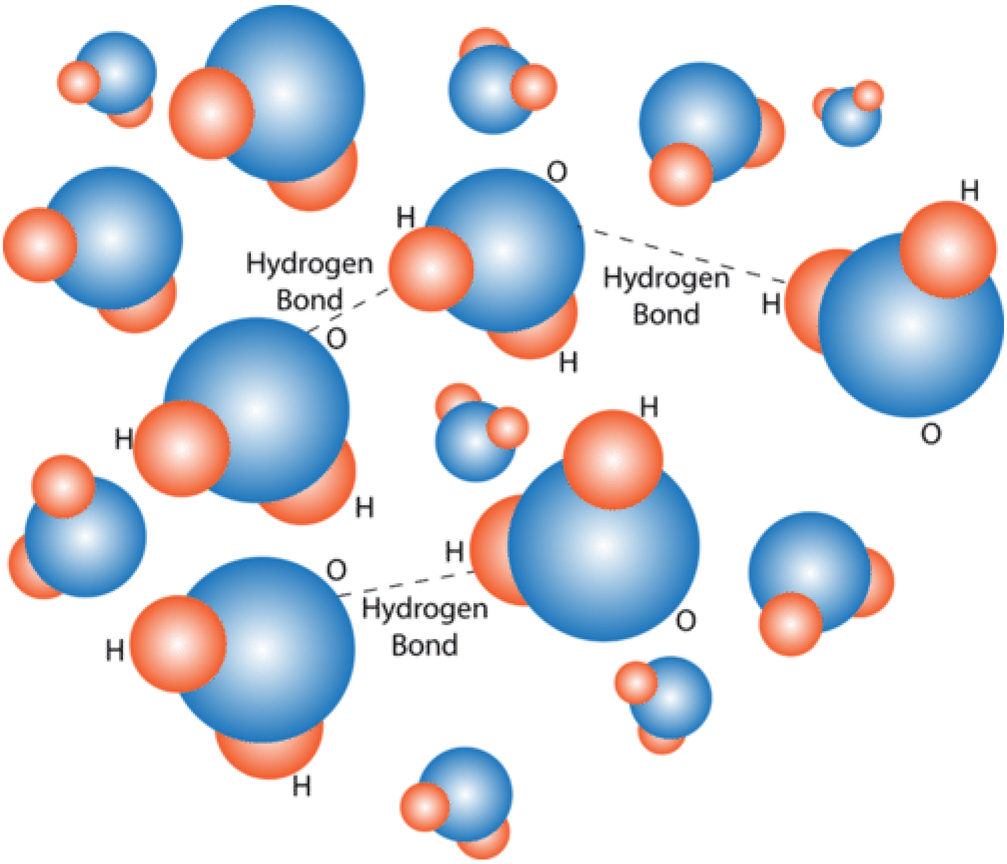
Water is an example of a common chemical compound. As you can see in the **Figure** below, each water molecule consists of two atoms of hydrogen and one atom of oxygen. Water always has this 2:1 ratio of hydrogen to oxygen. Like water, all compounds consist of a fixed ratio of elements. It doesn't matter how much or how little of a compound there is. It always has the same composition.



[Figure 2]

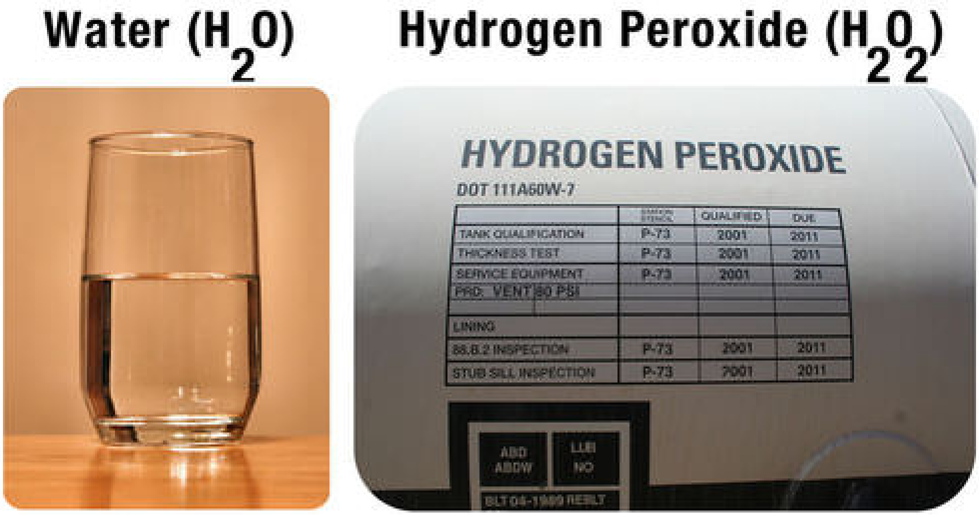
All water molecules have two hydrogen atoms (red) and one oxygen atom (blue).

Q: Sometimes the same elements combine in different ratios. How can this happen if a compound always consists of the same elements in the same ratio?

A: If the same elements combine in different ratios, they form different compounds.

Same Elements, Different Compounds

Look at the **Figure** below of water (H_2O) and hydrogen peroxide (H_2O_2), and read about these two compounds. Both compounds consist of hydrogen and oxygen, but they have different ratios of the two elements. As a result, water and hydrogen peroxide are different compounds with different properties. If you've ever used hydrogen peroxide to disinfect a cut, then you know that it is very different from water!



[Figure 3]

Water: Water is odorless and colorless. We drink it, bathe in it, and use it to wash our clothes. In fact, we can't live without it. Hydrogen Peroxide: Hydrogen peroxide is also odorless and colorless. It's used as an antiseptic to kill germs on cuts. It's also used as bleach to remove color form hair.

Q: Read the **Figure** below about carbon dioxide (CO_2) and carbon monoxide (CO). Both compounds consist of carbon and oxygen, but in different ratios. How can you tell that carbon dioxide and carbon monoxide are different compounds?

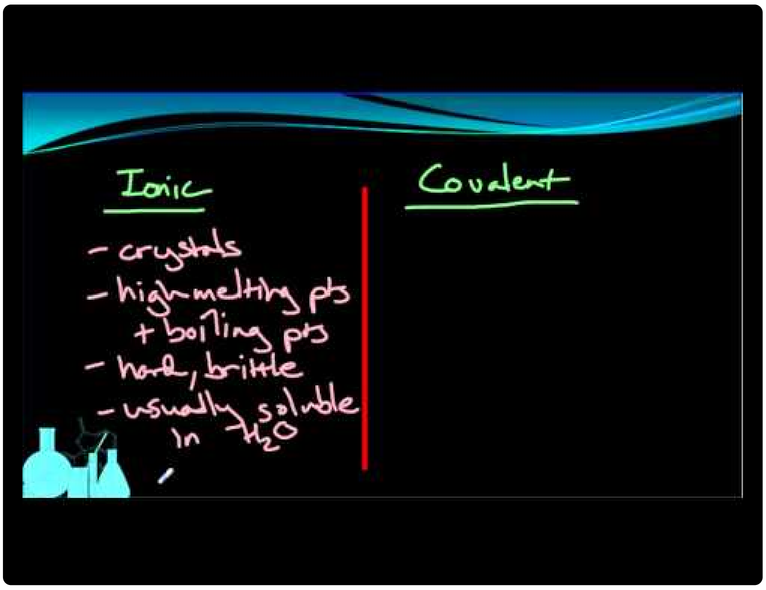
A: You can tell that they are different compounds from their very different properties. Carbon dioxide is a harmless gas that living things add to the atmosphere during respiration. Carbon monoxide is a deadly gas that can quickly kill people if it becomes too concentrated in the air.

[Figure 4]

Carbon Dioxide: Every time you exhale, you release carbon dioxide into the air. It's an odorless, colorless gas. Carbon dioxide contributes to global climate change, but it isn't directly harmful to human health. Carbon Monoxide: Carbon monoxide is produced when matter burns. It's a colorless, odorless gas that is very harmful to human health. In fact, it can kill people in minutes. Because you can't see or smell carbon monoxide, it must be detected with an alarm.

Types of Compounds

There are two basic types of compounds that differ in the nature of the bonds that hold their atoms or ions together. They are covalent and ionic compounds. Both types are described below.



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- Covalent compounds consist of atoms that are held together by covalent bonds. These bonds form between nonmetals that share valence electrons. Covalent compounds exist as individual molecules. Water is an example of a covalent compound.

- Ionic compounds consist of ions that are held together by ionic bonds. These bonds form when metals transfer electrons to nonmetals. Ionic compounds exist as a matrix of many ions, called a crystal. Sodium chloride (table salt) is an example of an ionic compound.

Summary

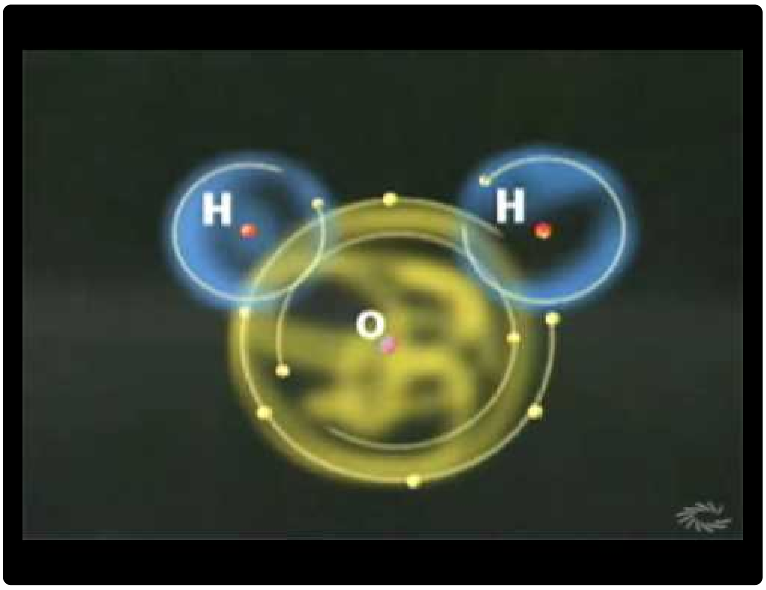
- A compound is a unique substance that forms when two or more elements combine chemically.
- A compound always consists of the same elements in the same ratio. If the same elements combine in different ratios, they form different compounds.
- Types of compounds include covalent and ionic compounds. They differ in the nature of the bonds that hold their atoms or ions together.

Review

1. What is a compound?
2. A mixture is a combination of two or more substances in any proportions. An example of a mixture is lemonade, which contains water, lemon juice, and sugar. How do compounds differ from mixtures such as lemonade?
3. Compare and contrast ionic and covalent.

Explore More

Watch the video about compounds, and then answer the questions below.



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1. What force holds together atoms in compounds?

2. Identify at least one property of water that differs from the properties of the elements that form it.
3. Which two elements make up the compound named butane? What is the ratio of these two elements in butane? How would you use chemical symbols to represent butane?

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5.3 Chemical Formula

FlexBooks® 2.0 > American HS Physical Science > Chemical Formula

Last Modified: Oct 17, 2019

[Figure 1]

You can make a simple salad dressing using just the two ingredients pictured above: oil and vinegar. Recipes for oil-and-vinegar salad dressing vary, but they typically include about three parts oil to one part vinegar, or a ratio of 3:1. For example, if you wanted to make a cup of salad dressing, you could mix together $\frac{3}{4}$ cup of oil and $\frac{1}{4}$ cup of vinegar. Chemical compounds also have "ingredients" in a certain ratio. However, unlike oil-and-vinegar salad dressing, a chemical compound always has exactly the same ratio of elements. This ratio can be represented by a chemical formula.

Representing Compounds

In a **chemical formula**, the elements in a compound are represented by their chemical symbols, and the ratio of different elements is represented by subscripts. Consider the compound water as an example. Each water molecule contains two hydrogen atoms and one oxygen atom. Therefore, the chemical formula for water is:

$$H_2O$$

The subscript 2 after the H shows that there are two atoms of hydrogen in the molecule. The O for oxygen has no subscript. When there is just one atom of an element in a molecule, no subscript is used in the chemical formula.

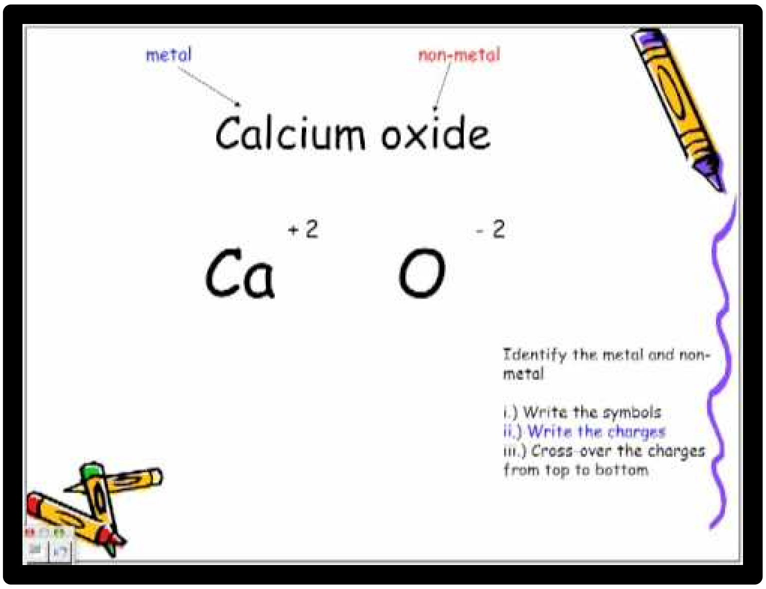
Formulas for Ionic and Covalent Compounds

The **Table** below shows four examples of compounds and their chemical formulas. The first two compounds are ionic compounds, and the second two are covalent compounds. Each formula shows the ratio of ions or atoms that make up the compound.

Name of Compound	Type of Compound	Ratio of Ions or Atoms of Each Element	Chemical Formulas
Sodium chloride	ionic	1 sodium ion (Na^+) 1 chloride ion (Cl^-)	NaCl
Calcium iodide	ionic	1 calcium ion (Ca^{2+}) 2 iodide ions (I^-)	CaI_2
Hydrogen peroxide	covalent	2 hydrogen atoms (H) 2 oxygen atoms (O)	H_2O_2
Carbon dioxide	covalent	1 carbon atom (C) 2 oxygen atoms (O)	CO_2

There is a different rule for writing the chemical formula for each type of compound.

Ionic compounds are compounds in which positive metal ions and negative nonmetal ions are joined by ionic bonds. In these compounds, the chemical symbol for the positive metal ion is written first, followed by the symbol for the negative nonmetal ion.



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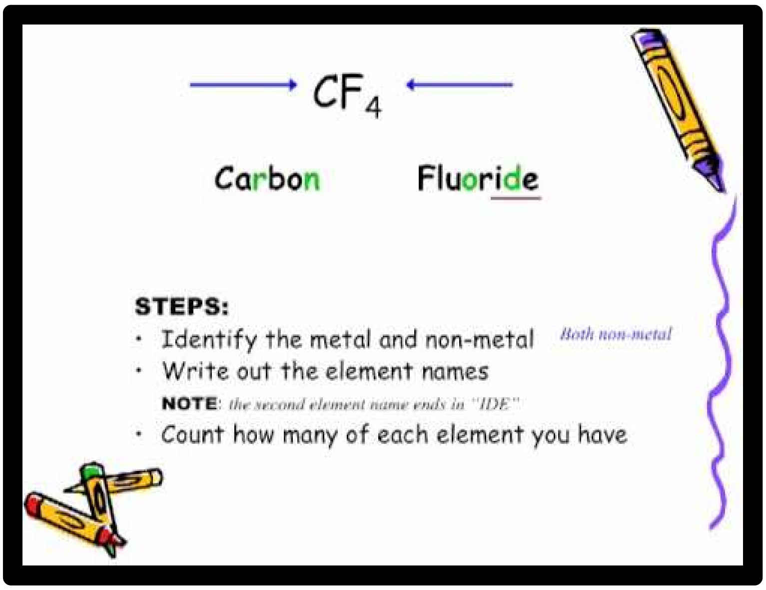
- **Q:** The ionic compound lithium fluoride consists of a ratio of one lithium ion (Li^+) to one fluoride ion (F^-). What is the chemical formula for this compound?
- **A:** The chemical formula is LiF.

Covalent compounds are compounds in which nonmetals are joined by covalent bonds. In these compounds, the element that is farther to the left in the periodic table is written first, followed by the element that is farther to the right. If both elements are in the same group of the periodic table, the one with the higher period number is written first.



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- **Q:** A molecule of the covalent compound nitrogen dioxide consists of one nitrogen atom (N) and two oxygen atoms (O). What is the chemical formula for this compound?
- **A:** The chemical formula is NO_2.

Summary

- Compounds are represented by chemical formulas. Elements in a compound are represented by chemical symbols, and the ratio of different elements is represented by subscripts.
- There are different rules for writing the chemical formulas for ionic and covalent compounds.

Review

1. Complete the following analogy: A chemical symbol is to an element as a chemical formula is to a(n) ____________.
2. The compound sodium sulfide consists of a ratio of two sodium ions (Na^+) to one sulfide ion (S^{2-}). Write the chemical formula for this compound.
3. A molecule of sulfur dioxide consists of one sulfur atom (S) and two oxygen atoms (O). What is the chemical formula for this compound?
4. Identify the ratio of atoms in the compound represented by the following chemical formula: N_2O_5.

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5.4 Ionic Bond

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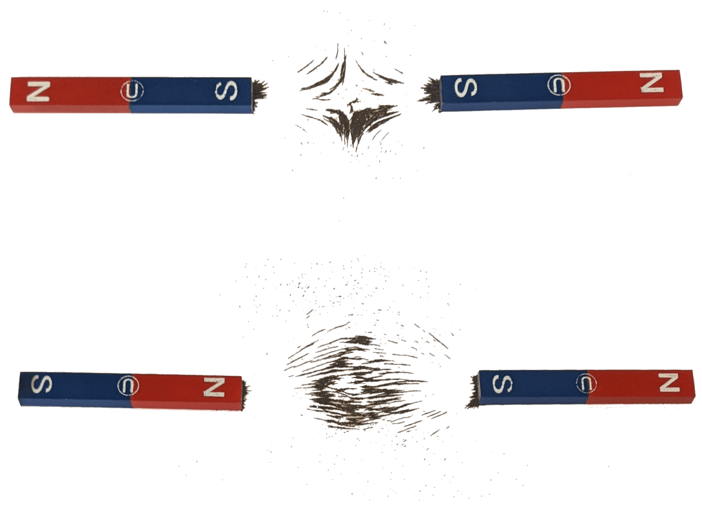
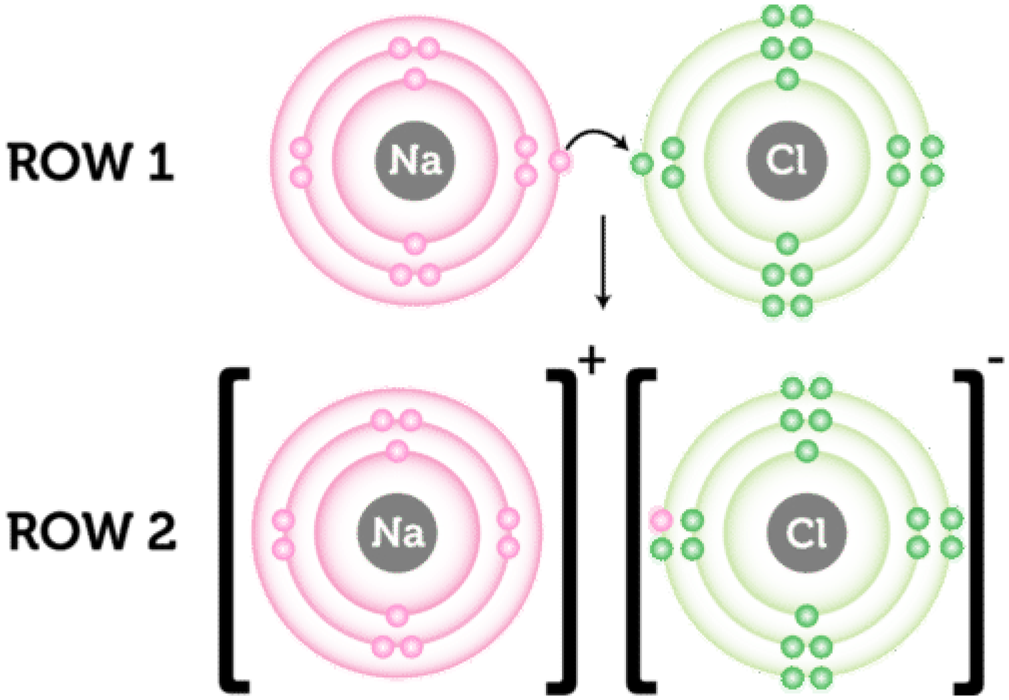


[Figure 1]

Look at the photos of bar magnets in the opening image. At first glance, the two photos look very similar, but they differ in one important way. In the top photo, the south (blue) poles of both magnets are placed close together. In the bottom photo, the north pole of one magnet is placed close to the north (red) pole of the other magnet. Now look closely at the iron filings in the two photos. The ion filings show the force of repulsion between the two north poles in the top photo and the force of attraction between the north and south poles in the bottom photo. Like the poles of magnets, electric charges repel or attract each other. Two positive or two negative charges repel each other, and two opposite charges attract each other. The attraction of opposite electric charges explains how ionic bonds form.

How Ionic Bonds Form

An **ionic bond** is the force of attraction that holds together positive and negative ions. It forms when atoms of a metallic element give up electrons to atoms of a nonmetallic element. The **Figure** below shows how this happens.



[Figure 2]

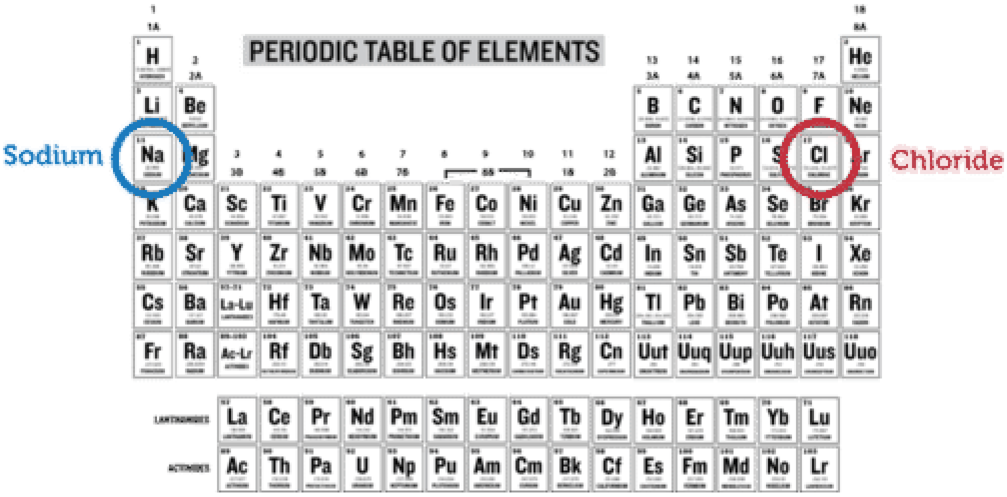
In row 1 of the **Figure** above, an atom of sodium (Na) donates an electron to an atom of chlorine (Cl).

- By losing an electron, the sodium atom becomes a sodium ion. It now has more protons than electrons and a charge of +1. Positive ions such as sodium are given the same name as the element. The chemical symbol has a plus sign to distinguish the ion from an atom of the element. The symbol for a sodium ion is Na^+.
- By gaining an electron, the chlorine atom becomes a chloride ion. It now has more electrons than protons and a charge of -1. Negative ions are named by adding the suffix –*ide* to the first part of the element name. The symbol for chloride is Cl^-.

Sodium and chloride ions have equal but opposite charges. Opposite electric charges attract each other, so sodium and chloride ions cling together in a strong ionic bond. You can see this in row 2 of the **Figure** above. (Brackets separate the ions in the diagram to show that the ions in the compound do not actually share electrons.) When ionic bonds hold ions together, they form an ionic compound. The compound formed from sodium and chloride ions is named sodium chloride. It is commonly called table salt.

Why Ionic Bonds Form

Ionic bonds form only between metals and nonmetals. That's because metals "want" to give up electrons, and nonmetals "want" to gain electrons. Find sodium (Na) in the **Figure** below. Sodium is an alkali metal in group 1. Like all group 1 elements, it has just one valence electron. If sodium loses that one electron, it will have a full outer energy level, which is the most stable arrangement of electrons. Now find fluorine (F) in the periodic table **Figure** below. Fluorine is a halogen in group 17. Like all group 17 elements, fluorine has seven valence electrons. If fluorine gains one electron, it will also have a full outer energy level and the most stable arrangement of electrons.



[Figure 3]

Q: Predict what other elements might form ionic bonds.

A: Metals on the left and in the center of the periodic table form ionic bonds with nonmetals on the right of the periodic table. For example, alkali metals in group 1 form ionic bonds with halogen nonmetals in group 17.

Energy and Ionic Bonds

It takes energy to remove valence electrons from an atom because the force of attraction between the negative electrons and the positive nucleus must be overcome. The amount of energy needed depends on the element. Less energy is needed to remove just one or a few valence electrons than many. This explains why sodium and other alkali metals form positive ions so easily. Less energy is also needed to remove electrons from larger atoms in the same group. For example, in group 1, it takes less energy to remove an electron from francium (Fr) at the bottom of the group than from lithium (Li) at the top of the group (see the **Figure** above). In bigger atoms, valence electrons are farther from the nucleus. As a result, the force of attraction between the valence electrons and the nucleus is weaker.

Q: What do you think happens when an atom gains an electron and becomes a negative ion?

A: Energy is released when an atom gains an electron. Halogens release the most energy when they form ions. As a result, they are very reactive elements.

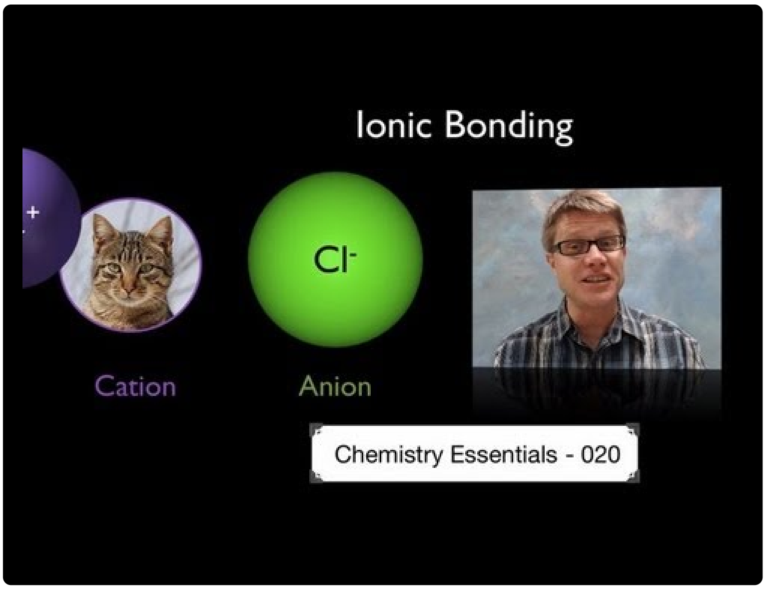
Summary

- An ionic bond is the force of attraction that holds together positive and negative ions. It forms when atoms of a metallic element give up electrons to atoms of a nonmetallic element.
- Ionic bonds form only between metals and nonmetals. That's because metals "want" to give up electrons, and nonmetals "want" to gain electrons.
- It takes energy to remove valence electrons from an atom and form a positive ion. Energy is released when an atom gains valence electrons and forms a negative ion.

Review

1. What is an ionic bond? How does it form?
2. Why do metals lose electrons and nonmetals gain electrons in the formation of ionic bonds?
3. Atoms of lithium (Li) and cesium (Cs) both lose electrons and become positive ions when they from ionic bonds. Which type of atom requires more energy to become an ion? Why?

Resources



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5.5 Covalent Bond

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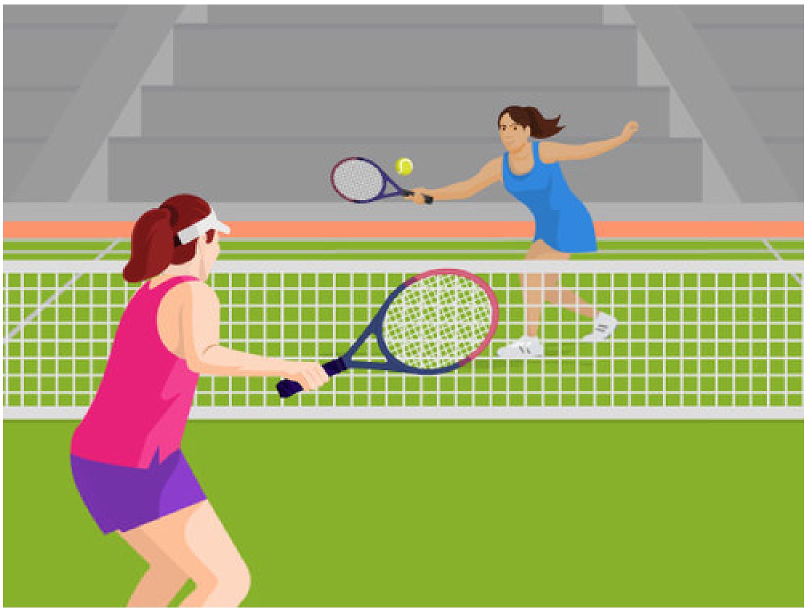


[Figure 1]

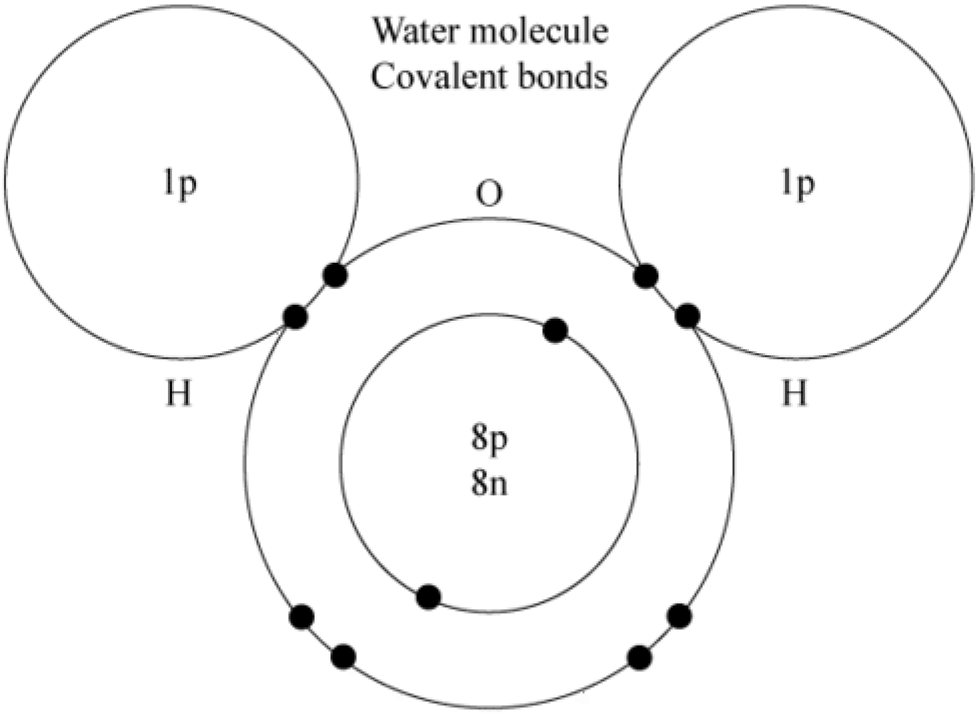
In a tennis match, two players keep hitting the ball back and forth. The ball bounces from one player to the other, over and over again. The ball keeps the players moving together on the court. What if the two players represented the nuclei of two atoms and the ball represented valence electrons? What would the back and forth movement of the ball represent? The answer is a covalent bond.

Sharing Electrons

A **covalent bond** is the force of attraction that holds together two atoms that share a pair of valence electrons. The shared electrons are attracted to the nuclei of both atoms. This forms a molecule consisting of two or more atoms. Covalent bonds form only between atoms of nonmetals.

Covalent Compounds and Diatomic Elements

The two atoms that are held together by a covalent bond may be atoms of the same element or different elements. When atoms of different elements form covalent bonds, a new substance, called a covalent compound, results. Water is an example of a covalent compound. A water molecule is modeled in the **Figure** below. A molecule is the smallest particle of a covalent compound that still has the properties of the compound.

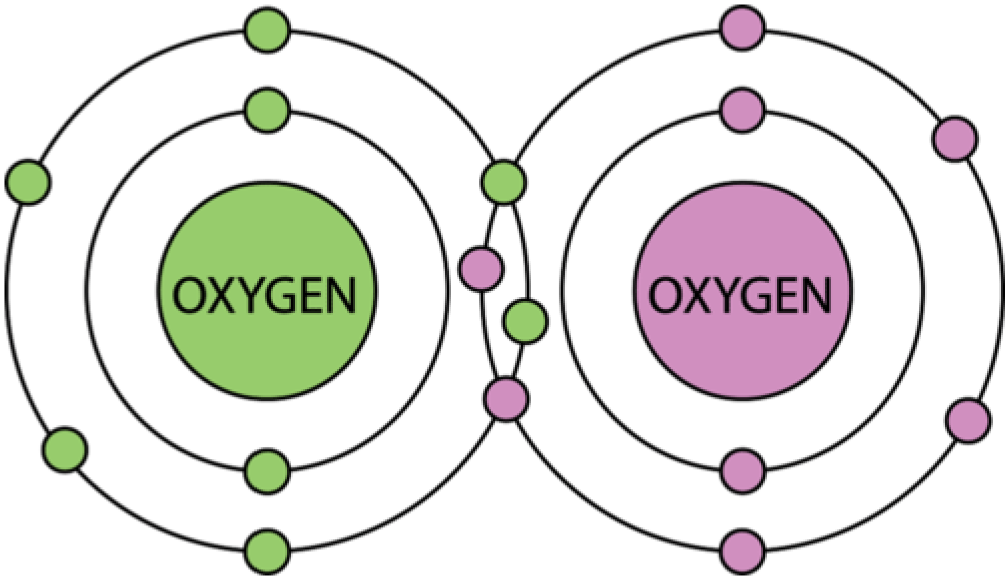


[Figure 2]

Q: How many valence electrons does the oxygen atom (O) share with each hydrogen atom (H)? How many covalent bonds hold the water molecule together?

A: The oxygen atom shares one pair of valence electrons with each hydrogen atom. Each pair of shared electrons represents one covalent bond, so two covalent bonds hold the water molecule together.

The diagram in the **Figure** below shows an example of covalent bonds between two atoms of the same element, in this case two atoms of oxygen. The diagram represents an oxygen molecule, so it's not a new compound. Oxygen normally occurs in diatomic ("two-atom") molecules. Several other elements also occur as diatomic molecules: hydrogen, nitrogen, and all but one of the halogens (fluorine, chlorine, bromine, and iodine).



[Figure 3]

Q: How many electrons do these two oxygen atoms share? How many covalent bonds hold the oxygen molecule together?

A: The two oxygen atoms share two pairs of electrons, so two covalent bonds hold the oxygen molecule together.

Why Covalent Bonds Form

Covalent bonds form because they give atoms a more stable arrangement of electrons. Look at the oxygen atoms in the **Figure** above. Alone, each oxygen atom has six valence electrons. By sharing two pairs of valence electrons, each oxygen atom has a total of eight valence electrons. This fills its outer energy level, giving it the most stable arrangement of electrons. The shared electrons are attracted to both oxygen nuclei, and this force of attraction holds the two atoms together in the oxygen molecule.

Summary

- A covalent bond is the force of attraction that holds together two atoms that share a pair of valence electrons. Covalent bonds form only between atoms of nonmetals.
- The two atoms that are held together in a covalent bond may be atoms of the same element or different elements. When atoms of different elements bond together, it forms a covalent compound.
- Covalent bonds form because the shared electrons fill each atom's outer energy level and this is the most stable arrangement of electrons.

Review

1. What is a covalent bond?
2. Nitrogen is a diatomic element with five valence electrons. Create a model of a molecule of nitrogen.
3. Which of the following represents a covalent compound?

   a. O_2

   b. CO_2

   c. Cl_2

   d. NaCl

Explore More

Watch the video about covalent bonding and then answer the questions below.

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1. How can you tell the number covalent bonds the atoms of an element can form?
2. How many covalent bonds can nitrogen form? How many covalent bonds can chlorine form?
3. How do ionic bonds differ from covalent bonds in terms of how electrons are shared?
4. Why do nonmetals near the right side of the periodic table tend to form diatomic molecules with themselves, like Cl_2 or O_2?

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5.6 Polarity

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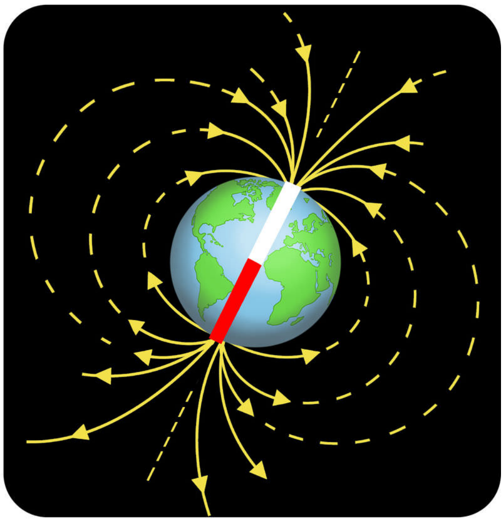
Last Modified: Jan 27, 2020



[Figure 1]

Like the north and south poles of a bar magnet, Earth's north and south magnetic poles—pictured above—are opposites in terms of their magnetic fields. Some types of chemical bonds and chemical compounds have "poles" similar to a bar magnet as well. But in the case of chemical bonds and compounds, the poles are opposites in terms of their electric charge. These bonds and compounds are described as polar.

Polar and Nonpolar Covalent Bonds

Covalent bonds are chemical bonds between atoms of nonmetals that share valence electrons. In some covalent bonds, electrons are not shared equally between the two atoms. These are called **polar** covalent bonds. The **Figure** below shows the polar bonds in a water molecule (H_2O). The oxygen atom attracts the shared electrons more strongly than the hydrogen atoms do because the nucleus of the oxygen atom has more positively charged protons. As a result, the oxygen atom becomes slightly negative in charge, and the hydrogen atoms become slightly positive in charge.

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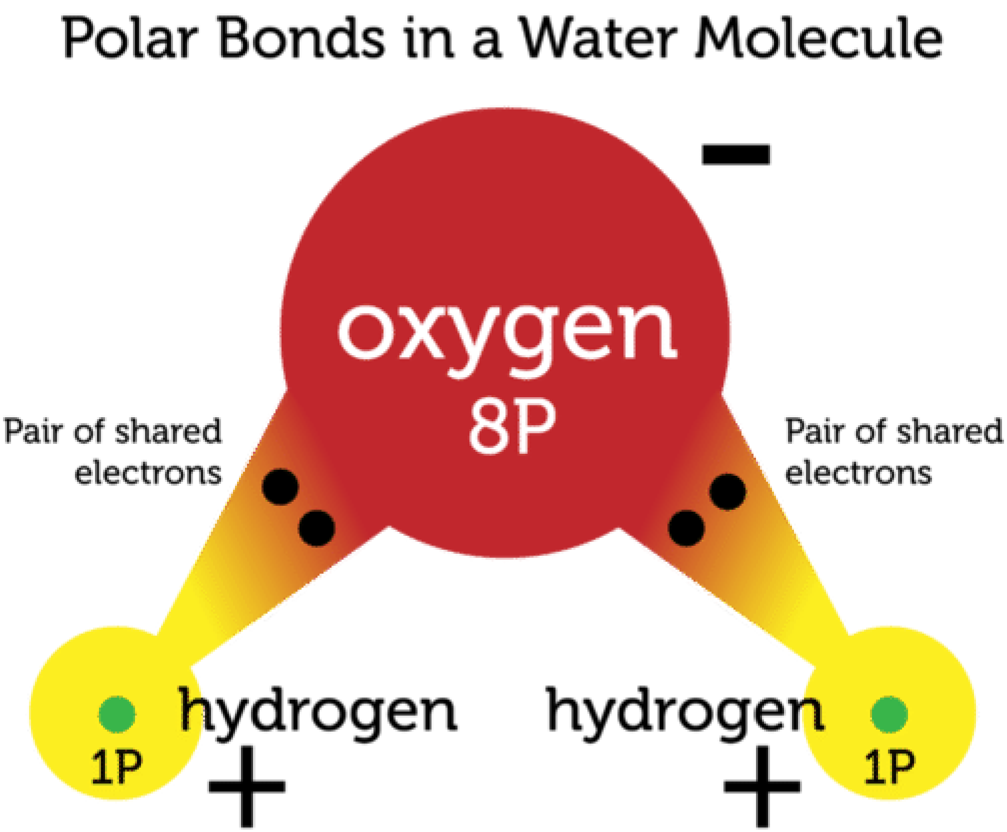
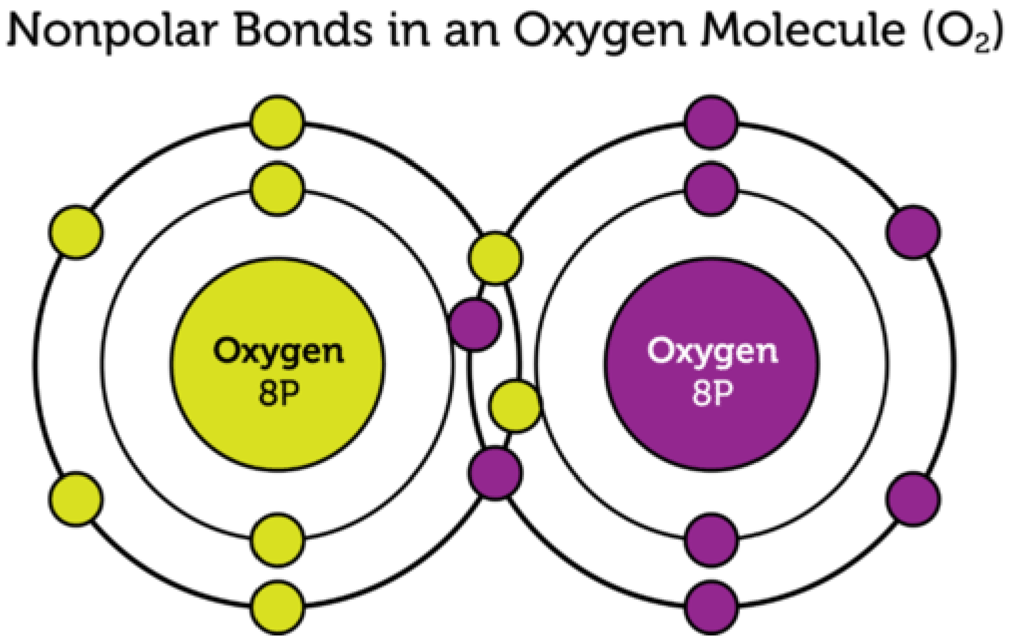


[Figure 2]

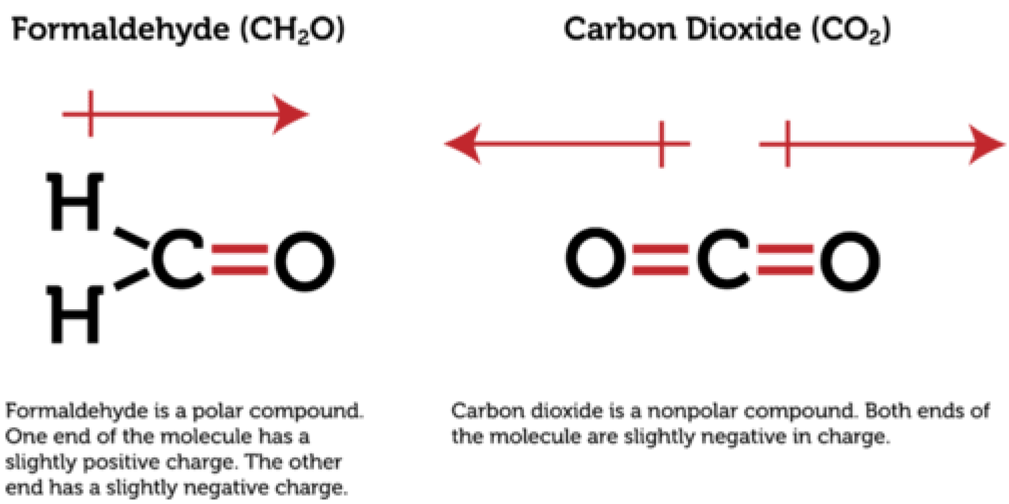
In other covalent bonds, electrons are shared equally. These bonds are called **nonpolar** covalent bonds. Neither atom attracts the shared electrons more strongly. As a result, the atoms remain neutral in charge. The oxygen (O_2) molecule in the **Figure** below has two nonpolar bonds. The two oxygen nuclei have an equal force of attraction for their four shared electrons.



[Figure 3]

Polar and Nonpolar Covalent Compounds

A covalent compound is a compound in which atoms are held together by covalent bonds. If the covalent bonds are polar, then the covalent compound as a whole may be polar. A polar covalent compound is one in which there is a slight difference in electric charge between opposite sides of the molecule. All polar compounds contain polar bonds. But having polar bonds does not necessarily result in a polar compound. It depends on how the atoms are arranged. This is illustrated in the **Figure** below. In both molecules, the oxygen atoms attract electrons more strongly than the carbon or hydrogen atoms do, so both molecules have polar bonds. However, only formaldehyde is a polar compound. Carbon dioxide is nonpolar.



[Figure 4]

Q: Why is carbon dioxide nonpolar?

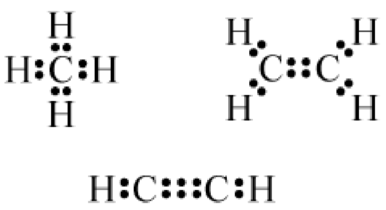
A: The symmetrical arrangement of atoms in carbon dioxide results in opposites sides of the molecule having the same charge.

Summary

- In polar covalent bonds, electrons are not shared equally between the two atoms, so one atom is slightly negative in charge and one is slightly positive in charge. In nonpolar covalent bonds, electrons are shared equally so the atoms remain neutral in charge.
- Covalent compounds with polar bonds may be polar or nonpolar, depending on their arrangement of atoms.

Review

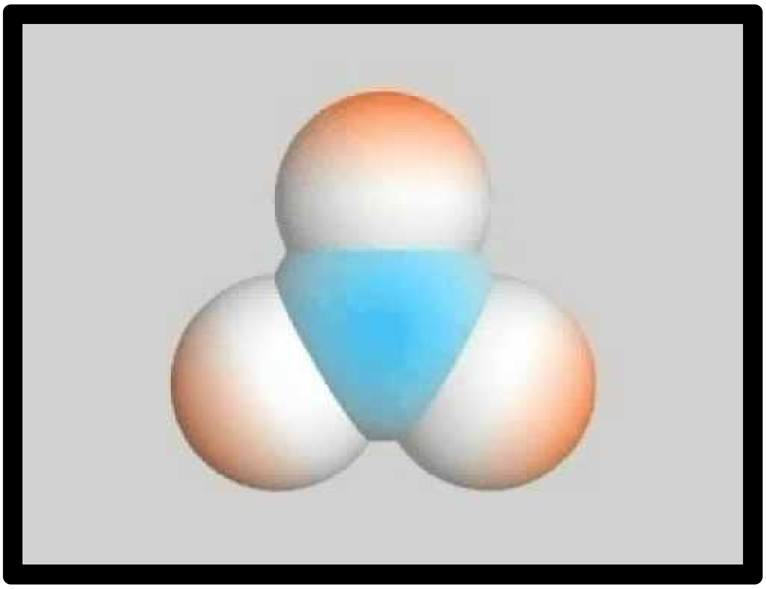
1. What are polar covalent bonds? Give an example.
2. Why are the covalent bonds in an oxygen molecule (O_2) nonpolar?
3. Carbon (C) atoms attract electrons a little more strongly than hydrogen (H) atoms do. The illustration below shows three covalent compounds containing only carbon and hydrogen atoms. Are the compounds polar or nonpolar? Explain.



[Figure 5]

Explore More

Watch the video about polarity of molecules, and then answer the questions below.



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1. When does a polar covalent bond always produce a polar covalent compound?
2. If a covalent compound has polar bonds and more than two atoms, what determines whether the compound is polar?
3. Is water a polar compound? Why or why not?
4. Which of the following compounds are polar?

   a. BF_3

   b. NH_3

   c. CCl_4

   d. $CHCl_3$

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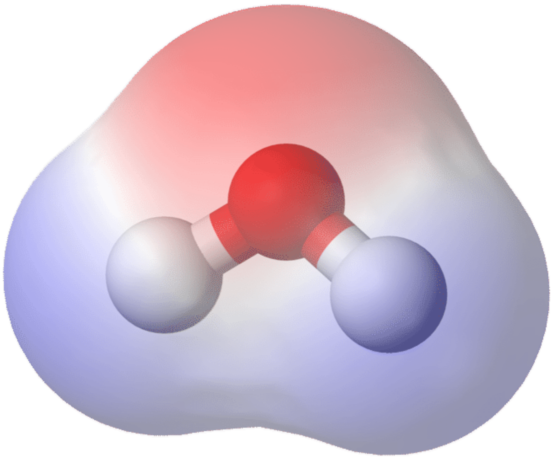
5.7 Hydrogen Bond

FlexBooks® 2.0 > American HS Physical Science > Hydrogen Bond

Last Modified: Jan 27, 2020



[Figure 1]

The colorful red and blue model in the opening image represents a water molecule. The molecule's one oxygen atom is colored red, and its two hydrogen atoms are colored blue. Can you guess why? The red color represents negative electric charge, and the blue color represents positive electric charge. The colors show that water is a polar compound.

What Are Polar Compounds?

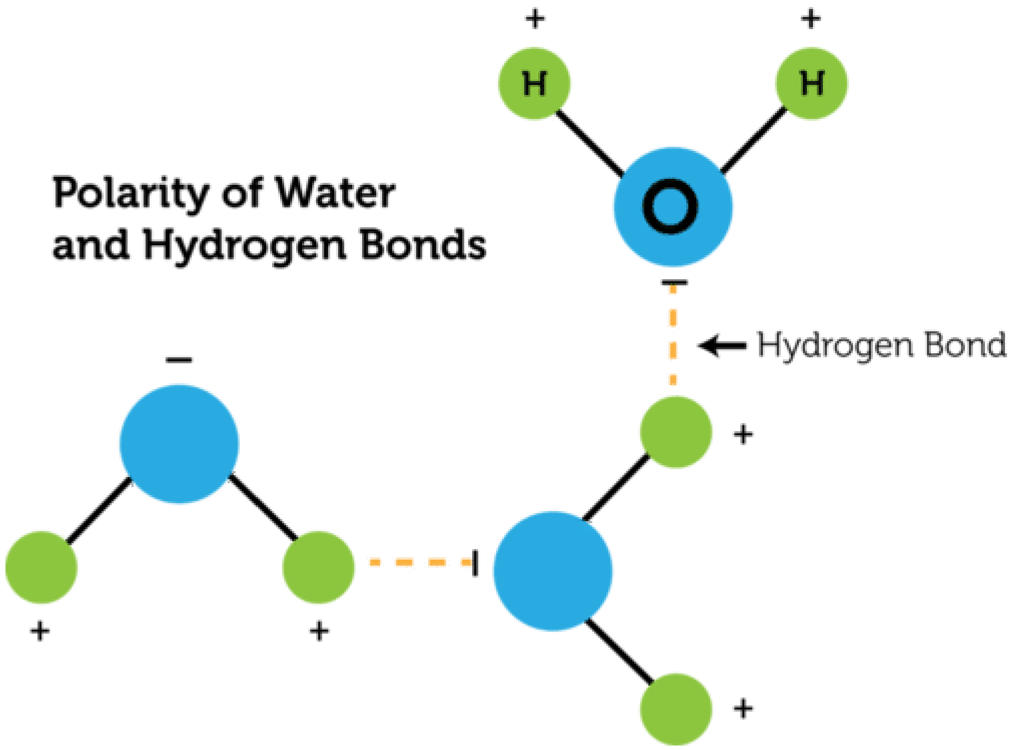
Polar compounds, such as water, are compounds that have a partial negative charge on one side of each molecule and a partial positive charge on the other side. All polar compounds contain polar bonds (although not all compounds that contain polar bonds are polar.) In a polar bond, two atoms share electrons unequally. One atom attracts the shared electrons more strongly, so it has a partial negative charge. The other atom attracts the shared electrons less strongly, so it is has a partial positive charge. In a water molecule, the oxygen atom attracts the shared electrons more strongly than the hydrogen atoms do. This explains why the oxygen side of the water molecule has a partial negative charge and the hydrogen side of the molecule has a partial positive charge.

Q: If a molecule is polar, how might this affect its interactions with nearby molecules of the same compound?

A: Opposite charges on different molecules of the same compound might cause the molecules to be attracted to each other.

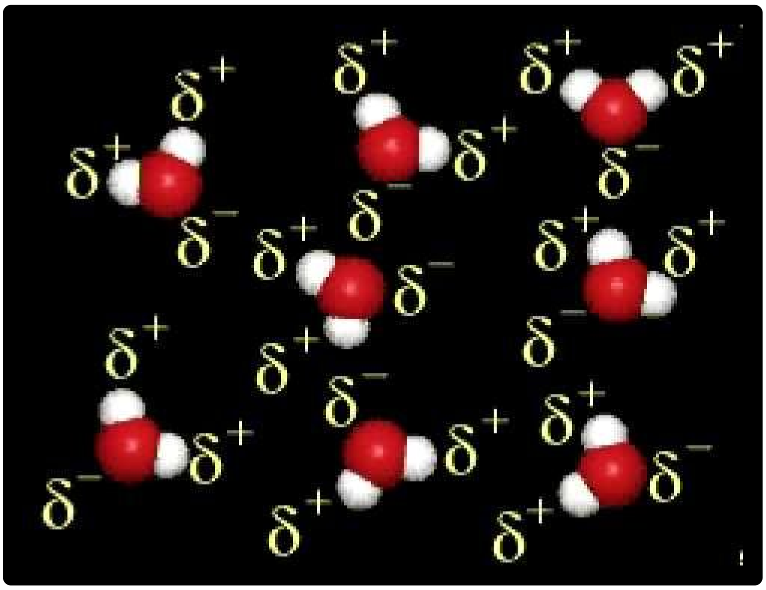
Hydrogen Bonding

Because of water's polarity, individual water molecules are attracted to one another. You can see this in the **Figure** below. The positively charged hydrogen side of one water molecule is attracted to the negatively charged oxygen side of a nearby water molecule. This force of attraction is called a **hydrogen bond**.



[Figure 2]

Hydrogen bonds are intermolecular forces ("between-molecule"), rather than intramolecular ("within-molecule") forces. They occur not only between water molecules, but between any polar molecules containing an H−N, H−O, or H−F bond. The positive hydrogen atoms are attracted to negative atoms (nitrogen, hydrogen, or fluorine) in nearby molecules. These bonds are extremely polar because of the high electronegativity difference between the atoms. This strong polarity causes very strong dipole-dipole interactions between molecules, called hydrogen bonding. Hydrogen bonds are weaker than chemical bonds. For example, they are much weaker than the covalent bonds holding atoms together within molecules of covalent compounds.



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Hydrogen Bonds and Changes of State

Changes of state from solid to liquid and from liquid to gas occur when matter gains energy. The energy allows individual molecules to separate and move apart from one another. It takes more energy to bring about these changes of state for polar molecules. Although hydrogen bonds are weak, they add to the energy needed for molecules to move apart from one another, so it takes higher temperatures for these changes of state to occur in polar compounds. This explains why polar compounds have relatively high melting and boiling points. The **Table** below compares melting and boiling points for some polar and nonpolar covalent compounds.

Name of Compound (Chemical Formula)	Polar or Nonpolar?	Melting Point(°C)	Boiling Point (°C)
Methane (CH_4)	nonpolar	-182	-162
Ethylene (C_2H_2)	nonpolar	-169	-104
Ammonia (NH_3)	polar	-78	-33
Water (H_2O)	polar	0	100

Q: Which compound in the **Table** above do you think is more polar, ammonia or water?

A: Water is more polar than ammonia. Its strong polarity explains why its melting and boiling points are high even for a polar covalent compound.

Summary

- Polar covalent compounds have molecules with a partial negative charge on one side and a partial positive charge on the other side. This occurs because the compounds contain polar bonds. In a polar bond, one atom attracts the shared electrons more strongly than the other atom does.

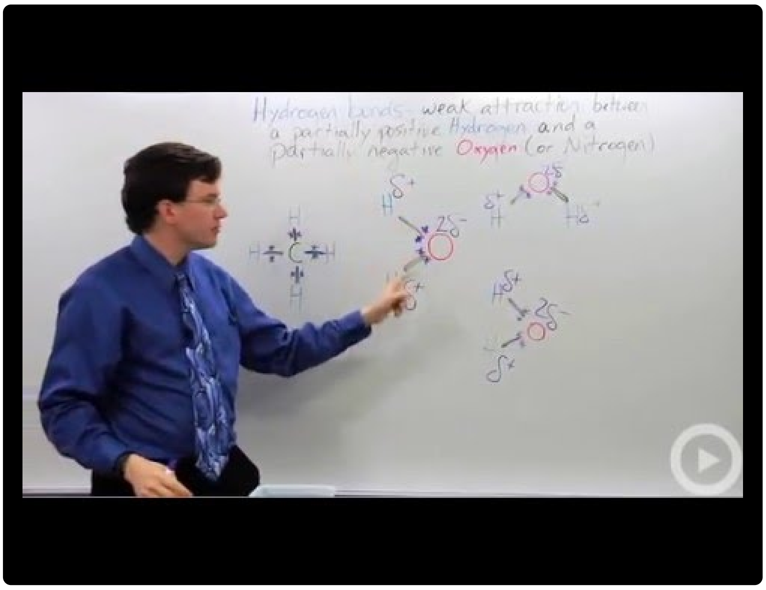
- In some polar molecules that contain hydrogen atoms, the partial positive charge of the hydrogen atoms of one molecule are attracted to the partial negative charge of an atom of a nearby molecule. This force of attraction is called a hydrogen bond.
- Hydrogen bonds are relatively weak, but they add to the energy needed for molecules to move apart from each other when matter changes state from a solid to a liquid or from a liquid to a gas. This explains why polar covalent compounds have relatively high melting and boiling points.

Review

1. What are polar covalent compounds?
2. Define hydrogen bond.
3. Explain why hydrogen bonds increase melting and boiling points of polar covalent compounds such as water.

Explore More

Watch the video about hydrogen bonds and then answer the questions below.



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1. What is electronegativity?
2. In water molecules, why do shared electrons spend more time orbiting the oxygen atom than the hydrogen atoms?
3. Hydrogen forms hydrogen bonds with oxygen. What is another element besides oxygen that may be involved in hydrogen bonds?

4. Water has the properties of cohesion and adhesion. Define these two properties, and explain why they occur in water.
5. Why are hydrogen bonds extremely important in biology?

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5.8 Metallic Bond

FlexBooks® 2.0 > American HS Physical Science > Metallic Bond

Last Modified: Sep 11, 2021

[Figure 1]

The thick, rigid trunk of the oak tree on the left might crack and break in a strong wind. The slim, flexible trunk of the willow tree on the right might bend without breaking. In one way, metals are like willow trees. They can bend without breaking. That's because metals form special bonds called metallic bonds.

What Are Metallic Bonds?

Metallic bonds are forces of attraction between positive metal ions and the valence electrons that are constantly moving around them (see the **Figure** below). The valence electrons include their own and those of other, nearby ions of the same metal. The valence electrons of metals move freely in this way because metals have relatively low electronegativity, or attraction to electrons. The positive metal ions form a lattice-like structure held together by all the metallic bonds.

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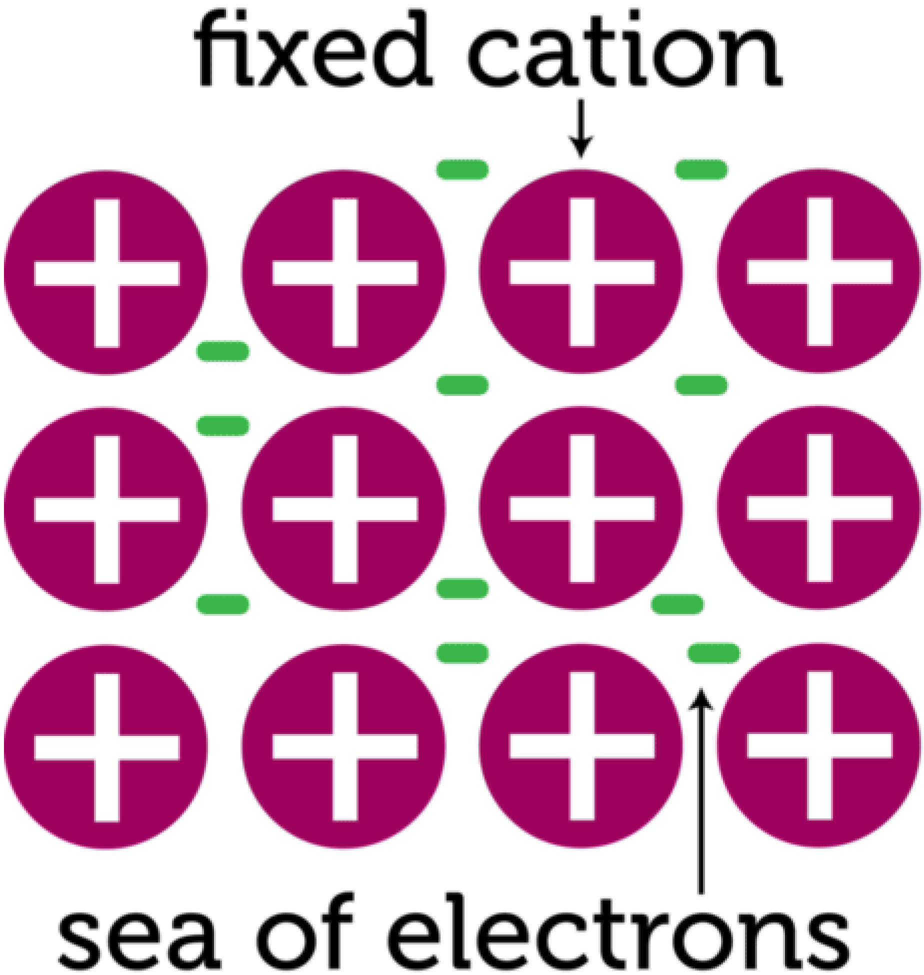


[Figure 2]

Metallic bonds.

Q: Why do metallic bonds form only in elements that are metals? Why don't similar bonds form in elements that are nonmetals?

A: Metal atoms readily give up valence electrons and become positive ions whenever they form bonds. When nonmetals bond together, the atoms share valence electrons and do not become ions. For example, when oxygen atoms bond together they form oxygen molecules in which two oxygen atoms share two pairs of valence electrons equally, so neither atom becomes charged.

Metallic Bonds and the Properties of Metals

The valence electrons surrounding metal ions are constantly moving. This makes metals good conductors of electricity. The lattice-like structure of metal ions is strong but quite flexible. This allows metals to bend without breaking. Metals are both ductile (can be shaped into wires) and malleable (can be shaped into thin sheets).

Q: Look at the metalworker in the **Figure** below. He's hammering a piece of hot iron in order to shape it. Why doesn't the iron crack when he hits it?

A: The iron ions can move within the "sea" of electrons around them. They can shift a little closer together or farther apart without breaking the metallic bonds between them. Therefore, the metal can bend rather than crack when the hammer hits it.

[Figure 3]

Metal worker shaping iron metal.

Summary

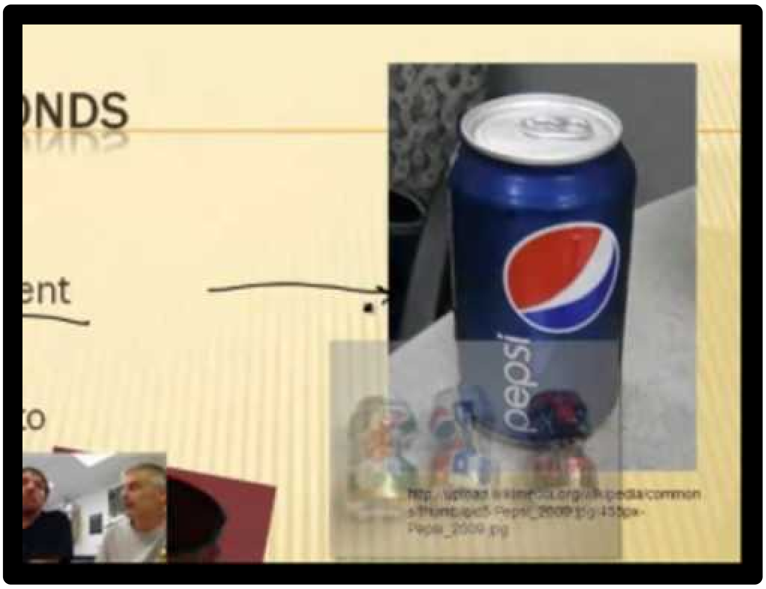
- Metallic bonds are the force of attraction between positive metal ions and the valence electrons that are constantly moving around them. The ions form a lattice-like structure held together by the metallic bonds.
- Metallic bonds explain why metals can conduct electricity and bend without breaking.

Review

1. What are metallic bonds?
2. How do metallic bonds relate to the properties of metals?
3. The iron in the metal working picture above (**Figure** above) is red hot. Infer why the metalworker heats the iron when he shapes it.

Explore More

Watch the video about metallic bonds at the following URL, and then answer the questions below.



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1. What is electricity? Why can metals conduct electricity?
2. What can metals conduct besides electricity?
3. How could you use an empty pop can to demonstrate that metals can bend without breaking?

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5.9 Chemical Reaction

FlexBooks® 2.0 > American HS Physical Science > Chemical Reaction

Last Modified: Feb 11, 2020

[Figure 1]

Does the term *chemical reaction* bring to mind an image like this one? In the picture, a chemist is mixing chemicals in a lab. Many chemical reactions take place in labs. However, most chemical reactions do not. Where do they occur? They happen in the world all around you. They even happen inside your own body. In fact, you are alive only because of the many chemical reactions that constantly take place inside your cells.

What Is a Chemical Reaction?

A **chemical reaction** is a process in which some substances change into different substances. Substances that start a chemical reaction are called reactants. Substances that are produced in the reaction are called products. Reactants and products can be elements or compounds. Chemical reactions are represented by chemical equations, like the one below, in which reactants (on the left) are connected by an arrow to products (on the right).

Reactants → Products

Chemical reactions may occur quickly or slowly. Look at the two pictures in the **Figure** below. Both represent chemical reactions. In the picture on the left, a reaction inside a fire extinguisher causes foam to shoot out of the extinguisher. This reaction occurs almost instantly. In the picture on the right, a reaction causes the iron tool to turn to rust. This reaction occurs very slowly. In fact, it might take many years for all of the iron in the tool to turn to rust.

[Figure 2]

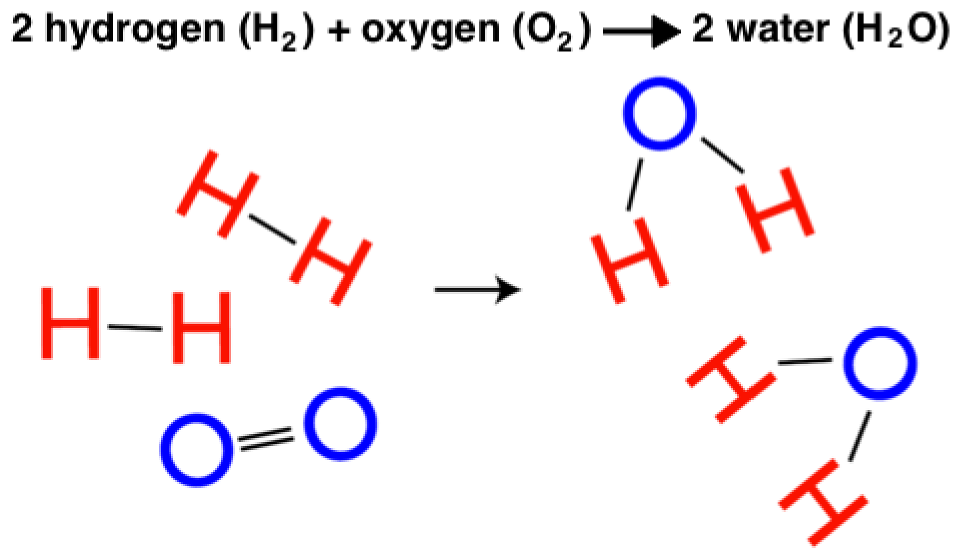
Q: What happens during a chemical reaction? Where do the reactants go, and where do the products come from?

A: During a chemical reaction, chemical changes take place. Some chemical bonds break and new chemical bonds form.

Same Atoms, New Bonds

The reactants and products in a chemical reaction contain the same atoms, but they are rearranged during the reaction. As a result, the atoms are in different combinations in the products than they were in the reactants. This happens because chemical bonds break in the reactants and new chemical bonds form in the products.

Consider the chemical reaction in which water forms from oxygen and hydrogen gases. The **Figure** below represents this reaction. Bonds break in molecules of hydrogen and oxygen, and then new bonds form in molecules of water. In both reactants and products there are four hydrogen atoms and two oxygen atoms, but the atoms are combined differently in water.



[Figure 3]

Types of Chemical Reactions

The chemical reaction in the **Figure** above, in which water forms from hydrogen and oxygen, is an example of a synthesis reaction. In this type of reaction, two or more reactants combine to synthesize a single product. There are several other types of chemical reactions, including decomposition, replacement, and combustion reactions. The **Table** below compares these four types of chemical reactions.

Type of Reaction	General Equation	Example
Synthesis	A+B → C	$2Na + Cl_2 \rightarrow 2NaCl$
Decomposition	AB → A + B	$2H_2O \rightarrow 2H_2 + O_2$
Single Replacement	A+BC → B+ AC	$2K + 2H_2O \rightarrow 2KOH + H_2$
Double Replacement	AB+ CD → AD + CB	NaCl+ AgF → NaF + AgCl
Combustion	fuel + oxygen → carbon dioxide + water	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Q: The burning of wood is a chemical reaction. Which type of reaction is it?

A: The burning of wood—or of anything else—is a combustion reaction. In the combustion example in the table, the fuel is methane gas (CH_4).

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Energy In and Energy Out

All chemical reactions involve energy. Energy is used to break bonds in reactants, and energy is released when new bonds form in products. In terms of energy, there are two types of chemical reactions: endothermic reactions and exothermic reactions.

- In exothermic reactions, more energy is released when bonds form in products than is used to break bonds in reactants. These reactions release energy to the environment, often in the form of heat or light.
- In endothermic reactions, more energy is used to break bonds in reactants than is released when bonds form in products. These reactions absorb energy from the environment.

Q: When it comes to energy, which type of reaction is the burning of wood? Is it an endothermic reaction or an exothermic reaction? How can you tell?

A: The burning of wood is an exothermic reaction. You can tell by the heat and light energy given off by a wood fire.

Summary

- A chemical reaction is a process in which some substances, called reactants, change into different substances, called products. During the reaction, chemical bonds break in the reactants and new chemical bonds form in the products.
- Types of chemical reactions include synthesis, decomposition, replacement, and combustion reactions.

- All chemical reactions involve energy. Exothermic reactions release more energy than they use. Endothermic reactions use more energy than they release.

Review

1. What is a chemical reaction?
2. Write a general chemical equation that shows the relationship of products to reactants in a chemical reaction.
3. Contrast exothermic and endothermic chemical reactions.

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5.10 Reactants and Products

FlexBooks® 2.0 > American HS Physical Science > Reactants and Products

Last Modified: Jun 07, 2021

[Figure 1]

Did you ever wonder what happens to a candle when it burns? A candle burning is a chemical change in matter. In a chemical change, one type of matter changes into a different type of matter, with different chemical properties. Chemical changes occur because of chemical reactions.

From Reactants to Products

All chemical reactions—including a candle burning—involve reactants and products.

- **Reactants** are substances that start a chemical reaction.
- **Products** are substances that are produced in the reaction.

When a candle burns, the reactants are fuel (the candlewick and wax) and oxygen (in the air). The products are carbon dioxide gas and water vapor.

Relating Reactants and Products

The relationship between reactants and products in a chemical reaction can be represented by a chemical equation that has this general form:

Reactants → Products

The arrow (→) shows the direction in which the reaction occurs. In many reactions, the reaction also occurs in the opposite direction. This is represented with another arrow pointing in the opposite direction (←).

Q: Write a general chemical equation for the reaction that occurs when a fuel such as candle wax burns.

A: The burning of fuel is a combustion reaction. The general equation for this type of reaction is:

$$\text{Fuel} + O_2 \rightarrow CO_2 + H_2O$$

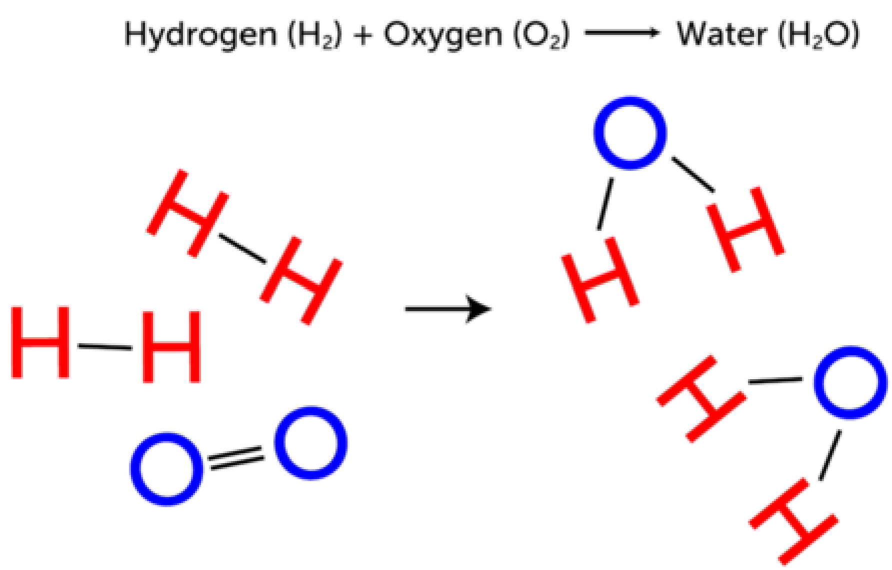
Q: How do the reactants in a chemical reaction turn into the products?

A: Bonds break in the reactants, and new bonds form in the products.

Breaking and Making Chemical Bonds

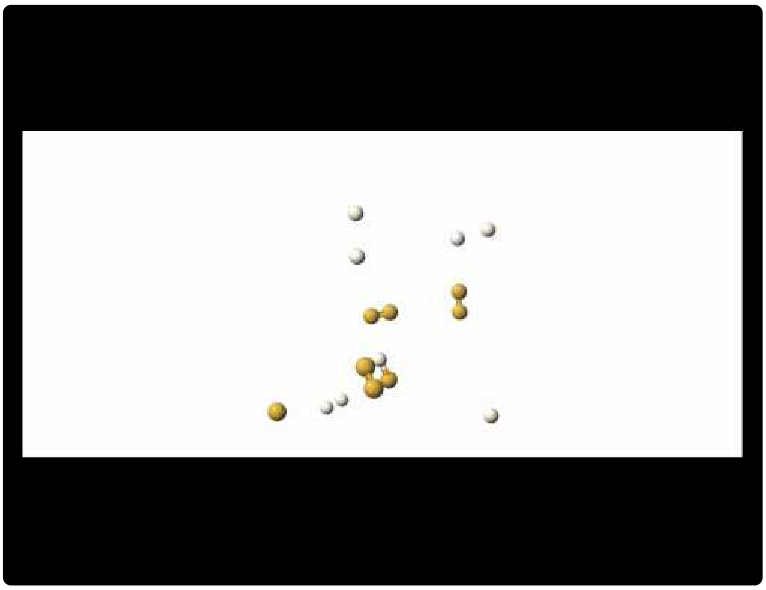
The reactants and products in a chemical reaction contain the same atoms, but they are rearranged during the reaction. As a result, the atoms end up in different combinations in the products. This makes the products new substances that are chemically different from the reactants.

Consider the example of water forming from hydrogen and oxygen. Both hydrogen and oxygen gases exist as diatomic ("two-atom") molecules. These molecules are the reactants in the reaction. The **Figure** below shows that bonds must break to separate the atoms in the hydrogen and oxygen molecules. Then new bonds must form between hydrogen and oxygen atoms to form water molecules. The water molecules are the products of the reaction.



[Figure 2]

Q: Watch the animation of a similar chemical reaction at the following URL. Can you identify the reactants and the product in the reaction?



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A: The reactants are hydrogen (H_2) and fluorine (F_2), and the product is hydrogen fluoride (HF).

Summary

- All chemical reactions involve both reactants and products. Reactants are substances that start a chemical reaction, and products are substances that are produced in the reaction.
- A chemical reaction can be represented by the general chemical equation:

$$\text{Reactants} \rightarrow \text{Products}$$

- Bonds break and reform during chemical reactions. Reactants and products contain the same atoms, but they are rearranged during the reaction, so reactants and products are different substances.

Review

1. Identify the reactants and products in the following chemical reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

2. How do reactants change into products during a chemical reaction?

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5.11 Signs of Chemical Reactions

FlexBooks® 2.0 > American HS Physical Science > Signs of Chemical Reactions

Last Modified: May 26, 2021

[Figure 1]

Look at the girl's hair in the photo above. It has obviously changed color. The process in which this occurred involved chemical reactions. How do you know that chemical reactions have occurred? The change in color is the most obvious clue.

Signs of Chemical Reactions

A change in color is just one of several potential signs that a chemical reaction has occurred. Other potential signs include:

- **Change in temperature.** Heat is released or absorbed during the reaction.
- **Formation of a gas.** Gas bubbles are released during the reaction.
- **Formation of a solid.** A solid settles out of a liquid solution. The solid is called a precipitate.

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Examples of Chemical Reactions

Look carefully at the **Figures** below, below, and below. All of the photos demonstrate chemical reactions. For each photo, identify a sign that one or more chemical reactions have taken place.

[Figure 2]

A burning campfire can warm you up on a cold day.

[Figure 3]

Dissolving an antacid tablet in water produces a fizzy drink.

[Figure 4]

Adding acid to milk produces solid curds of cottage cheese.

Q: Did you ever make a “volcano” by pouring vinegar over a “mountain” of baking soda? If you did, you probably saw the mixture bubble up and foam over. Did a chemical reaction occur? How do you know?

A: Yes, a chemical reaction occurred. You know because the bubbles are evidence that a gas has been produced and production of a gas is a sign of a chemical reaction.

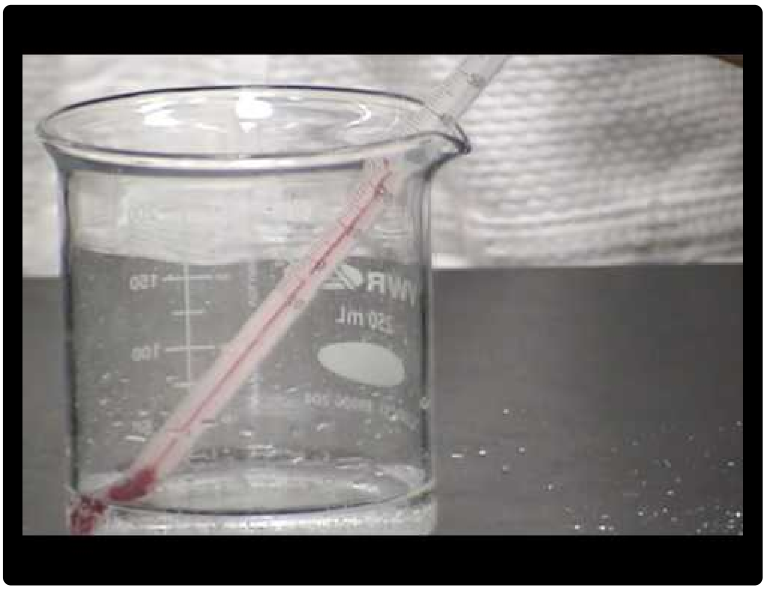
Summary

- Potential signs that chemical reactions have occurred include a change in color, change in temperature, formation of a gas, and formation of a precipitate.

Review

1. How can you tell whether a change in matter is caused by a chemical reaction?
2. When water freezes, it changes to ice. Is this a chemical reaction? Why or why not?

Resources



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5.12 Conservation of Mass in Chemical Reactions

FlexBooks® 2.0 > American HS Physical Science > Conservation of Mass in Chemical Reactions

Last Modified: Apr 19, 2019

[Figure 1]

These vividly colored maple leaves were all bright green during the summer. Every fall, leaves of maple trees change to brilliant red, orange, and yellow colors. A change of color is a sign that a chemical change has taken place. Maple leaves change color because of chemical reactions.

Chemical Reactions and Balanced Equations

A chemical reaction occurs when some substances change chemically to other substances. Chemical reactions are represented by chemical equations. Consider a simple chemical reaction, the burning of methane. In this reaction, methane (CH_4) combines with oxygen (O_2) in the air and produces carbon dioxide (CO_2) and water vapor (H_2O). The reaction is represented by the following chemical equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

This equation shows that one molecule of methane combines with two molecules of oxygen to produce one molecule of carbon dioxide and two molecules of water vapor. All chemical equations must be balanced. This means that the same number of each type of atom must appear on both sides of the arrow.

Q: Is the chemical equation for the burning of methane balanced? Count the atoms of each type on both sides of the arrow to find out.

A: Yes, the equation is balanced. There is one carbon atom on both sides of the arrow. There are also four hydrogen atoms and four oxygen atoms on both sides of the arrow.

Following the Law

Why must chemical equations be balanced? It's the law! Matter cannot be created or destroyed in chemical reactions. This is the **law of conservation of mass**. In every chemical reaction, the same mass of matter must end up in the products as started in the reactants. Balanced chemical equations show that mass is conserved in chemical reactions.

Lavoisier and Conservation of Mass

How do scientists know that mass is always conserved in chemical reactions? Careful experiments in the 1700s by a French chemist named Antoine Lavoisier led to this conclusion. Lavoisier carefully measured the mass of reactants and products in many different chemical reactions. He carried out the reactions inside a sealed jar, like the one in the **Figure** below. In every case, the total mass of the jar and its contents was the same after the reaction as it was before the reaction took place. This showed that matter was neither created nor destroyed in the reactions. Another outcome of Lavoisier's research was the discovery of oxygen.

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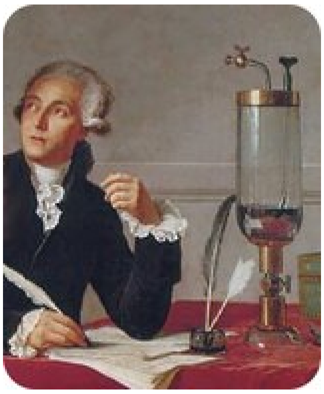

[Figure 2]

Antoine Lavoisier.

Q: Lavoisier carried out his experiments inside a sealed glass jar. Why was sealing the jar important for his results? What might his results have been if he hadn't sealed the jar?

A: Sealing the jar was important so that any gases produced in the reactions were captured and could be measured. If he hadn't sealed the jar, gases might have escaped detection. Then his results would have shown that there was less mass after the reactions than before. In other words, he would not have been able to conclude that mass is conserved in chemical reactions.

Summary

- A chemical reaction occurs when some substances change chemically to other substances. Chemical reactions are represented by chemical equations.
- All chemical equations must be balanced because matter cannot be created or destroyed in chemical reactions.
- Antoine Lavoisier did careful experiments to discover the law of conservation of mass in chemical reactions.

Review

1. Why must all chemical equations be balanced?
2. How did Lavoisier demonstrate that mass is conserved in chemical reactions?

Explore More

Watch the lab demonstration below, and then answer the questions that follow.

https://flexbooks.ck12.org/flx/render/embeddedobject/82376

1. What reaction is demonstrated in the video?
2. How can you tell that oxygen is used up in the reaction?
3. How can you tell that the product of the reaction is different from the iron that began the reaction?
4. What evidence shows that mass is conserved in the reaction?

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5.13 Balancing Chemical Equations

FlexBooks® 2.0 > American HS Physical Science > Balancing Chemical Equations

Last Modified: Jun 22, 2020

[Figure 1]

The little boy on this seesaw weighs more than the little girl on the other side. That's why his side of the seesaw is on the ground and her side is up in the air. For a seesaw to balance, the two riders must be the same weight. A chemical equation that represents a chemical reaction is a little bit like a seesaw. For a chemical equation to balance, there must be the same number of each type of atom on both sides of the equation.

Writing Chemical Equations

A chemical equation represents the changes that occur during a chemical reaction. A chemical equation has the general form:

Reactants → Products

An example of a simple chemical reaction is the reaction in which hydrogen (H_2) and oxygen (O_2) combine to produce water (H_2O). In this reaction, the reactants are hydrogen and oxygen and the product is water. To write the chemical equation for this reaction, you would start by writing the reactants on the left and the product on the right, with an arrow between them to show the direction in which the reaction occurs:

Equation 1:

$H_2 + O_2 \rightarrow H_2O$

Q: Look closely at equation 1. There's something wrong with it. Do you see what it is?

A: All chemical equations must be balanced. This means that there must be the same number of each type of atom on both sides of the arrow. That's because mass is always conserved in chemical reactions. Count the number of hydrogen and oxygen atoms on each side of the arrow. There are two hydrogen atoms in both reactants and products. There are two oxygen atoms in the reactants but only one in the product. Therefore, equation 1 is not balanced.

Using Coefficients

Coefficients are used to balance chemical equations. A coefficient is a number placed in front of a chemical symbol or formula. It shows how many atoms or molecules of the substance are involved in the reaction. For example, two molecules of hydrogen would be written as 2 H_2, and two molecules of water would be written 2 H_2O. A coefficient of 1 usually isn't written. Coefficients can be used to balance equation 1 (above) as follows:

Equation 2:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Equation 2 shows that two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. The two molecules of hydrogen each contain two hydrogen atoms and so do the two molecules of water. Therefore, there are now four hydrogen atoms in both reactants and products.

Q: Is equation 2 balanced?

A: Count the oxygen atoms to find out. There are two oxygen atoms in the one molecule of oxygen in the reactants. There are also two oxygen atoms in the products, one in each of the two water molecules. Therefore, equation 2 is balanced.

Steps in Balancing a Chemical Equation

Balancing a chemical equation involves a certain amount of trial and error. In general, however, you should follow these steps:

1. Count each type of atom in reactants and products. Does the same number of each atom appear on both sides of the arrow? If not, the equation is not balanced, and you need to

go to step 2.

2. Place coefficients, as needed, in front of the symbols or formulas to increase the number of atoms or molecules of the substances. Use the smallest coefficients possible. Warning! Never change the subscripts in chemical formulas. Changing subscripts changes the substances involved in the reaction. Change only the coefficients.
3. Repeat steps 1 and 2 until the equation is balanced.

Q: Balance this chemical equation for the reaction in which nitrogen (N_2) and hydrogen (H_2) combine to form ammonia (NH_3):

$$N_2 + H_2 \rightarrow NH_3$$

A: First count the nitrogen atoms on both sides of the arrow. There are two nitrogen atoms in the reactants so there must be two in the products as well. Place the coefficient 2 in front of NH_3 to balance nitrogen:

$$N_2 + H_2 \rightarrow 2\ NH_3$$

Now count the hydrogen atoms on both sides of the arrow. There are six hydrogen atoms in the products so there must also be six in the reactants. Place the coefficient 3 in front of H_2 to balance hydrogen:

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$

Summary

- A chemical equation represents the changes that occur during a chemical reaction. It has the general form: Reactants → Products. All chemical equations must be balanced. This means that there must be the same number of each type of atom on both sides of the arrow.
- Coefficients are used to balance chemical equations. A coefficient is a number placed in front of a chemical symbol or formula. It shows how many atoms or molecules of the substance are involved in the reaction.
- To balance a chemical equation, place coefficients as needed in front of the symbols or formulas so the same number of each type of atom occurs in both reactants and products.

Review

1. Which of the following chemical equations is balanced?

   a. $Zn + HCl \rightarrow ZnCl_2 + H_2$

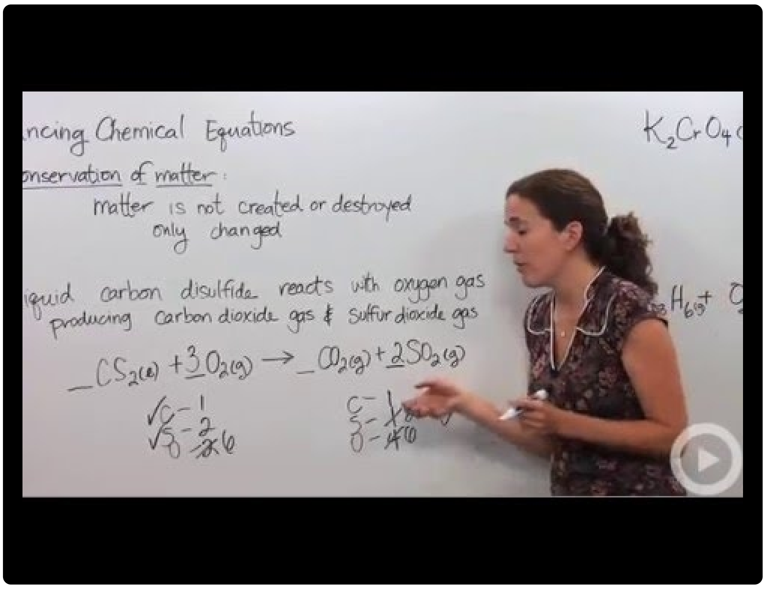
b. $2\ Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$

c. $2\ Zn + HCl \rightarrow ZnCl_2 + H_2$

d. $Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$

2. Balance this chemical equation: $CH_4 + O_2 \rightarrow CO_2 + H_2O$
3. Sam was given the following equation to balance: $H_2O \rightarrow H_2 + O_2$. She balanced it as follows: $2\ HO \rightarrow H_2 + O_2$. What did she do wrong? What is the correct way to balance the equation?

Resources



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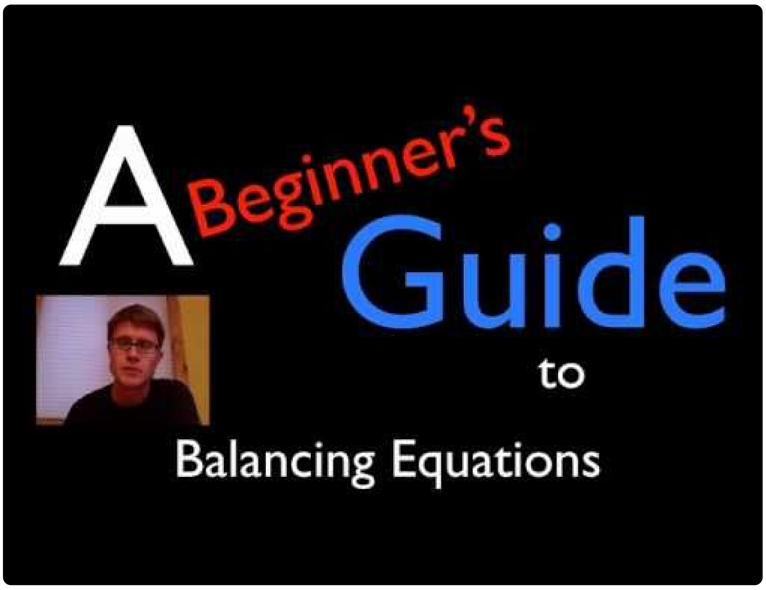

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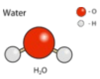	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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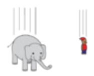	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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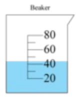
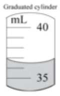
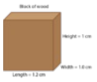
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 6

Solutions, Acids, and Bases

Chapter Outline

6.1 Solution

FlexBooks® 2.0 > American HS Physical Science > Solution

Last Modified: Jul 07, 2019

[Figure 1]

It can be really exciting to explore a big underground cave like the one in this picture. Do you know how caves form? Believe it or not, water is the answer. Water slowly dissolves rocks, especially certain types of rocks such as limestone. When rocks or other substances dissolve in water, they form a solution.

What is a Solution?

A **solution** is a mixture of two or more substances, but it's not just any mixture. A solution is a homogeneous mixture. In a homogeneous mixture, the dissolved particles are spread evenly through the mixture. The particles of the solution are also too small to be seen or to settle out of the mixture.

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Parts of a Solution

All solutions have two parts: the solute and the solvent. The solute is the substance that dissolves, and the solvent is the substance that dissolves the solute. Particles of solvent pull apart particles of solute, and the solute particles spread throughout the solvent. Salt water, such as the ocean water in the **Figure** below, is an example of a solution. In a saltwater solution, salt is the solute and water is the solvent.

[Figure 2]

Q: A scientist obtained a sample of water from the Atlantic Ocean and determined that the sample was about 3.5 percent dissolved salt. Predict the percent of dissolved salt in a sample of water from the Pacific Ocean.

A: As a solution, ocean water is a homogeneous mixture. Therefore, no matter where the water sample is obtained, its composition will be about 3.5 percent dissolved salt.

Soluble or Insoluble?

Not only salt, but many other solutes can dissolve in water. In fact, so many solutes can dissolve in water that water has been called the universal solvent. Even rocks can dissolve in water, which explains the cave that opened this article. A solute that can dissolve in a given solvent, such as water, is said to be **soluble** in that solvent. Conversely, a solute that cannot dissolve in a given solvent is said to be **insoluble** in that solvent.

Although most solutes can dissolve in water, some solutes are insoluble in water. Oil is an example. Did you ever try to mix oil with water? No matter how well you mix the oil into the water, after the mixture stands for a while, the oil separates from the water and rises to the top. You can see how oil floats on ocean water in the **Figure** below.

[Figure 3]

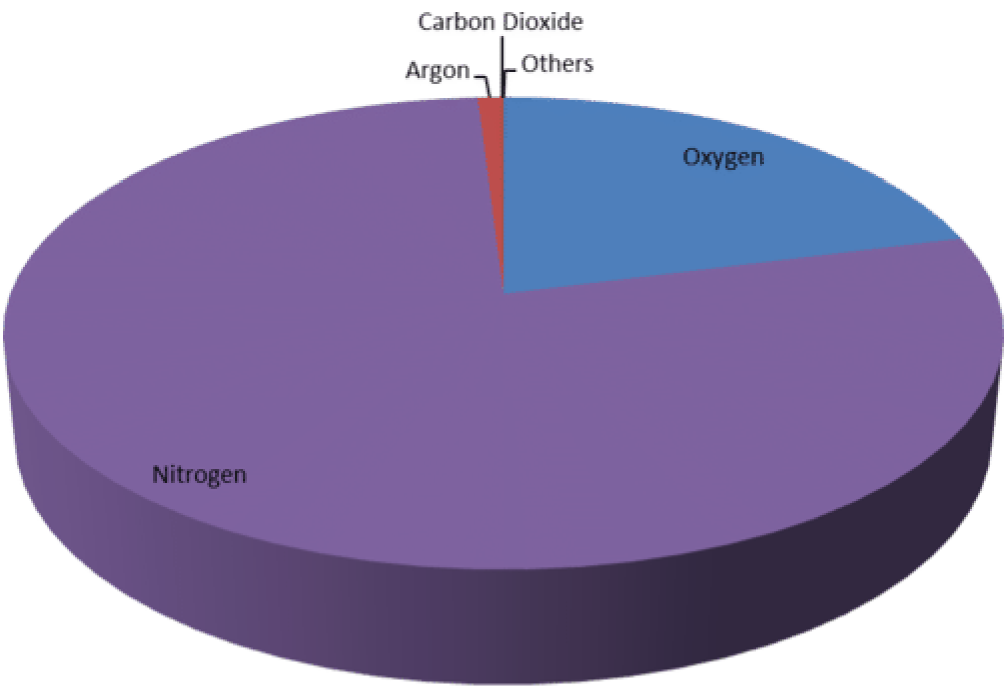
Oil from an oil spill floats on ocean water.

Solutions and States of Matter

Like salt water in the ocean, many solutions are normally in the liquid state. However, matter in any state can form a solution. An alloy, which is a mixture of a metal with one or more other substances, is a solid solution at room temperature. For example, the alloy bronze is a solution of copper and tin. Matter in the gaseous state can also form solutions.

Q: What is an example of a gaseous solution?

A: Air in the atmosphere is a gaseous solution. It is a mixture that contains mainly nitrogen and oxygen gases, with very small amounts of several other gases. The circle graph in the **Figure** below shows the composition of air. Because air is a solution, it is homogeneous. In other words, no matter where you go, the air always contains the same proportion of gases that are shown in the graph.



[Figure 4]

Summary

- A solution is a homogeneous mixture of two or more substances in which the dissolved particles are too small to be seen or to settle out of the mixture.
- In a solution, the substance that dissolves is the solute, and the substance that dissolves the solute is the solvent.
- A solute that can dissolve in a given solvent is said to be soluble in that solvent. A solute that cannot dissolve in a given solvent is said to be insoluble in that solvent.
- Solutions may be liquids such as salt water, solids such as alloys, or gases such as air.

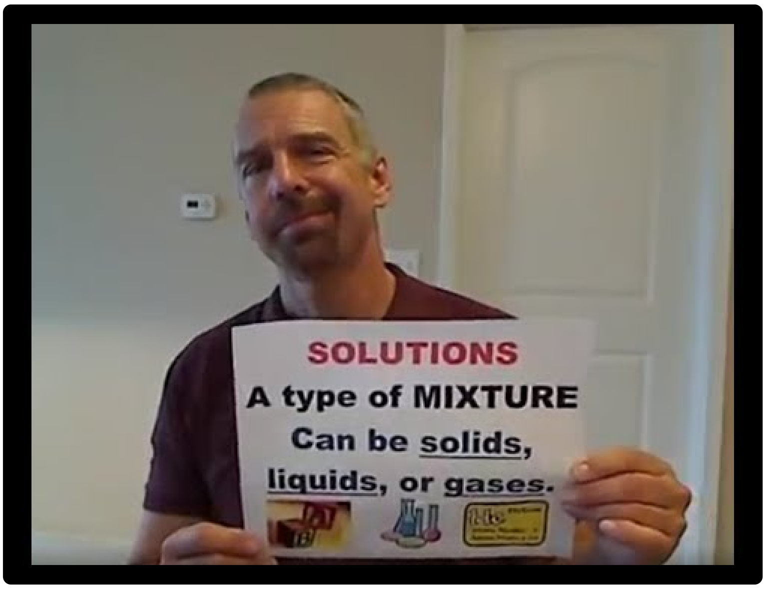
Review

1. What is a solution?
2. Identify and describe the two parts of a solution.

3. Give an example of a substance that is soluble in water and a substance that is insoluble in water.
4. Which of the following statements about solutions is false?
   a. All solutions are mixtures.
   b. All solutions are homogeneous.
   c. All solutions contain two or more compounds.
   d. All solutions contain at least two substances.

Explore More

Listen to the solutions song and then fill in the blanks in the sentences below.



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1. What state(s) of matter can form a solution?
2. The term that means the same throughout is ____________.
3. A solution in which the solvent is water is called a(n) ____________ solution.
4. The lesser portion of a solution is the ____________.
5. The greater portion of a solution is the ____________.

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6.2 Properties of Solutions

FlexBooks® 2.0 > American HS Physical Science > Properties of Solutions

Last Modified: Sep 21, 2018

[Figure 1]

Why hasn't the ocean water in this photo turned to ice? The water in the glacier on shore is frozen solid, but the water in the ocean is still in a liquid state.

Q: What is it about ocean water that keeps it from freezing when the temperature falls below the freezing point of pure water?

A: Ocean water is salty.

How Solutes Affect Solvents

Salt water in the ocean is a solution. In a solution, one substance, called the solute, dissolves in another substance, called the solvent. In ocean water, salt is the solute and water is the solvent. When a solute dissolves in a solvent, it changes the physical properties of the solvent. In particular, the solute generally lowers the freezing point of the solvent, which is called freezing point depression, and raises the boiling point of the solvent, which is called boiling point elevation. For example, adding either salt to water lowers the freezing point and raises the boiling point of the water.

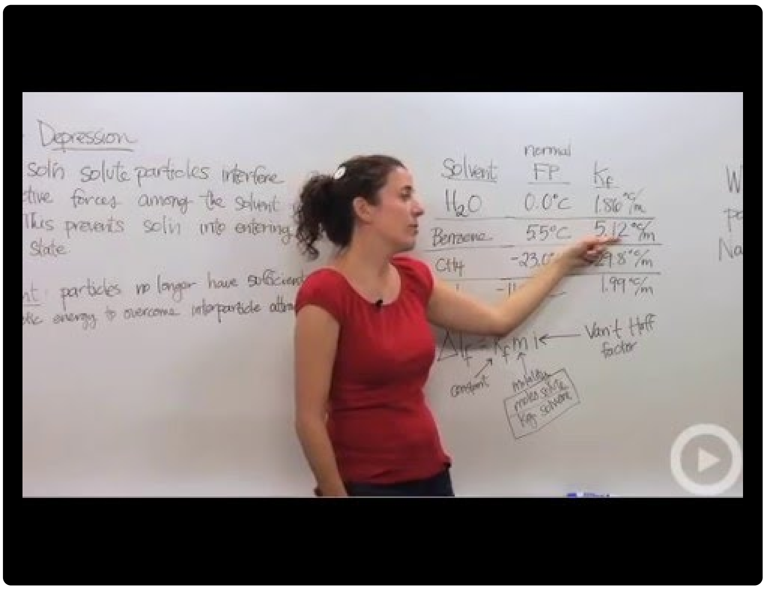
Freezing Point Depression

Pure water freezes at 0 °C, but the salt water in the ocean freezes at -2.2 °C because of freezing point depression. We take advantage of the freezing point depression of salt in water by putting salt on ice to melt it. That's why the truck in the **Figure** below is spreading salt on an icy road.

[Figure 2]

Did you ever see anyone add a fluid to their car radiator? The fluid might be antifreeze, like in the **Figure** below. Antifreeze lowers the temperature of the water in the car radiator so it won't freeze, even when the temperature falls far below 0 °C. For example, a 50 percent antifreeze solution won't freeze unless the temperature goes below -37 °C.

[Figure 3]



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Boiling Point Elevation

Antifreeze could also be called “antiboil” because it also raises the boiling point of the water in a car radiator. Hot weather combined with a hot engine can easily raise the temperature of the water in the radiator above 100 °C, which is the boiling point of pure water. If the water boils, it could cause the engine to overheat and become seriously damaged. However, if antifreeze has been added to the water, the boiling point is much higher. For example a 50 percent antifreeze solution has a boiling point of 129 °C. Unless the water gets hotter than this, it won’t boil and ruin the engine.

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Summary

- When a solute dissolves in a solvent, it changes the physical properties of the solvent.

- A solute generally lowers the freezing point of a solvent, which is called freezing point depression. For example, spreading salt on an icy road melts the ice.
- A solute generally raises the boiling point of a solvent, which is called boiling point elevation. For example, adding antifreeze to the water in a car radiator prevents the water from boiling.

Review

1. What is freezing point depression?
2. Give an example of boiling point elevation.
3. Assume you are going to boil water to cook spaghetti. If you add salt to the water, how will this affect the temperature at which the water boils? How might it affect the time it takes the spaghetti to cook?

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6.3 Acid

FlexBooks® 2.0 > American HS Physical Science > Acid

Last Modified: Jun 07, 2021

[Figure 1]

Look at the man in the photo above. You can tell by the expression on his face that lemon juice tastes sour. Lemon juice is an acid, and all acids taste sour. They share certain other properties as well. You will learn more about acids and their properties in this article.

What Are Acids?

Acids are ionic compounds that produce positive hydrogen ions (H^+) when dissolved in water. Ionic compounds are compounds that contain positive metal ions and negative nonmetal ions held together by ionic bonds. (Ions are atoms that have become charged particles by gaining or losing electrons.) An example of an acid is hydrogen chloride (HCl). When it dissolves in water, it separates into positive hydrogen ions and negative chloride ions (Cl^-). This is represented by the chemical equation:

$$HCl \overset{H_2O}{\rightarrow} H^+ + Cl^-$$

Properties of Acids

You already know that a sour taste is one property of acids. (*Warning*: **Never** taste an unknown substance to see whether it is an acid!) Acids have certain other properties as well. For example, acids can conduct electricity when dissolved in water because they consist of charged particles in solution. (Electric current is a flow of charged particles.) Acids can also react with metals, and when they do they produce hydrogen gas. An example of this type of reaction is hydrochloric acid reacting with the metal zinc (Zn). The reaction is pictured in the **Figure** below. It can be represented by the chemical equation:

$$Zn + 2HCl \rightarrow H_2 + ZnCl_2$$

[Figure 2]

Hydrochloric acid reacting with the metal zinc.

Q: What sign indicates that a gas is being produced in this reaction?

A: The bubbles are hydrogen gas rising through the acid.

Q: Besides hydrogen gas, what else is produced in this reaction?

A: This reaction also produces zinc chloride $ZnCl_2$, which is a neutral ionic compound called a salt.

Detecting Acids

Certain compounds, called indicators, change color when acids come into contact with them, so indicators can be used to detect acids. An example of an indicator is the compound called litmus. It is placed on small strips of paper that may be red or blue. If you place a few drops of acid on a strip of blue litmus paper, the paper will turn red. You can see this in the **Figure** below. Litmus isn't the only indicator for detecting acids. Red cabbage juice also works well, as you can see in this entertaining video.

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[Figure 3]

Drawing of blue litmus paper turning red in acid.

Strength of Acids

The strength of acids is measured on a scale called the pH scale. The pH value of a solution represents its concentration of hydrogen ions. A pH value of 7 indicates a neutral solution, and a pH value less than 7 indicates an acidic solution. The lower the pH value is, the greater is the concentration of hydrogen ions and the stronger the acid. The strongest acids, such as battery acid, have pH values close to zero.

Uses of Acids

Acids have many important uses, especially in industry. For example, sulfuric acid is used to manufacture a variety of different products, including paper, paint, and detergent. Some other uses of acids are be seen in the **Figure** below.

[Figure 4]

Nitric acid and Phosphoric acid: Both nitric acid and phosphoric acid are used to make fertilizer. Hydrochloric acid: Hydrochloric acid is used to clean swimming pools, bricks, and concrete. Sulfuric acid: Sulfuric Acid is an important component of car batteries.

Summary

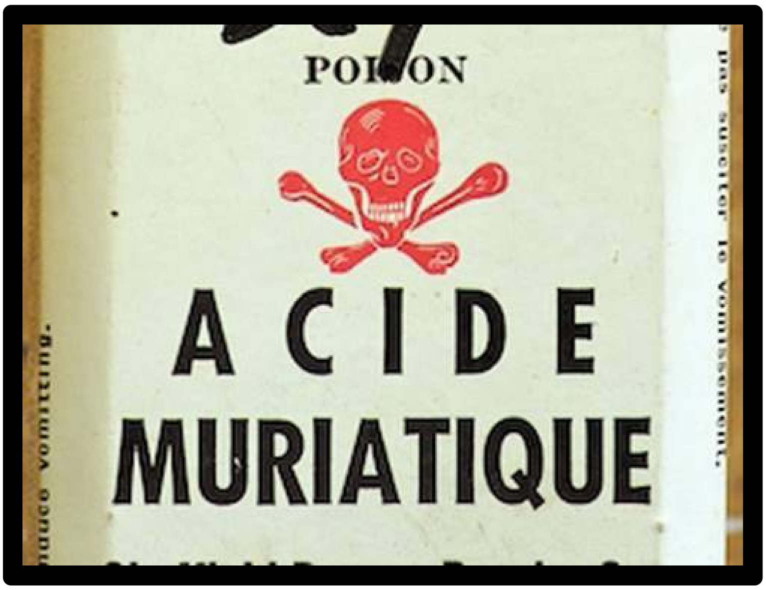
- Acids are ionic compounds that produce positive hydrogen ions (H^+) when dissolved in water.
- Acids taste sour, conduct electricity when dissolved in water, and react with metals to produce hydrogen gas.
- Certain indicator compounds, such as litmus, can be used to detect acids. Acids turn blue litmus paper red.
- The strength of acids is measured on the pH scale. A pH value less than 7 indicates an acid, and the lower the number is, the stronger the acid.
- Acids have many important uses, especially in industry.

Review

1. What is an acid?
2. List properties of acids.
3. How can you tell whether a compound is an acid?
4. Milk is a very weak acid. What might its pH value be?
5. Based on your knowledge of the properties of acids, which one of the following substances do you think is an acid?
   a. vinegar
   b. salt
   c. sugar
   d. baking soda

Explore More

Watch these videos about hydrochloric acid, and then answer the questions below.



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1. What is hydrochloric acid?
2. Everyone carries around a sample of hydrochloric acid. Where is the hydrochloric acid, and what is its function?
3. Describe what happens when a cheeseburger and then a goose skull are placed in hydrochloric acid.
4. When zinc metal is added to hydrochloric acid, how can you tell that hydrogen gas is produced?

Resources

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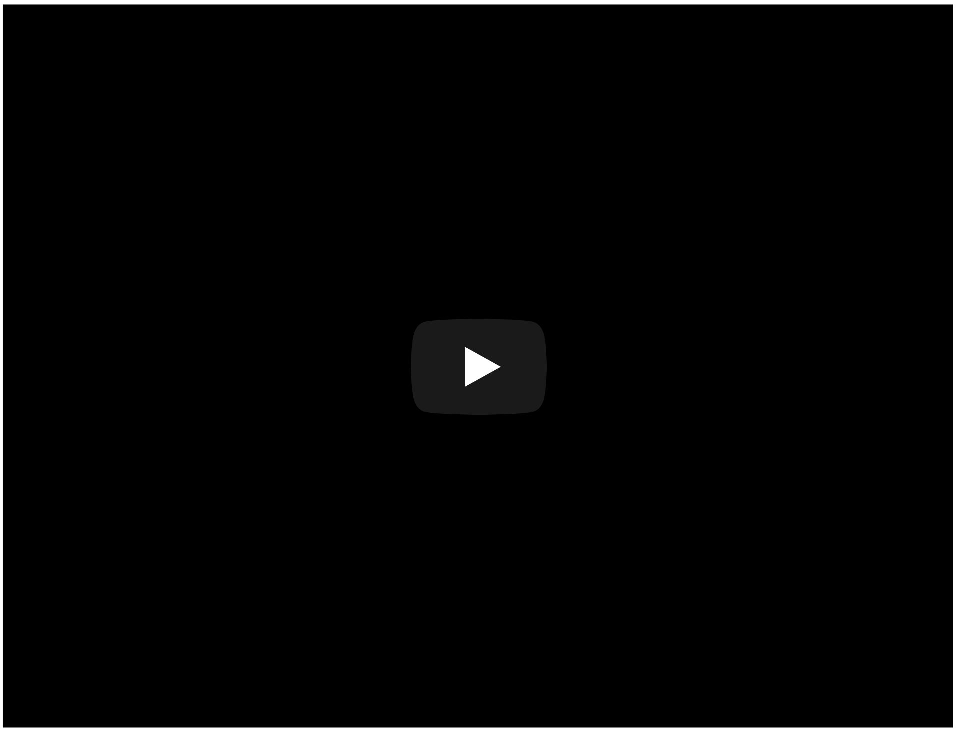

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6.4 Base

FlexBooks® 2.0 > American HS Physical Science > Base

Last Modified: Oct 20, 2020

[Figure 1]

These blocks of baking chocolate may make your mouth water, but if you were to taste them, you would be in for an unpleasant surprise. The blocks are unsweetened chocolate. Without any added sugar, chocolate tastes bitter. Chocolate tastes bitter because it's a base.

What Are Bases?

Bases are ionic compounds that produce negative hydroxide ions (OH^-) when dissolved in water. An ionic compound contains positive metal ions and negative nonmetal ions held together by ionic bonds. (Ions are atoms that have become charged particles because they have either lost or gained electrons.) An example of a base is sodium hydroxide (NaOH). When it dissolves in water, it produces negative hydroxide ions and positive sodium ions (Na^+). This can be represented by the equation:

$$NaOH \overset{H_2O}{\rightarrow} OH^- + Na^+$$

Properties of Bases

All bases share certain properties, including a bitter taste. (*Warning:* Never taste an unknown substance to see whether it is a base!) Bases also feel slippery. Think about how slippery soap feels. That's because it's a base. In addition, bases conduct electricity when dissolved in water because they consist of charged particles in solution. (Electric current is a flow of charged particles.)

Q: Bases are closely related to compounds called acids. How are their properties similar? How are they different?

A: A property that is shared by bases and acids is the ability to conduct electricity when dissolved in water. Some ways bases and acids are different is that acids taste sour whereas bases taste bitter. Also, acids but not bases react with metals.

Detecting Bases

Certain compounds, called indicators, change color when bases come into contact with them, so they can be used to detect bases. An example of an indicator is a compound called litmus. It is placed on small strips of paper that may be red or blue. If you place a few drops of a base on a strip of red litmus paper, the paper will turn blue. You can see this in the **Figure** below. Litmus isn't the only detector of bases. Red cabbage juice can also detect bases, as you can see in this video.

https://flexbooks.ck12.org/flx/render/embeddedobject/5011

[Figure 2]

Drawing of red litmus paper turning blue in a base.

Strength of Bases

The strength of bases is measured on a scale called the pH scale, which ranges from 0 to 14. On this scale, a pH value of 7 indicates a neutral solution, and a pH value greater than 7 indicates a basic solution. The higher the pH value is, the stronger the base. The strongest bases, such as drain cleaner, have a pH value close to 14.

Uses of Bases

Bases are used for a variety of purposes. For example, soaps contain bases such as potassium hydroxide (KOH). Other uses of bases can be seen in the **Figure** below.

[Figure 3]

Summary

- Bases are ionic compounds that produce negative hydroxide ions (OH-) when dissolved in water.
- Bases taste bitter, feel slippery, and conduct electricity when dissolved in water.
- Indicator compounds such as litmus can be used to detect bases. Bases turn red litmus paper blue.

- The strength of bases is measured on the pH scale. A pH value greater than 7 indicates a base, and the higher the number is, the stronger the base.
- Bases have many important uses. For example, they are found in many cleaning products and in concrete.

Review

1. What is a base?
2. What are some properties of bases?
3. How can you use litmus paper to detect a base?
4. Ocean water is slightly basic. What might its pH value be?
5. Considering the properties of bases, which of the following do you think is a base?
   a. orange juice
   b. lemonade
   c. vinegar
   d. baking soda

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6.5 pH

FlexBooks® 2.0 > American HS Physical Science > pH

Last Modified: Oct 20, 2020

[Figure 1]

This scientist is collecting and testing samples of water from the river. One of the properties of the water she is testing is acidity. She wants to know how acidic the water is because water that is too acidic can harm the health of water organisms.

Strength of Acids and Bases

Acids are ionic compounds that produce positively charged hydrogen ions (H^+) when dissolved in water. Acids taste sour and react with metals. Bases are ionic compounds that produce negatively charged hydroxide ions (OH^-) when dissolved in water. Bases taste bitter and do not react with metals. Examples of acids are vinegar and battery acid. The acid in vinegar is weak enough to safely eat on a salad. The acid in a car battery is strong enough to eat through skin. Examples of bases include those in antacid tablets and drain cleaner. Bases in antacid tablets are weak enough to take for an upset stomach. Bases in drain cleaner are strong enough to cause serious burns.

Q: What do you think causes these differences in the strength of acids and bases?

A: The strength of an acid or a base depends on how much of it breaks down into ions when it dissolves in water.

Concentration of Ions

The strength of an acid depends on how many hydrogen ions it produces when it dissolves in water. A stronger acid produces more hydrogen ions than a weaker acid. For example, sulfuric acid (H_2SO_4), which is found in car batteries, is a strong acid because nearly all of it breaks down into ions when it dissolves in water. On the other hand, acetic acid (CH_3CO_2H), which is the acid in vinegar, is a weak acid because less than 1 percent of it breaks down into ions in water.

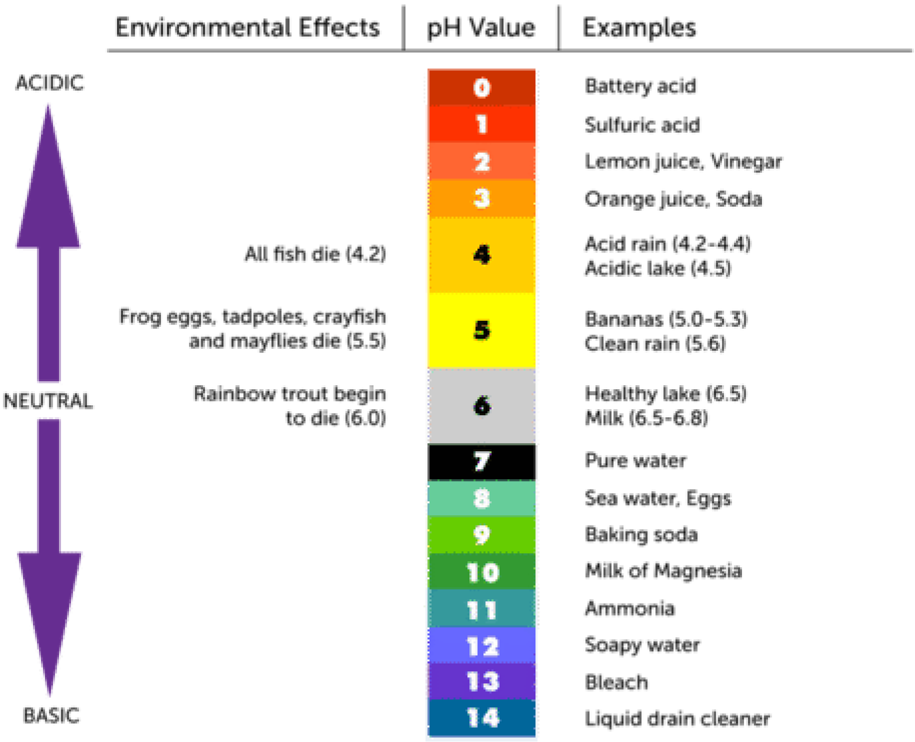
The strength of a base depends on how many hydroxide ions it produces when it dissolves in water. A stronger base produces more hydroxide ions than a weaker base. For example, sodium hydroxide (NaOH), a base in drain cleaner, is a strong base because all of it breaks down into ions when it dissolves in water. Calcium carbonate ($CaCO_3$), a base in antacids, is a weak base because only a small percentage of it breaks down into ions in water.

The pH Scale

The strength of acids and bases is measured on a scale called the pH scale, which is shown in the **Figure** below. By definition, **pH** represents the **acidity**, or hydrogen ion (H^+) concentration, of a solution. Pure water, which is neutral, has a pH of 7. With a higher the concentration of hydrogen ions, a solution is more acidic and has a lower pH. Acids have a pH less than 7, and the strongest acids have a pH close to zero. Bases have a pH greater than 7, and the strongest bases have a pH close to 14. It's important to realize that the pH scale is based on powers of ten. For example, a solution with a pH of 8 is 10 times more basic than a solution with a pH of 7, and a solution with a pH of 9 is 100 times more basic than a solution with a pH of 7.

Q: How much more acidic is a solution with a pH of 4 than a solution with a pH of 7?

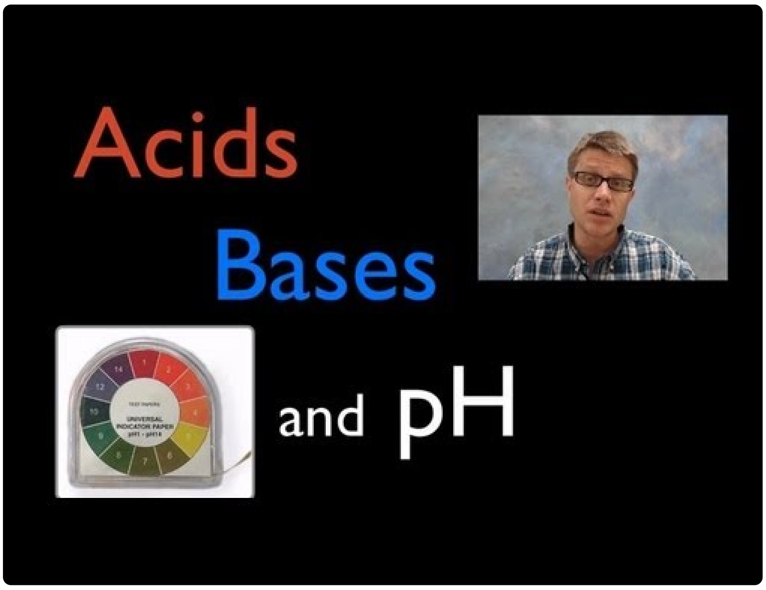
A: A solution with a pH of 4 is 1000 ($10 \times 10 \times 10$, or 10^3) times more acidic than a solution with a pH of 7.



[Figure 2]

Q: Which solution on the pH scale in the **Figure** above is the weakest acid? Which solution is the strongest base?

A: The weakest acid on the scale is milk, which has a pH value between 6.5 and 6.8. The strongest base on the scale is liquid drain cleaner, which has a pH of 14.



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Why pH Matters

Acidity is an important factor for living things. For example, many plants grow best in soil that has a pH between 6 and 7. Fish may also need a pH between 6 and 7. Certain air pollutants form acids when dissolved in water droplets in the air. This results in acid fog and acid rain, which may have a pH of 4 or even lower. The pH chart in the **Figure** above and the **Figure** below reveal some of the adverse effects of acid fog and rain. Acid rain not only kills trees. It also lowers the pH of surface waters such as ponds and lakes. As a result, the water may become too acidic for fish and other water organisms to survive.

[Figure 3]

Acid fog and acid rain killed the trees in this forest.

Even normal (clean) rain is somewhat acidic. That's because carbon dioxide (CO_2) in the air dissolves in raindrops, producing a weak acid called carbonic acid (H_2CO_3), which has a pH of about 5.5. When rainwater soaks into the ground, it can slowly dissolve rocks, particularly those containing calcium carbonate. This is how water forms underground caves.

Q: How do you think acid rain might affect buildings and statues made of stone?

A: Acid rain dissolves and damages stone buildings and statues. The **Figure** below shows a statue that has been damaged by acid rain.

[Figure 4]

Summary

- The strength of an acid or base is called acidity. It depends on how much of the substance breaks down into ions when it dissolves in water.
- Acidity is measured by pH, which is the concentration of hydrogen ions in a solution.
- Acidity is an important factor for living things because most can survive only within a relatively narrow range of acidity.

Review

1. What determines how acidic or basic a solution is?
2. What is pH? What is the pH of a neutral substance?
3. How much more or less acidic is soapy water than pure water? (*Hint*: See the pH chart in the **Figure** above.
4. Why is the pH of the environment important for living things?

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6.6 REFERENCES

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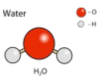	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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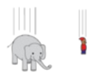	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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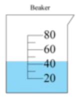
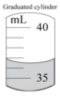
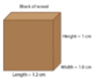
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 7

Objects in Motion

Chapter Outline

7.1 Motion

FlexBooks® 2.0 > American HS Physical Science > Motion

Last Modified: Aug 09, 2019

[Figure 1]

The wings of this hummingbird are moving so fast that they're just a blur of motion. You can probably think of many other examples of things in motion. If you can't, just look around you. It's likely that you'll see something moving, and if nothing else, your eyes will be moving. So you know from experience what motion is. No doubt it seems like a fairly simple concept. However, when you read this article, you'll find out that it's not quite as simple as it seems.

Defining Motion

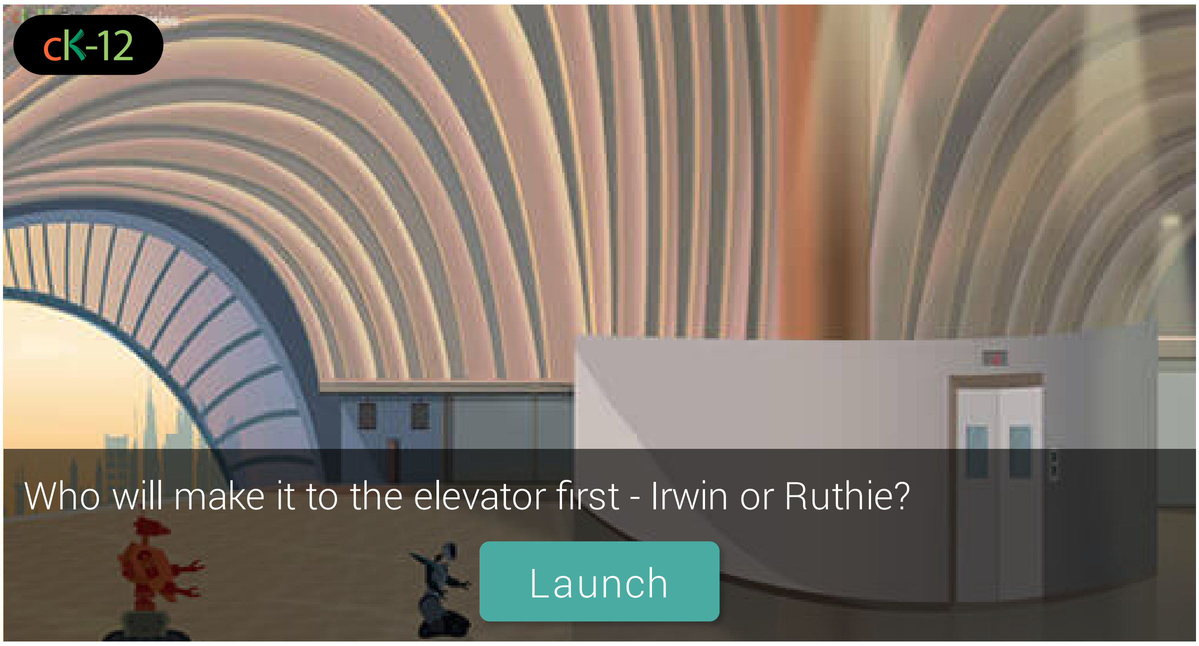
In science, **motion** is defined as a change in position. An object's position is its location. Besides the wings of the hummingbird in the opening image, you can see other examples of motion in the **Figure** below. In each case, the position of something is changing.

[Figure 2]

Q: In each picture in the **Figure** above, what is moving and how is its position changing?

A: The train and all its passengers are speeding straight down a track to the next station. The man and his bike are racing along a curving highway. The geese are flying over their wetland environment. The meteor is shooting through the atmosphere toward Earth, burning up as it goes.

Launch the simulation below to observe two moving robots, Irwin and Ruthie, as they race to the elevator and learn more about motion:



https://flexbooks.ck12.org/flx/show/interactive/user:sathist/https://interactives.ck12.org/simulations/embed.html?embeded=true&interactive=irwin-and-ruthie&subject=physics&lang=en&assignment=true&hash=4b186b078176ee6ee896e3e56235c369

Frame of Reference

There's more to motion than objects simply changing position. You'll see why when you consider the following example. Assume that the school bus pictured in the **Figure** below passes by you as you stand on the sidewalk. It's obvious to you that the bus is moving, but what about to the children inside the bus? The bus isn't moving relative to them, and if they look at the other children sitting on the bus, they won't appear to be moving either. If the ride is really smooth, the children may only be able to tell that the bus is moving by looking out the window and seeing you and the trees whizzing by.

[Figure 3]

This example shows that how we perceive motion depends on our frame of reference. **Frame of reference** refers to something that is not moving with respect to an observer that can be used to detect motion. For the children on the bus, if they use other children riding the bus as their frame of reference, they do not appear to be moving. But if they use objects outside the bus as their frame of reference, they can tell they are moving.

Q: What is your frame of reference if you are standing on the sidewalk and see the bus go by? How can you tell that the bus is moving?

A: Your frame of reference might be the trees and other stationary objects across the street. As the bus goes by, it momentarily blocks your view of these objects, and this helps you detect the bus' motion.

Watch this video to observe an experiment involving the motion of a tennis ball:

https://flexbooks.ck12.org/flx/render/embeddedobject/254279

Summary

- Motion is defined as a change of position.
- How we perceive motion depends on our frame of reference. Frame of reference refers to something that is not moving with respect to an observer that can be used to detect motion.

Review

1. How is motion defined in science?
2. Describe an original example that shows how frame of reference influences the perception of motion.

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7.2 Distance

FlexBooks® 2.0 > American HS Physical Science > Distance

Last Modified: Aug 09, 2019

[Figure 1]

Do you participate in track like the boys pictured here? If not, you may have attended a track meet. The boys in the picture are running a 100-meter sprint. Running events in track are named for their distance.

What Is Distance?

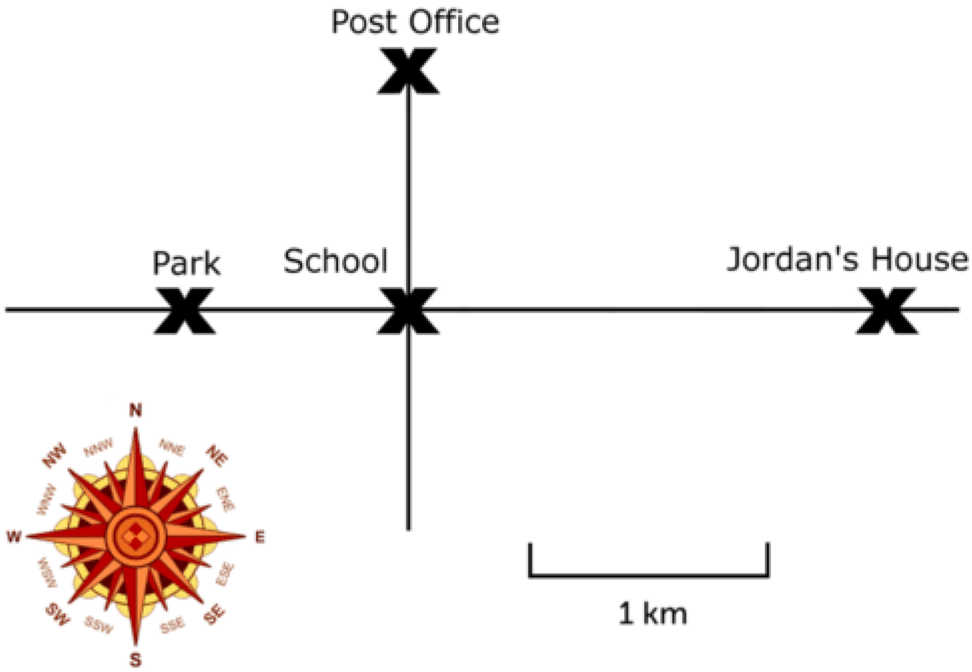
Distance is the length of the route between two points. The distance of a race, for example, is the length of the track between the starting and finishing lines. In a 100-meter sprint, that distance is 100 meters.

SI Unit for Distance

The SI unit for distance is the meter (m). Short distances may be measured in centimeters (cm), and long distances may be measured in kilometers (km). For example, you might measure the distance from the bottom to the top of a sheet of paper in centimeters and the distance from your house to your school in kilometers.

Using Maps to Measure Distance

Maps can often be used to measure distance. The map in the **Figure** below shows the route from Jordan's house to his school. You can use the scale at the bottom of the map to measure the distance between these two points.

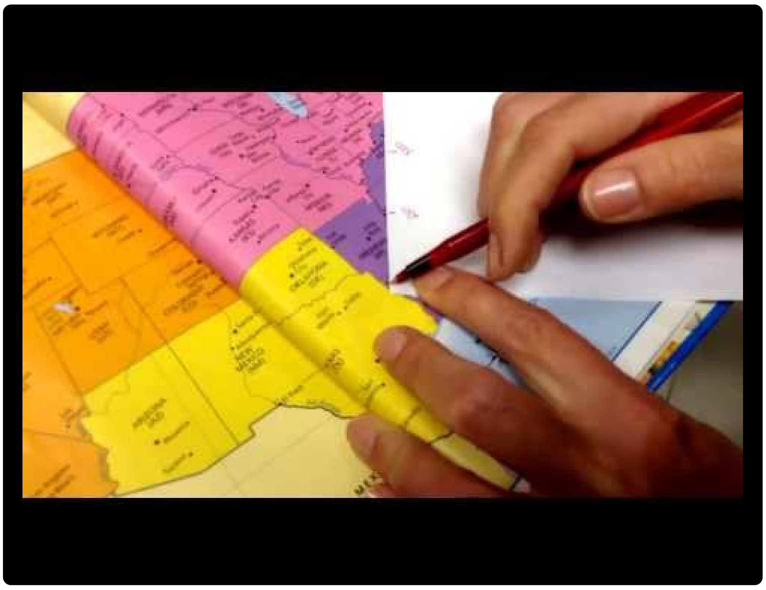


[Figure 2]

Q: What is the distance from Jordan's house to his school?

A: The distance is 2 kilometers.

Watch the following video to learn more about how to use a scale on a map to measure distance:



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Summary

- Distance is the length of the route between two points.
- The SI unit for distance is the meter.

- The scale of a map can be used to find the distance between different locations.

Review

1. Define distance.
2. What is the SI unit for distance? Give an example of something you might measure in this unit.
3. Runners in different lanes on an oval racetrack have different starting marks. Explain why.
4. On the map in the **Figure** above, what is the distance between Jordan's house and the park?

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7.3 Direction

FlexBooks® 2.0 > American HS Physical Science > Direction

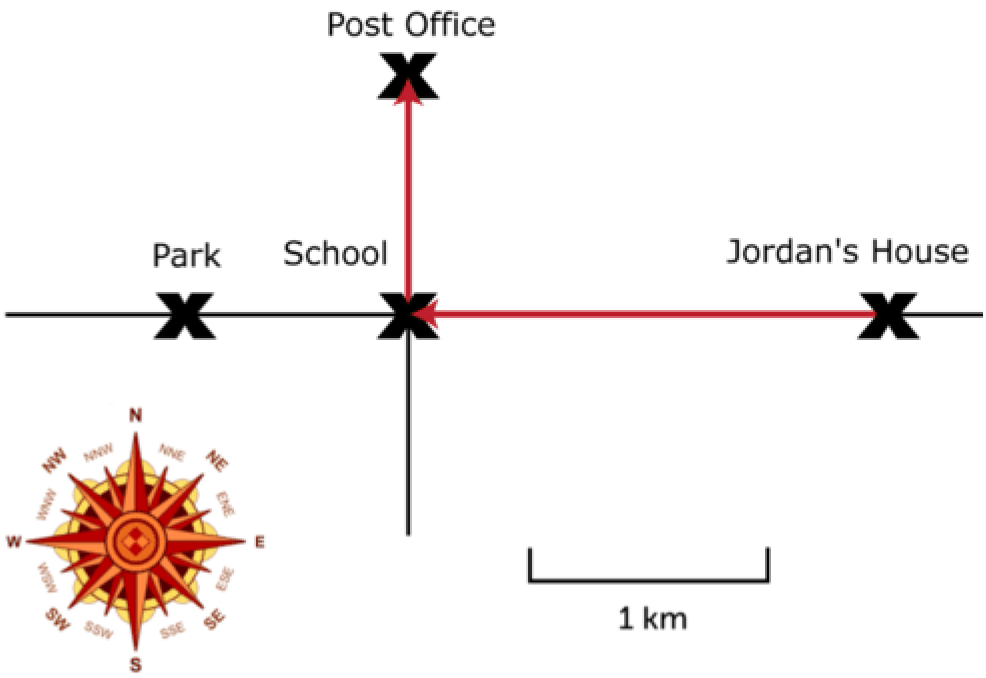
Last Modified: Dec 06, 2021

[Figure 1]

Imagine traveling several miles in one of the directions indicated by this sign. Now suppose that a friend travels the same distance in another direction indicated by the sign. You and your friend would end up in very different locations. Obviously, direction is an important component of motion.

Introducing Direction

Direction is the location of something relative to something else. Direction can be described in relative terms, such as up, down, in, out, left, right, forward, backward, or sideways. Direction can also be described with the cardinal directions: north, south, east, or west. On maps, cardinal directions are indicated with a compass rose. You can see one in the bottom left corner of the map in the **Figure** below. You can use the compass rose to find directions on the map. For example, to go to the school from Jordan's house, you would travel from east to west. If you wanted to go on to the post office, you would change direction at the school and then travel from south to north.

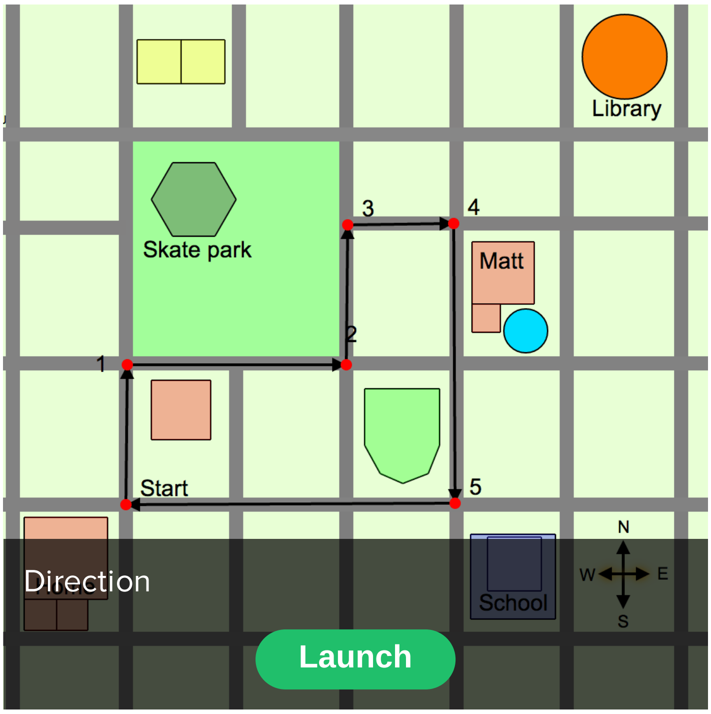


[Figure 2]

Why Direction Is Important

Look again at the map in the **Figure** above. The distance from Jordan's house to the post office is 3 km. But if Jordan told a friend how to reach the post office from his house, he couldn't just say "go 3 kilometers." The friend might end up at the park instead of the post office. Jordan would have to include direction as well as distance. He could say, "go west for 2 kilometers and then go north for 1 kilometer."

Launch the PLIX Interactive below and try to turn the path outlined on the map into a series of written directions:



https://flexbooks.ck12.org/assessment/tools/geometry-tool/fullscreen.html?qID=53618601da2cfe0f2ff0ab94

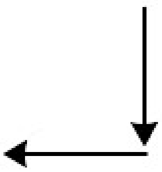
Motion and Vectors

When both distance and direction are considered, motion can be represented by a vector. A **vector** is a measurement that has both size and direction. It may be represented by an arrow. If you are representing motion with an arrow, the length of the arrow represents distance, and the way the arrow points represents direction.

The red arrows on the map in the **Figure** above are vectors for Jordan's route from his house to the school and from the school to the post office.

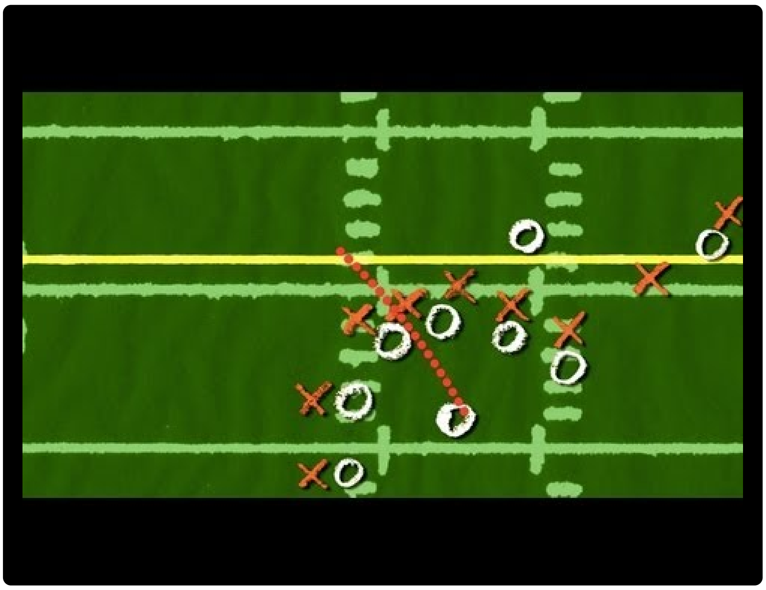
Q: How would you draw arrows to represent the distances and directions from the post office to the park on the map in the **Figure** above?

A: The vectors would look like this:



[Figure 3]

Watch the video below to learn more about the differences between vectors and scalars demonstrated in a football play:



https://flexbooks.ck12.org/flx/render/embeddedobject/254287

Summary

- Direction is the location of something relative to something else.
- A compass rose shows cardinal directions on a map.
- A vector is a measurement that has both size and direction and may be represented by an arrow. A vector can be used to represent both distance and direction of motion.

Review

1. Think of a short route you commonly take, such as the route from your home to a friend's house or your school. Describe the direction(s) and distance(s) you travel over this route.
2. What is a vector? How can an arrow represent distance and direction of motion?
3. Draw vectors to represent these motions:

   a. moving 3 cm to the right

   b. moving 2 cm to the left

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7.4 Speed

FlexBooks® 2.0 > American HS Physical Science > Speed

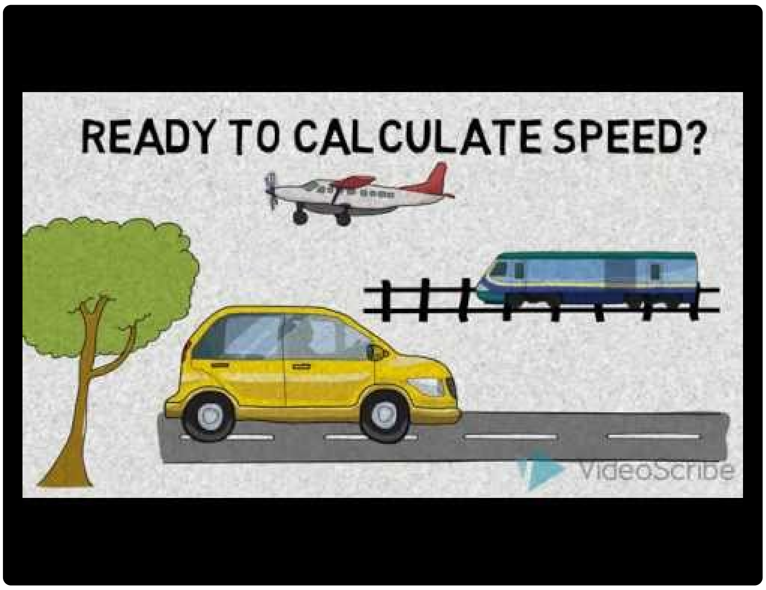
Last Modified: Feb 19, 2021

[Figure 1]

Did you ever play fast-pitch softball? If you did, then you probably have some idea of how fast the pitcher throws the ball. For a female athlete like the one in the opening image, the ball may reach a speed of 120 km/h (about 75 mi/h). For a male athlete, the ball may travel even faster. A fast-pitch pitcher uses a “windmill” motion to throw the ball. This is a different technique than other softball pitches, and it explains why the ball travels so fast.

Introducing Speed

How fast or slow something moves is its **speed**. Speed determines how far something travels in a given amount of time. The SI unit for speed is meters per second (m/s). Speed may be constant, but often it varies from moment to moment.



https://flexbooks.ck12.org/flx/render/embeddedobject/254315

Average Speed

Even if speed varies during the course of a trip, it's easy to calculate the average speed by using this formula:

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

For example, assume you go on a car trip with your family. The total distance you travel is 120 miles, and it takes 3 hours to travel that far. The average speed for the trip is:

$$\begin{aligned}\text{speed} &= \frac{120 \text{ mi}}{3 \text{ h}}\\ &= 40 \text{ mi/h}\end{aligned}$$

Q: Terri rode her bike very slowly to the top of a big hill. Then she coasted back down the hill at a much faster speed. The distance from the bottom to the top of the hill is 3 kilometers. It took Terri ¼ hour to make the round trip. What was her average speed for the entire trip? (*Hint*: The round-trip distance is 6 km.)

A: Terri's speed can be calculated as follows:

$$\begin{aligned}\text{speed} &= \frac{6 \text{ km}}{0.25 \text{ h}}\\ &= 24 \text{ km/h}\end{aligned}$$

Instantaneous Speed

When you travel by car, you usually don't move at a constant speed. Instead you go faster or slower depending on speed limits, traffic lights, the number of vehicles on the road, and other factors. For example, you might travel 65 miles per hour on a highway but only 20 miles per hour on a city street (see the pictures in the **Figure** below.) You might come to a complete stop at traffic lights, slow down as you turn corners, and speed up to pass other cars. Therefore, your speed at any given instant, or your instantaneous speed, may be very different than your speed at other times. Instantaneous speed is much more difficult to calculate than average speed.

[Figure 2]

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

Calculating Distance or Time from Speed

If you know the average speed of a moving object, you can calculate the distance it will travel in a given period of time or the time it will take to travel a given distance. To calculate distance from speed and time, use this version of the average speed formula given above:

distance = speed × time

For example, if a car travels at an average speed of 60 km/h for 5 hours, then the distance it travels is:

distance = 60 km/h × 5 h = 300 km

To calculate time from speed and distance, use this version of the formula:

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

Q: If you walk 6 km at an average speed of 3 km/h, how much time does it take?

A: Use the formula for time as follows:

$$\begin{aligned}\text{time} &= \frac{\text{distance}}{\text{speed}}\\ &= \frac{6\text{ km}}{3\text{ km/h}}\\ &= 2\text{ h}\end{aligned}$$

Summary

- How fast or slow something moves is its speed. The SI unit for speed is meters per second (m/s).
- Average speed is calculated with this formula:

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

- Speed may be constant, but often it varies from moment to moment. Speed at any given instant is called instantaneous speed. It is much more difficult to calculate than average speed.
- Distance or time can be calculated by solving the average speed formula for distance or time.

Review

1. What is speed?
2. If you walk 3 kilometers in 30 minutes, what is your average speed in kilometers per hour?
3. Compare and contrast instantaneous and average speed.
4. What distance will a truck travel in 3 hours at an average speed of 50 miles per hour?

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7.5 Velocity

FlexBooks® 2.0 > American HS Physical Science > Velocity

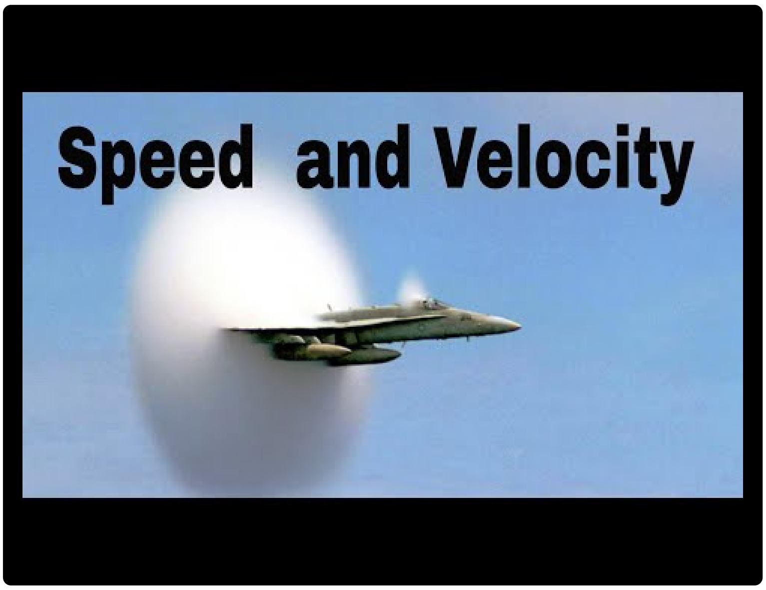
Last Modified: Aug 09, 2019

[Figure 1]

Ramey and her mom were driving down this highway at 45 miles per hour, which is the speed limit on this road. As they approached this sign, Ramey's mom put on the brakes and started to slow down so she could safely maneuver the upcoming curves in the road. This speed limit sign actually represents two components of motion: speed and direction.

Speed and Direction

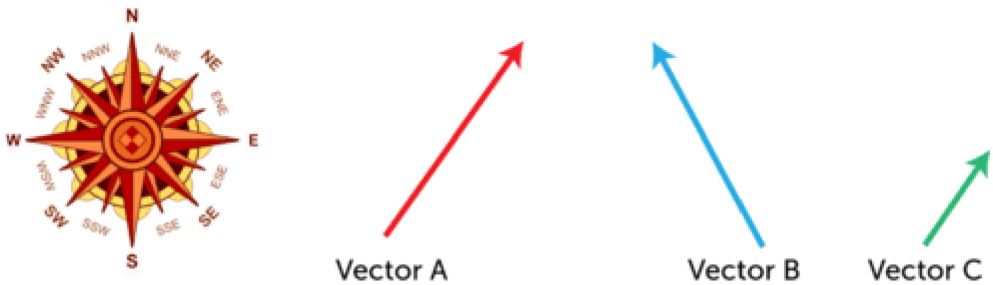
Speed tells you only how fast or slow an object is moving. It doesn't tell you the direction the object is moving. The measure of both speed and direction is called **velocity**. Velocity is a vector. A **vector** is measurement that includes both size and direction. Vectors are often represented by arrows. When using an arrow to represent velocity, the length of the arrow stands for speed, and the way the arrow points indicates the direction.



https://flexbooks.ck12.org/flx/render/embeddedobject/221540

Using Vector Arrows to Represent Velocity

The arrows in the **Figure** below represent the velocity of three different objects. Arrows A and B are the same length but point in different directions. They represent objects moving at the same speed but in different directions. Arrow C is shorter than arrow A or B but points in the same direction as arrow A. It represents an object moving at a slower speed than A or B but in the same direction as A.



[Figure 2]

Differences in Velocity

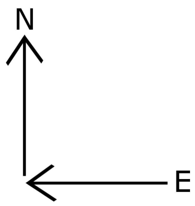
Objects have the same velocity only if they are moving at the same speed and in the same direction. Objects moving at different speeds, in different directions, or both have different velocities. Look again at arrows A and B from the **Figure** above. They represent objects that have different velocities only because they are moving in different directions. A and C represent objects that have different velocities only because they are moving at different speeds. Objects represented by B and C have different velocities because they are moving in different directions and at different speeds.

Q: Jerod is riding his bike at a constant speed. As he rides down his street he is moving from east to west. At the end of the block, he turns right and starts moving from south to north, but he's still traveling at the same speed. Has his velocity changed?

A: Although Jerod's speed hasn't changed, his velocity has changed because he is moving in a different direction.

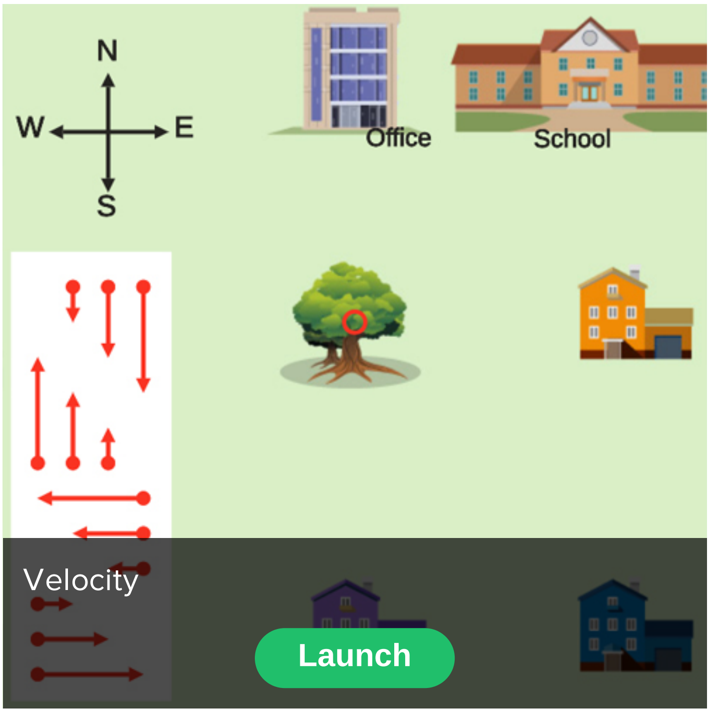
Q: How could you use vector arrows to represent Jerod's velocity and how it changes?

A: The arrows might look like this:



[Figure 3]

Launch the PLIX Interactive below and try to use the vector arrows to illustrate the bike messenger's velocity throughout his day:



https://flexbooks.ck12.org/assessment/tools/geometry-tool/fullscreen.html?qID=5772e0945aa4132a45390a1c

Calculating Average Velocity

You can calculate the average velocity of a moving object that is not changing direction by dividing the distance the object travels by the time it takes to travel that distance. You would use this formula:

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

This is the same formula that is used for calculating average speed. It represents velocity only if the answer also includes the direction that the object is traveling.

Let's work through a sample problem. Toni's dog is racing down the sidewalk toward the east. The dog travels 36 meters in 18 seconds before it stops running. The velocity of the dog is:

$$\begin{aligned}\text{velocity} &= \frac{\text{distance}}{\text{time}}\\ &= \frac{36\text{ m}}{18\text{ s}}\\ &= 2\text{ m/s east}\end{aligned}$$

Note that the answer is given in the SI unit for velocity, which is m/s, and it includes the direction that the dog is traveling.

Q: What would the dog's velocity be if it ran the same distance in the opposite direction but covered the distance in 24 seconds?

A: In this case, the velocity would be:

$$\begin{aligned}\text{velocity} &= \frac{\text{distance}}{\text{time}}\\ &= \frac{36\text{ m}}{24\text{ s}}\\ &= 1.5\text{ m/s west}\end{aligned}$$

Watch the video below to gain a better understanding of the relationship between speed, velocity and acceleration:

https://flexbooks.ck12.org/flx/render/embeddedobject/186663

Summary

- Velocity is a measure of both speed and direction of motion. Velocity is a vector, which is a measurement that includes both size and direction.
- Velocity can be represented by an arrow, with the length of the arrow representing speed and the way the arrow points representing direction.
- Objects have the same velocity only if they are moving at the same speed and in the same direction. Objects moving at different speeds, in different directions, or both have different velocities.
- The average velocity of an object moving in a constant direction is calculated with the formula: $\text{velocity} = \frac{\text{distance}}{\text{time}}$. The SI unit for velocity is m/s, plus the direction the object is traveling.

Review

1. What is velocity?
2. How does velocity differ from speed? Why is velocity a vector?
3. Explain how an arrow can be used to represent velocity.
4. Use vector arrows to represent the velocity of a car that travels north at 50 mi/h and then travels east at 25 mi/h.
5. Another car travels northwest for 2 hours and covers a distance of 90 miles. What is the average velocity of the car?

7.6 Acceleration

FlexBooks® 2.0 > American HS Physical Science > Acceleration

Last Modified: Nov 02, 2020

[Figure 1]

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

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Defining Acceleration

Acceleration is a measure of the change in velocity of a moving object. It measures the rate at which velocity changes. Velocity, in turn, is a measure of the speed and direction of motion, so a change in velocity may reflect a change in speed, a change in direction, or both. Both velocity and acceleration are vectors. A vector is any measurement that has both size and direction. People commonly think of acceleration as an increase in speed, but a decrease in speed is also acceleration. In this case, acceleration is negative and called deceleration. A change in direction without a change in speed is acceleration as well.

Q: Can you think of an example of acceleration that doesn't involve a change in speed?

A: Driving at a constant speed around a bend in a road is one example. Use your imagination to think of others.

Examples of Acceleration

You can see several examples of acceleration in the pictures from the **Figure** below. In each example, velocity is changing but in different ways. For example, direction may be changing but not speed, or vice versa. Figure out what is moving and how it's moving in each of the photos.

[Figure 2]

Q: Describe how velocity is changing in each of the motions you identified from the **Figure** above.

A: You should describe how both direction and speed are changing. For example, the boy on the carousel is moving up and down and around in a circle, so his direction is constantly changing, but his speed changes only at the beginning and end of the ride. The skydiver is falling straight down toward the ground so her direction isn't changing, but her speed keeps increasing as she falls until she opens her parachute.

Feeling Acceleration

If you are accelerating, you may be able to feel the change in velocity. This is true whether the change is in speed, direction, or both. You often feel acceleration when you ride in a car. As the car speeds up, you feel as though you are being pressed against the seat. When the car slows down, you feel like you are being pushed forward, especially if the change in speed is sudden. If the car changes direction and turns right, you feel as though you are being pushed to the left. With a left turn, you feel a push to the right. The next time you ride in a car, notice how it feels as the car accelerates in each of these ways.

Use this simulation to further explore the acceleration of a model rocket due to gravity. Can you use the graphs to determine when the rocket is speeding up or slowing down?

https://flexbooks.ck12.org/flx/show/interactive/https://interactives.ck12.org/simulations/embed.html?embeded=true&interactive=model-rocket&subject=physics&lang=en&assignment=true&hash=ffff3e85fa649afa4ee90ba7d481af31

Summary

- Acceleration is a measure of the change in velocity of a moving object. It measures the rate at which the change is occurring. It may reflect a change in speed, a change in direction, or both. Like velocity, acceleration is a vector.
- Examples of acceleration include a person riding a carousel and a skydiver in free fall.
- When you experience acceleration, you may be able to feel the changes in speed and/or direction.

Review

1. Define acceleration.
2. Describe an example of acceleration and explain how velocity is changing.
3. The skydiver pictured in the **Figure** above will soon open her parachute. How will her velocity change when the parachute first opens?

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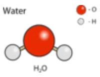	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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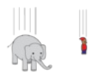
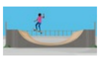
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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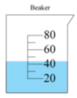
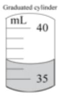
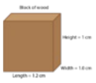
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 8

Forces

Chapter Outline

8.1 Force

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Last Modified: Jun 07, 2021

[Figure 1]

Jean has been riding a scooter for almost as long as he can remember. As you can see, he's really good at it. He can even do tricks in the air. It takes a lot of practice to be able to control a scooter like this. Jean automatically applies just the right forces to control his scooter.

Defining Force

Force is defined as a push or pull acting on an object. There are several fundamental forces in the universe, including the force of gravity, electromagnetic force, and weak and strong nuclear forces. When it comes to the motion of everyday objects, however, the forces of interest include mainly gravity, friction, and applied force. Applied force is force that a person or thing applies to an object.

Q: What forces act on Jean's scooter?

A: Gravity, friction, and applied forces all act on Jean's scooter. Gravity keeps pulling both Jean and the scooter toward the ground. Friction between the wheels of the scooter and the ground prevent the scooter from sliding but also slow it down. In addition, Jean applies forces to his scooter to control its speed and direction.

Force and Motion

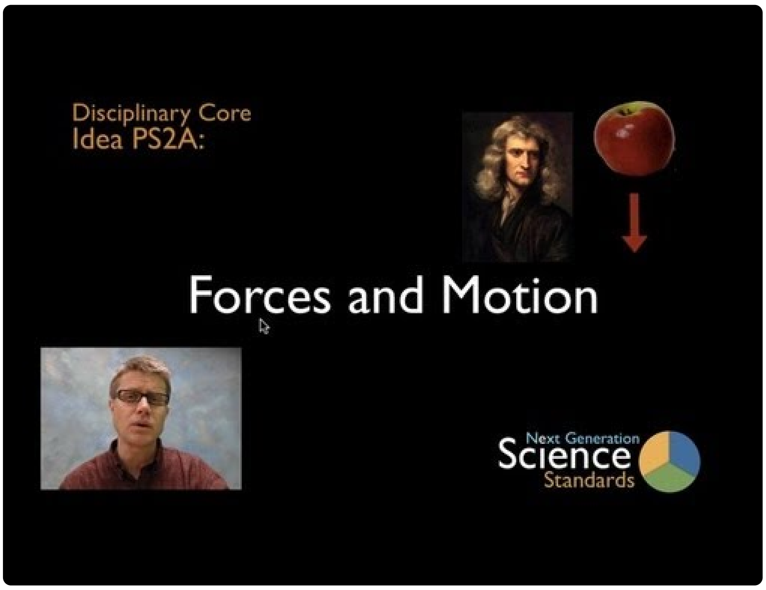
Forces cause all motions. Every time the motion of an object changes, it's because a force has been applied to it. Force can cause a stationary object to start moving or a moving object to change its speed or direction or both. A change in the speed or direction of an object is called acceleration. Look at Jean's brother Gordon in the **Figure** below. He's getting his scooter started by pushing off with his foot. The force he applies to the ground with his foot starts the scooter moving in the opposite direction. The harder he pushes against the ground, the faster the scooter will go.


[Figure 2]

How much an object accelerates when a force is applied to it depends not only on the strength of the force but also on the object's mass. For example, a heavier scooter would be harder to accelerate. Gordon would have to push with more force to start it moving and move it faster.

Q: What units do you think are used to measure force?

A: The SI unit for force is the Newton (N). A **Newton** is the force needed to cause a mass of 1 kilogram to accelerate at 1 m/s^2, so a Newton equals 1 kg • m/s^2. The Newton was named for the scientist Sir Isaac Newton, who is famous for his laws of motion and gravity.



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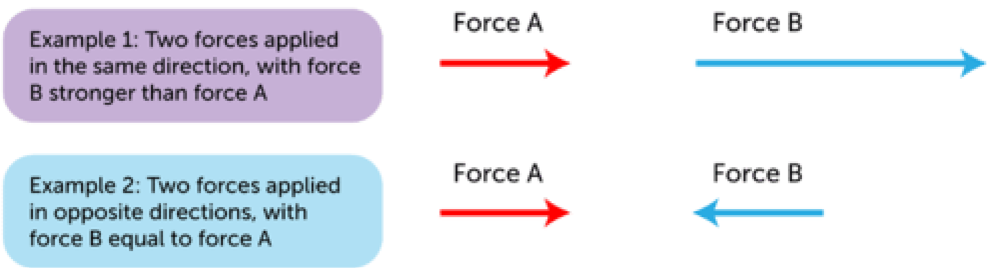
Force as a Vector

Force is a vector, or a measure that has both size and direction. For example, Gordon pushes on the ground in the opposite direction that the scooter moves, so that's the direction of the force he is applies. He can give the scooter a strong push or a weak push. That's the size of the force. Like other vectors, a force can be represented with an arrow. You can see some examples in the **Figure** below. The length of each arrow represents the strength of the force, and the way the arrow points represents the direction of the force.



[Figure 3]

Q: How could you use arrows to represent the forces that start Gordon's scooter moving?

A: Gordon pushes against the ground behind him (to the right in the **Figure** above). The ground pushes back with equal force to the left, causing the scooter to move in that direction. Force arrows A and B (in example 2 in the **Figure** above) could represent these forces.

Summary

- Force is defined as a push or pull acting on an object. Forces include gravity, friction, and applied force.

- Force causes changes in the speed or direction of motion. These changes are called acceleration.
- The SI unit for force is the Newton (N).
- Force is a vector because it has both size and direction. Like other vectors, it can be represented by an arrow.

Review

1. What is force?
2. Relate force and motion.
3. What forces control the motion of everyday objects?
4. Identify and define the SI unit for force.
5. Draw a diagram to represent a foot kicking a resting soccer ball. Use arrows to represent the force applied to the ball and to show how the ball moves after it is kicked.

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8.2 Friction

FlexBooks® 2.0 > American HS Physical Science > Friction

Last Modified: Jan 27, 2020

[Figure 1]

Did you ever rub your hands together to warm them up, like the young man in the opening image? Why does this make your hands warmer? The answer is friction.

What Is Friction?

Friction is a force that opposes motion between any surfaces that are touching. Friction can work for or against us. For example, putting sand on an icy sidewalk increases friction so you are less likely to slip. On the other hand, too much friction between moving parts in a car engine can cause the parts to wear out. Other examples of friction are illustrated in the two **Figures** below and below.

Friction between the graphite in a pencil and a sheet of paper leaves a mark on the paper.

Friction between a bicycle brake pad and the rim of a wheel causes the wheel to stop turning.

[Figure 2]

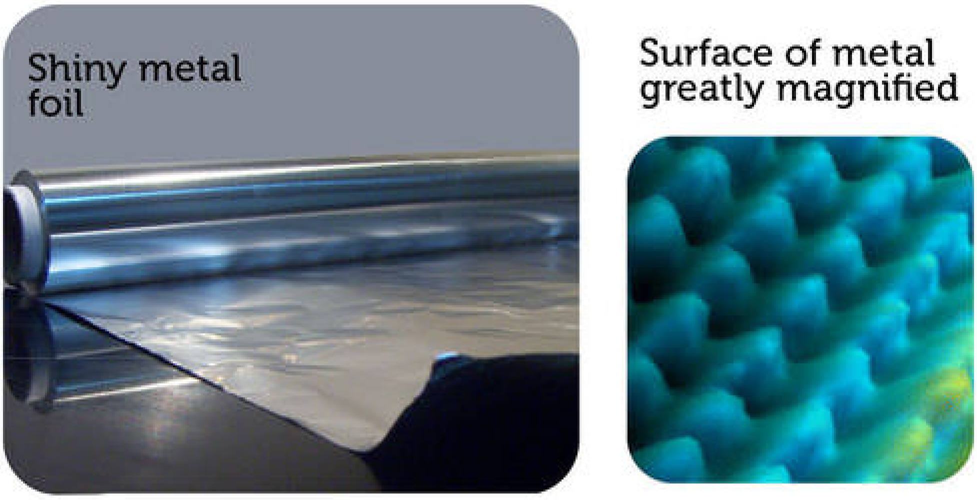
These photos show two ways that friction is useful

Watch the video below to learn more about friction and consider what our life would be like without friction:

https://flexbooks.ck12.org/flx/render/embeddedobject/254450

Why Friction Occurs

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



[Figure 3]

Factors That Affect Friction

Rougher surfaces have more friction between them than smoother surfaces. That's why we put sand on icy sidewalks and roads. You can't slide as far across ice with shoes as you can on the blades of skates (see **Figure** below). The rougher surface of the soles of the shoes causes more friction and slows you down.

[Figure 4]

Q: Heavier objects also have more friction. Can you explain why?

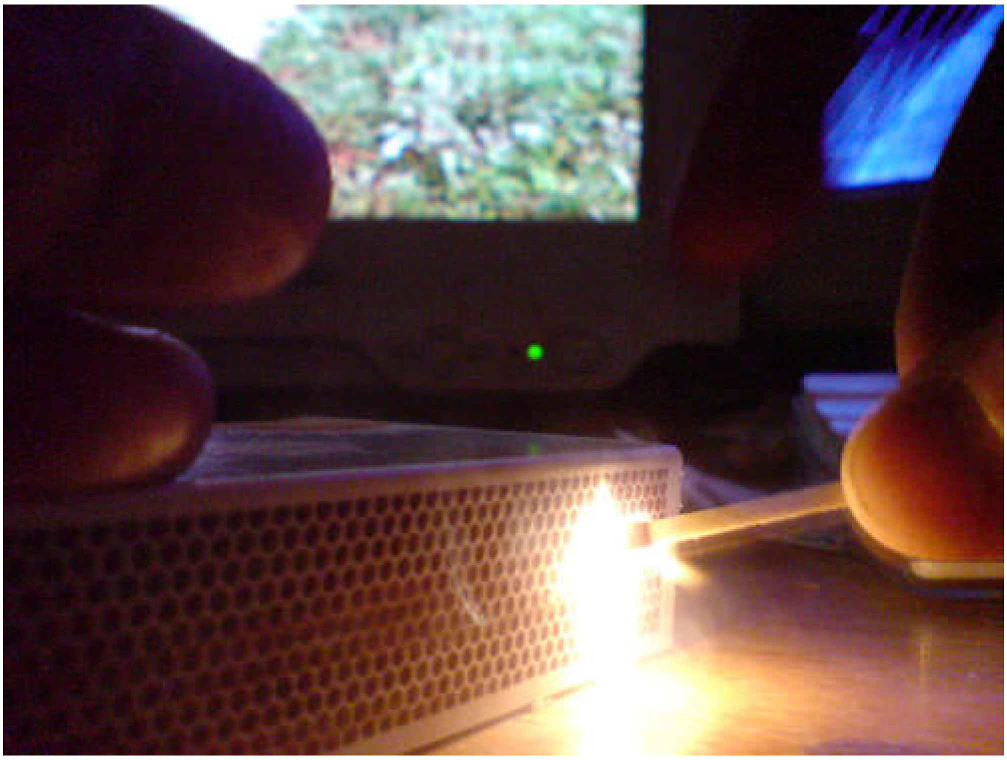
A: Heavier objects press together with greater force, and this causes greater friction between them. Have you ever tried to push furniture across the floor? It's harder to overcome friction between a heavier piece of furniture and the floor than between lighter pieces and the floor.

Friction Produces Heat

You know that friction produces heat. That's why rubbing your hands together makes them warmer. But do you know why? Friction causes the molecules on rubbing surfaces to move faster, so they have more energy. This gives them a higher temperature, and they feel warmer. Heat from friction can be useful. It not only warms your hands. It also lets you light a match as shown in the **Figure** below. On the other hand, heat from friction between moving parts inside a car engine can be a big problem. It can cause the car to overheat.

Q: How is friction reduced between the moving parts inside a car engine?

A: To reduce friction, oil is added to the engine. The oil coats the surfaces of the moving parts and makes them slippery. They slide over each other more easily, so there is less friction.



[Figure 5]

Summary

- Friction is a force that opposes motion between any surfaces that are touching.
- Friction occurs because no surface is perfectly smooth.

- Rougher surfaces have more friction between them. Heavier objects also have more friction because they press together with greater force.
- Friction produces heat because it causes the molecules on rubbing surfaces to move faster and have more energy.

Review

1. Define friction, and explain why it occurs.
2. Identify two factors that affect friction.
3. Why does friction warm your hands when you rub them together?
4. Outside wooden steps may get slippery when they are wet. How could you make them less slippery?

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8.3 Gravity

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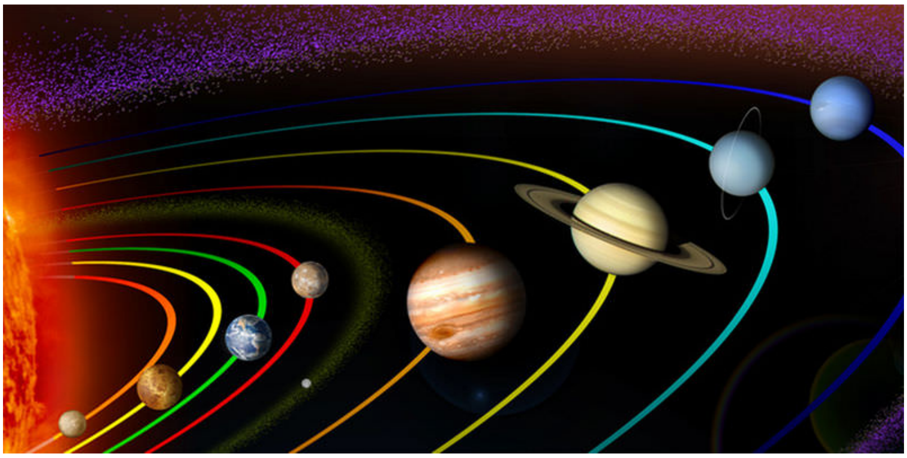
Last Modified: Aug 13, 2019



[Figure 1]

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

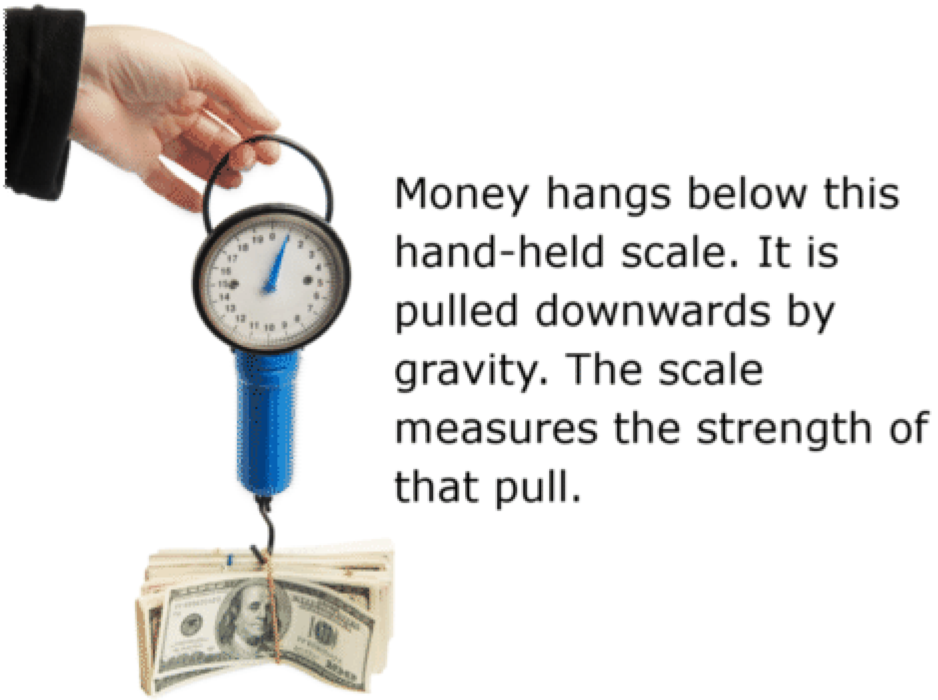
You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from being flung out into space as the planet spins on its axis. It also pulls objects that are above the surface—from meteors to skydivers—down to 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. 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** below. The scale measures the force with which gravity pulls an object downward.



[Figure 2]

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

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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.

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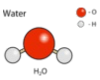	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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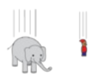	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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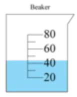
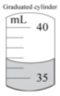
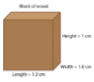
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 9

Newton's Laws of Motion

Chapter Outline

9.1 Newton's First Law

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Last Modified: Dec 06, 2021

[Figure 1]

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.

Keep on Rolling

Have you ever ridden a skateboard? If so, 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.

Therefore, a skateboard at rest will remain at rest unless acted upon by an unbalanced force. In the absence of friction or any other unbalanced force, a skateboard in motion will just keep on rolling!

Starting and Stopping

So how do we change motion? 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 below.

[Figure 2]

[Figure 3]

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

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.

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 4]

Corey's friend Jerod likes to skate on the flat banks at Newton's Skate Park. That's Jerod in the **Figure** above. 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.

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 5]

3. Jerod ran into a rough patch of pavement, but he thought she could ride right over it. Instead, the skateboard stopped suddenly and Jerod ended up on the ground (see **Figure** above). 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?

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9.2 Newton's Second Law

FlexBooks® 2.0 > American HS Physical Science > Newton's Second Law

Last Modified: Aug 22, 2019

[Figure 1]

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:

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

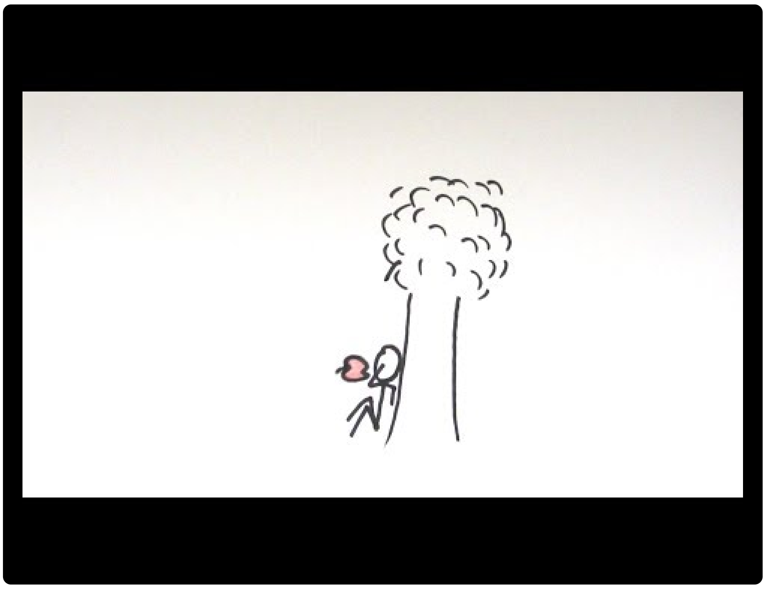
or $a = \frac{F}{m}$

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** below, 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 2]

Watch the video below to learn more about Newton's second law and the relationship between force, mass, and acceleration:



https://flexbooks.ck12.org/flx/render/embeddedobject/161710

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:

https://flexbooks.ck12.org/flx/render/embeddedobject/177561

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

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9.3 Newton's Third Law

FlexBooks® 2.0 > American HS Physical Science > Newton's Third Law

Last Modified: Apr 29, 2020

[Figure 1]

This is a sketch of Jerod on his skateboard. He's on his way to Newton's Skate Park. When he pushes his foot against the ground, what happens next? He moves on his skateboard in the opposite direction. How does this happen?

Action and Reaction

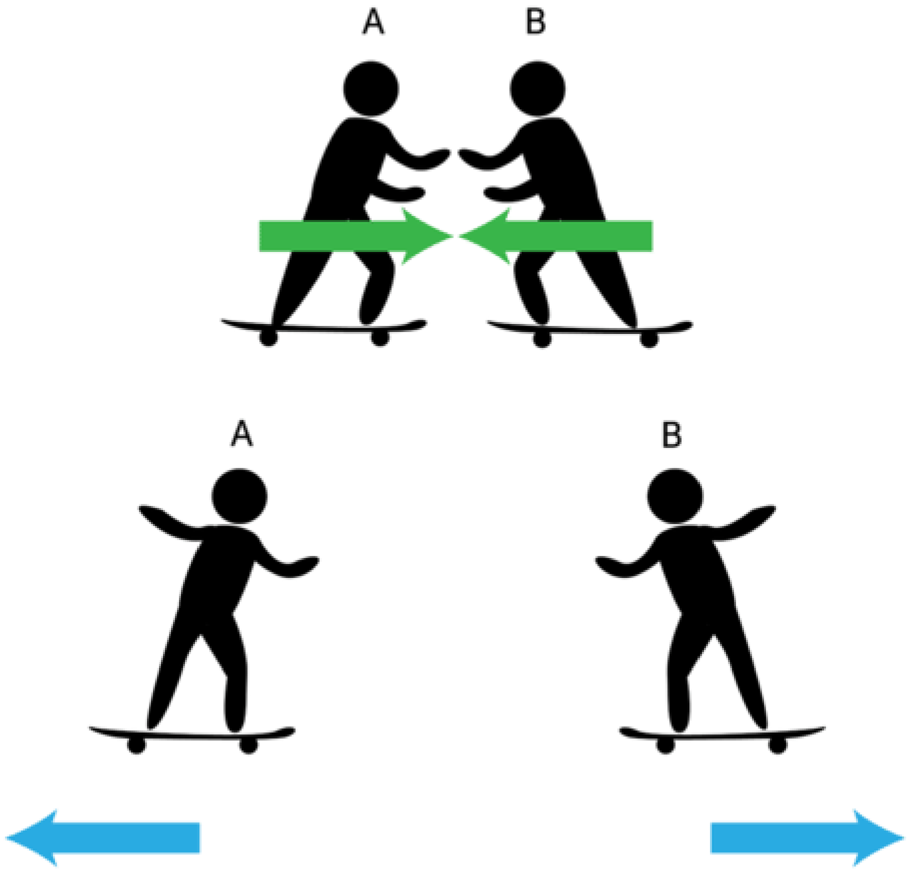
Newton's third law of motion explains how Jerod starts his skateboard moving. This law states that every action has an equal and opposite reaction. This means that forces always act in pairs. First an action occurs—Jerod pushes against the ground with his foot. Then a reaction occurs—the ground pushes back on Jerod! This force causes Jerod to move forward. The reaction is always equal in strength to the action but in the opposite direction.

Q: If Jerod pushes against the ground with greater force, how will this affect his forward motion?

A: His action force will be greater, so the reaction force will be greater as well. Jerod will be pushed forward by the ground with more force, and this will make him go faster and farther.

Equal and Opposite Forces

The forces involved in actions and reactions can be represented with arrows. The way an arrow points shows the direction of the force, and the size of the arrow represents the strength of the force. Look at the skateboarders in the **Figure** below. In the top row, the arrows represent the forces with which the skateboarders push against each other. This is the action. In the bottom row, the arrows represent the forces with which the skateboarders move apart. This is the reaction. Compare the top and bottom arrows. They point in different directions, but they are the same size. This shows that the reaction forces are equal and opposite to the action forces.



[Figure 2]

Equal and Opposite but Not Balanced

Because action and reaction forces are equal and opposite, you might think they would cancel out, as balanced forces do. But you would be wrong. Balanced forces are equal and opposite forces that act on the same object. That's why they cancel out. Action-reaction forces are equal and opposite forces that act on different objects, so they don't cancel out. In fact, they often result in motion. Think about Jerod again. He applies force with his foot to the ground, whereas the ground applies force to Jerod and the skateboard, causing them to move forward.

Q: Actions and reactions occur all the time. Can you think of an example in your daily life?

A: Here's one example. If you lean on something like a wall or your locker, you are applying force to it. The wall or locker applies an equal and opposite force to you. If it didn't, you would go right through it or else it would tip over.

Watch the video below to learn more about Newton's third law of motion:

https://flexbooks.ck12.org/flx/render/embeddedobject/187300

Summary

- Newton's third law of motion states that every action has an equal and opposite reaction. This means that forces always act in pairs.
- Action and reaction forces are equal and opposite, but they are not balanced forces because they act on different objects so they don't cancel out.

Review

1. State Newton's third law of motion.
2. Describe an example of an action and reaction. Identify the forces and their directions.
3. Explain why action and reaction forces are not balanced forces.

Explore More

Watch this video about Newton's third law of motion and then answer the questions that follow:

https://flexbooks.ck12.org/flx/render/embeddedobject/270513

1. Describe all the forces acting on the coffee mug as it is resting on the coffee table.
2. Identify one action and reaction force pair involving the coffee mug resting on the coffee table.

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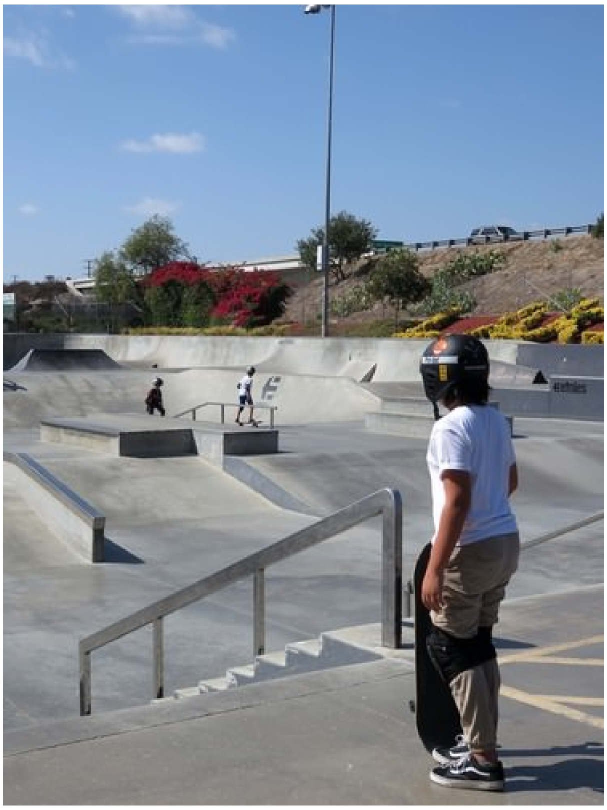
9.4 Momentum

FlexBooks® 2.0 > American HS Physical Science > Momentum

Last Modified: Jun 07, 2021



[Figure 1]

Cody seems a little reluctant to launch himself down this ramp at Newton's Skate Park. It will be his first time down the ramp, and he knows from watching his older brother Jerod that he'll be moving fast by the time he gets to the bottom. The faster he goes, the harder it will be to stop. That's because of momentum.

What Is Momentum?

Momentum is a property of a moving object that makes it hard to stop. The more mass it has or the faster it's moving, the greater its momentum. Momentum equals mass times velocity and is represented by the equation:

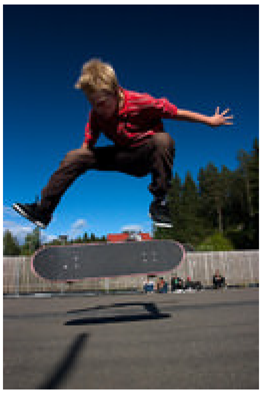
Momentum = Mass × Velocity

Q: What is Cody's momentum as he stands at the top of the ramp?

A: Cody has no momentum as he stands there because he isn't moving. In other words, his velocity is zero. However, Cody will gain momentum as he starts moving down the ramp and picks up speed.

Q: Cody's older brother Jerod is pictured in the **Figure** below. If Jerod were to travel down the ramp at the same velocity as Cody, who would have greater momentum? Who would be harder to stop?

A: Jerod obviously has greater mass than Cody, so he would have greater momentum. He would also be harder to stop.



[Figure 2]

Calculating Momentum

To calculate momentum with the equation above, mass is measured in (kg), and velocity is measured in meters per second (m/s). For example, Cody and his skateboard have a combined mass of 40 kg. If Cody is traveling at a velocity of 1.1 m/s by the time he reaches the bottom of the ramp, then his momentum is:

Momentum = 40 kg × 1.1 m/s = 44 kg • m/s

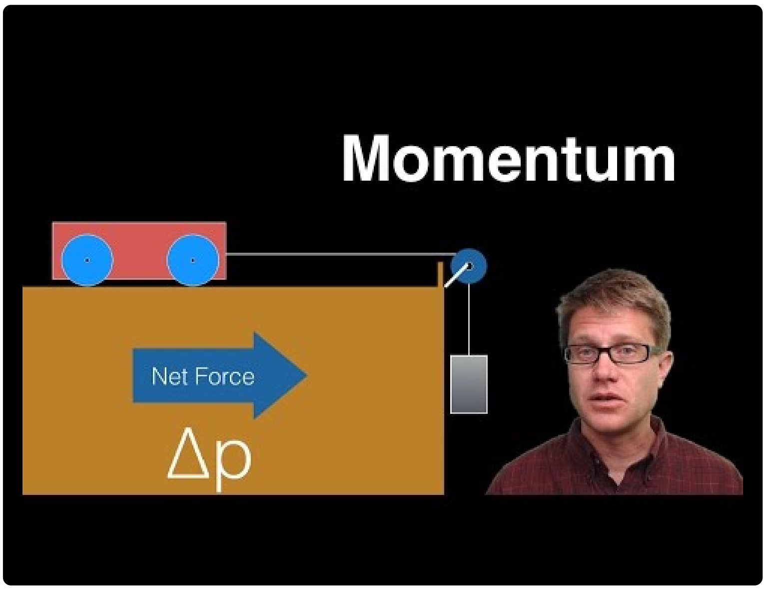
Note that the SI unit for momentum is kg • m/s.

Q: The combined mass of Jerod and his skateboard is 68 kg. If Jerod goes down the ramp at the same velocity as Cody, what is his momentum at the bottom of the ramp?

A: His momentum is:

Momentum = 68 kg × 1.1 m/s = 75 kg • m/s

Watch the video below to learn more about calculating the momentum of a moving object:



https://flexbooks.ck12.org/flx/render/embeddedobject/187302

Summary

- Momentum is a property of a moving object that makes it hard to stop. It equals the object's mass times its velocity.
- To calculate the momentum of a moving object, multiply its mass in kilograms (kg) by its velocity in meters per second (m/s). The SI unit of momentum is kg • m/s.

Review

1. Define momentum.
2. Write the equation for calculating momentum from mass and velocity.
3. What is the SI unit for momentum?
4. Which skateboarder has greater momentum?
   a. Skateboarder A: mass = 60 kg; velocity = 1.5 m/s
   b. Skateboarder B: mass = 50 kg; velocity = 2.0 m/s

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9.5 Conservation of Momentum

FlexBooks® 2.0 > American HS Physical Science > Conservation of Momentum

Last Modified: Jul 09, 2021

[Figure 1]

These skaters are racing each other at Newton's Skate Park. The first skater in line loses focus on her task. She starts to slow down without realizing it. The skater behind her isn't paying attention and keeps skating at the same speed.

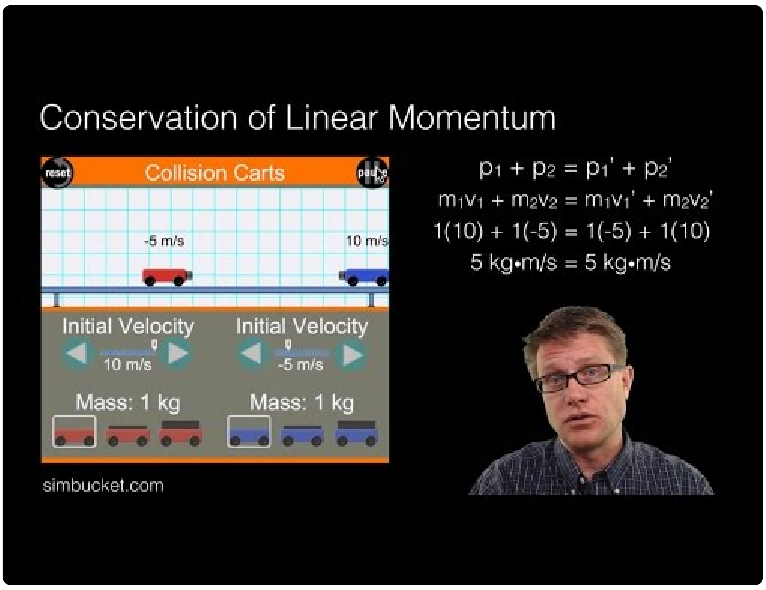
Q: Can you guess what happens next?

A: Skater 2 runs into skater 1.

Conserving Momentum

When skater 2 runs into skater 1, she's going faster than skater 1 so she has more momentum. **Momentum** is a property of a moving object that makes it hard to stop. It's a product of the object's mass and velocity. At the moment of the collision, skater 2 transfers some of her momentum to skater 1, who shoots forward when skater 2 runs into her. Whenever an action and reaction such as this occur, momentum is transferred from one object to the other. However, the combined momentum of the objects remains the same. In other words, momentum is conserved. This is the **law of conservation of momentum**.

Watch the video below to learn more:



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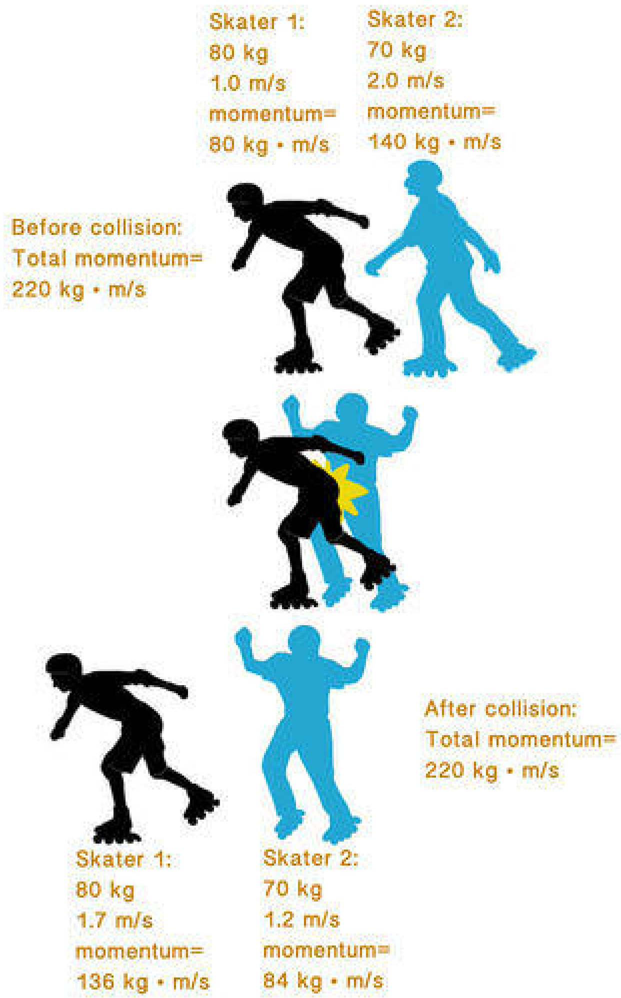
Modeling Momentum

The **Figure** below shows how momentum is conserved in the two colliding skaters. The total momentum is the same after the collision as it was before. However, after the collision, skater 1 has more momentum and skater 2 has less momentum than before.



[Figure 2]

Q: What if two skaters have a head-on collision? Do you think momentum is conserved then?

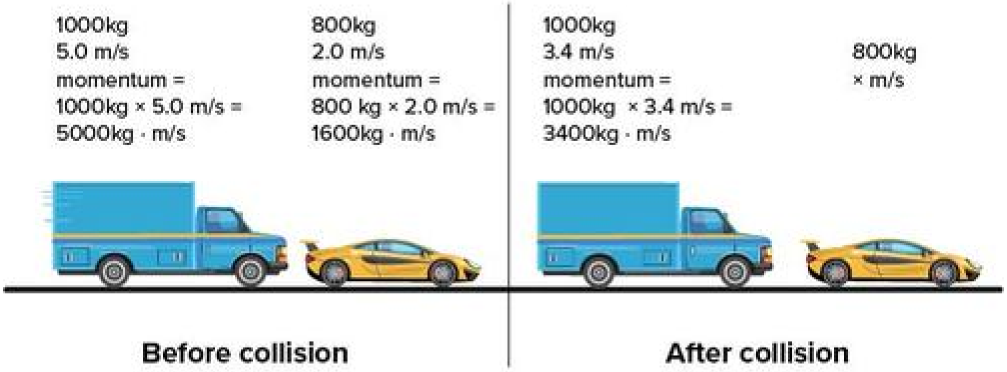
A: As in all actions and reactions, momentum is also conserved in a head-on collision.

Summary

- Whenever an action and reaction occur, momentum is transferred from one object to the other. However, total momentum is conserved. This is the law of conservation of momentum.

Review

1. State the law of conservation of momentum.
2. Fill in the missing velocity (x) in the diagram of a vehicle collision seen in the **Figure** below so that momentum is conserved.



[Figure 3]

Solve for x.

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9.6 References

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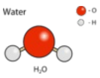	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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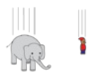
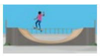
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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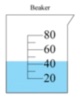
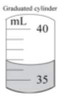
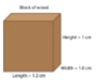
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 10

Work and Machines

Chapter Outline

10.1 Work

FlexBooks® 2.0 > American HS Physical Science > Work

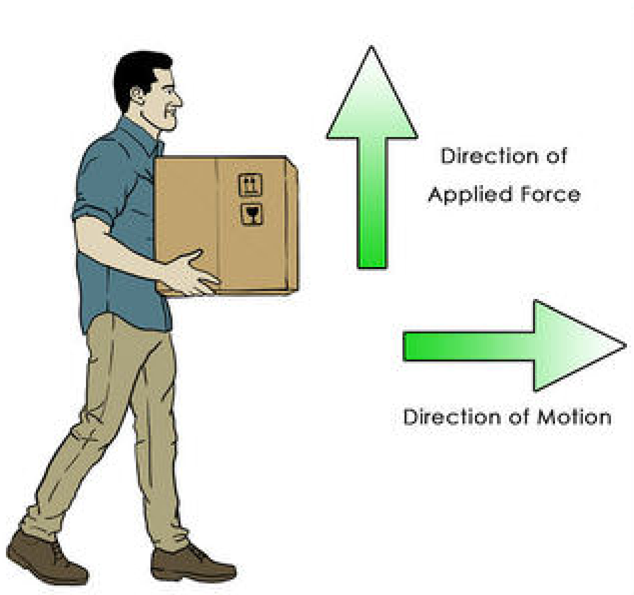
Last Modified: Nov 03, 2021

[Figure 1]

The kids in the picture on the left are having fun playing flag football. The teen in the picture on the right is working hard studying for an exam. It's obvious who is doing work—or is it? Would it surprise you to learn that the kids who are working are the ones who are having fun playing football, while the teen who is studying isn't doing any work at all? The reason why has to do with how work is defined in physics.

Defining Work

Work is defined differently in physics than in everyday language. In physics, **work** means the use of force to move an object. The kids who are playing football in the picture above are using force to move their bodies and the football, so they are doing work. The teen who is studying isn't moving anything, so she isn't doing work. Not all force that is used to move an object does work. For work to be done, the force must be applied in the same direction that the object moves. If a force is applied in a different direction than the object moves, no work is done. The **Figure** below illustrates this point.



[Figure 2]

When the man lifts the box he must do work in the vertical direction. As he moves forward, no more work is done in the vertical direction.

Q: If the box the man is carrying is very heavy, does he do any work to keep it raised as he walks across the room with it?

A: Regardless of the weight of the box, the man does no work on to hold it while walking across the room. However, he does have to do some work to get the box moving in the horizontal direction.

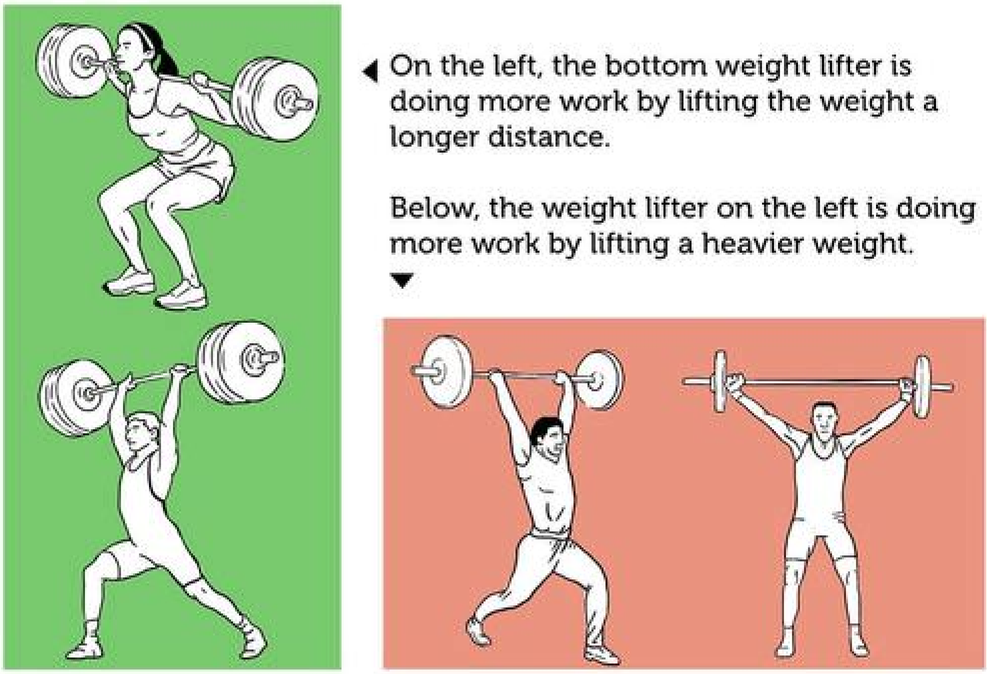
Work, Force, and Distance

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

Work = Force × Distance

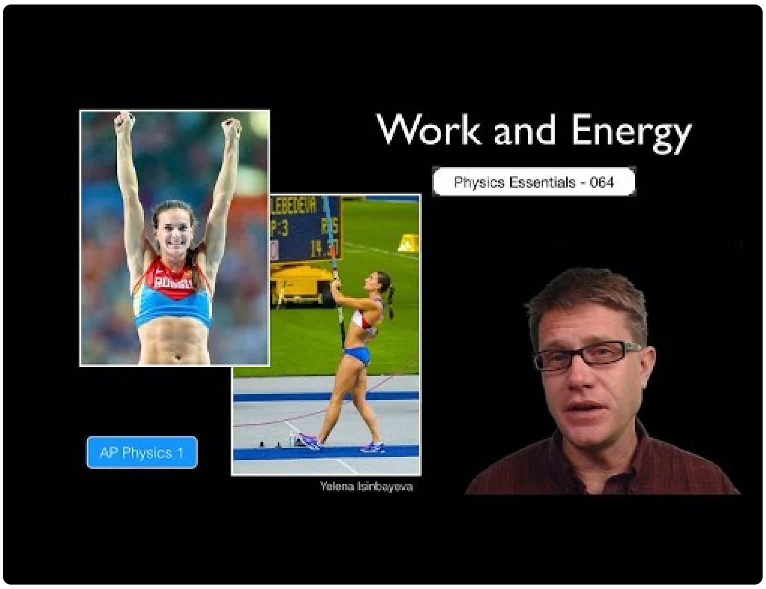
This equation shows that the greater the force that is used to move an object or the farther the object is moved, the more work that is done.

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



[Figure 3]

Watch the video below to learn more about the relationship between work and energy:



https://flexbooks.ck12.org/flx/render/embeddedobject/187320

Summary

- In physics, work is defined as the use of force to move an object. For work to be done, the force must be applied in the same direction that the object moves.
- Work is directly related to both the force applied to an object and the distance the object moves. It can be represented by the equation: Work = Force × Distance.

Review

1. How is work defined in physics?
2. Write the equation that relates work to force and distance.
3. Assume that a friend hands you a heavy book to hold as he turns the combination lock on his locker. Which of you does more work?

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10.2 Machine

FlexBooks® 2.0 > American HS Physical Science > Machine

Last Modified: May 20, 2019

[Figure 1]

When you hear the word *machine*, do you think of power tools or construction equipment, like the ones pictured above? While both of these examples are machines, you might be surprised to learn that devices as simple as hammers and screws are also machines.

Q: Why are simple tools considered to be machines?

A: Like all machines, they change forces and make work easier.

What Is A Machine?

A **machine** is any device that makes work easier by changing a force. Work is done whenever a force moves an object over a distance. The amount of work done is represented by the equation:

Work = Force x Distance

When you use a machine, you apply force to the machine. This force is called the input force. The machine, in turn, applies force to an object. This force is called the output force. The output force may or may not be the same as the input force. The force you apply to the machine is applied over a given distance, called the input distance. The force applied by the machine to the object is also applied over a distance, called the output distance. The output distance may or may not be the same as the input distance.

How Machines Make Work Easier

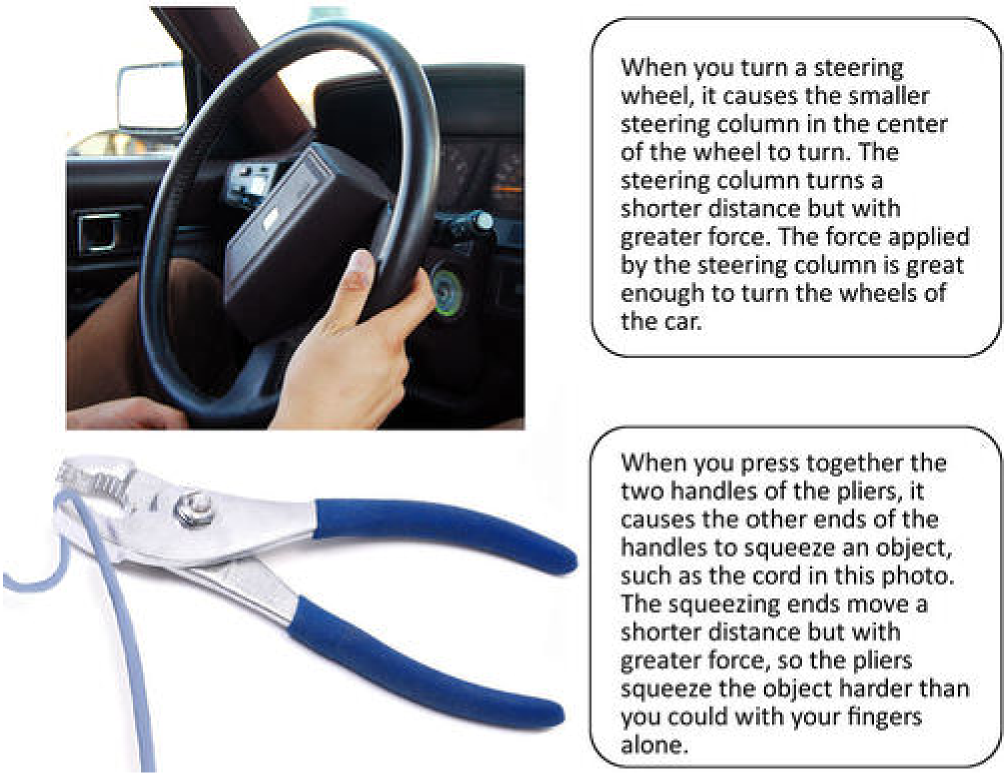
Contrary to popular belief, machines do not increase the amount of work that is done. They just change how the work is done. Machines make work easier by increasing the amount of force that is applied, increasing the distance over which the force is applied, or changing the direction in which the force is applied.

Q: If a machine increases the force applied, what does this tell you about the distance over which the force is applied by the machine:

A: The machine must apply the force over a shorter distance. That's because a machine doesn't change the amount of work and work equals force times distance. Therefore, if force increases, distance must decrease. For the same reason, if a machine increases the distance over which the force is applied, it must apply less force.

Increasing Force

Examples of machines that increase force are steering wheels and pliers (see **Figure** below). Read below to find out how both of these machines work. In each case, the machine applies more force than the user applies to the machine, but the machine applies the force over a shorter distance.



[Figure 2]

Increasing Distance

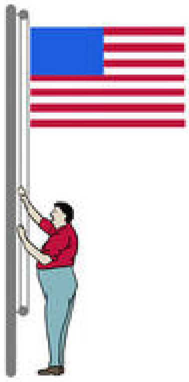
Examples of machines that increase the distance over which force is applied are leaf rakes and hammers (see **Figure** below). Read below to find out how these two machines work. In each case, the machine increases the distance over which the force is applied, but it reduces the strength of the force.

[Figure 3]

Changing the Direction of Force

Some machines change the direction of the force applied by the user. They may or may not also change the strength of the force or the distance over which the force is applied. Two examples of machines that work this way are the claw ends of hammers and flagpole pulleys. You can see in the **Figure** below how each of these machines works. In both cases, the direction of the force applied by the user is reversed by the machine.

When the user of the hammer pushes down on the handle, the claw of the hammer pulls up on the nail. The hammer changes the direction of the force. It also applies greater force over a smaller distance.



The rope on a flagpole wraps around the pulley, which is a wheel with a groove in the rim. When a person pulls down on one end of the rope, the other end of the rope pulls up on the flag. However, the pulley doesn't change the strength of the force or the distance over which it is applied.

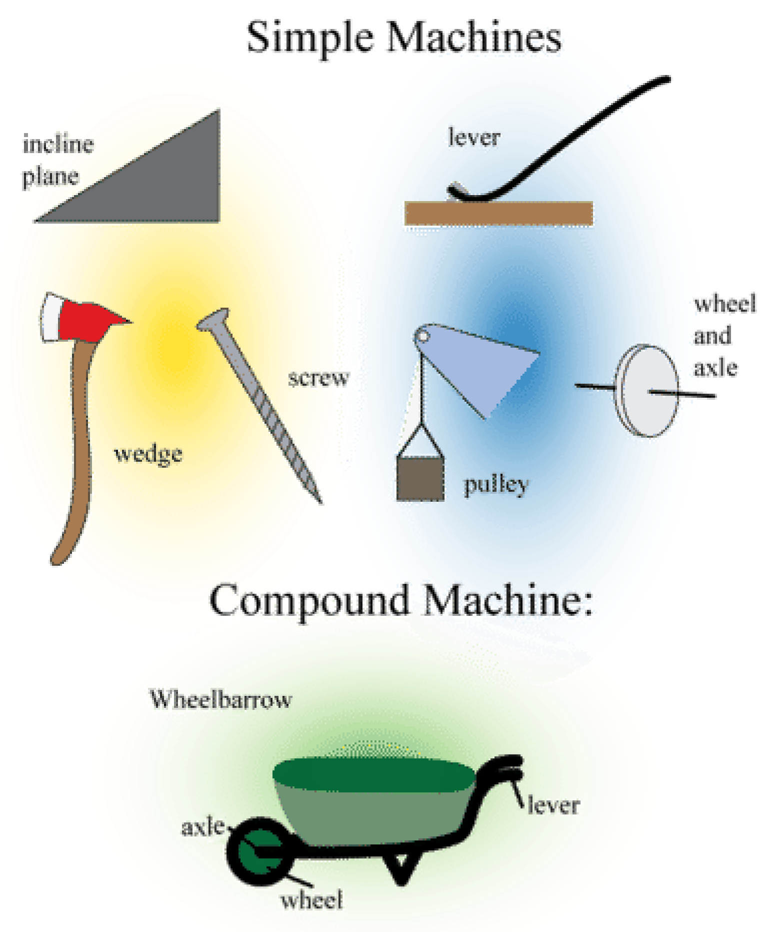
[Figure 4]

Q: If the pulley only changes the direction of the force, how does it make the work of raising the flag easier?

A: The pulley makes it easier to lift the flag because it allows a person to pull down on the rope and add his or her own weight to the effort, rather than simply lifting the load.

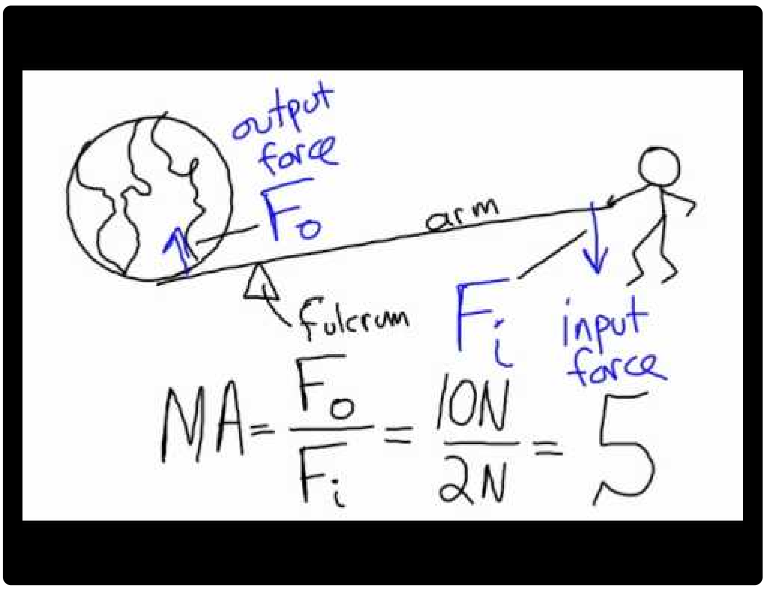
Simple and Compound Machines

There are six types of simple machines that are the basis of all other machines. They are the inclined plane, lever, wedge, screw, pulley, and wheel and axle. The six types are pictured in the **Figure** below. You've probably used some of these simple machines yourself. Most machines are combinations of two or more simple machines. These machines are called compound machines. An example of a compound machine is a wheelbarrow (see bottom of **Figure** below). It consists of two simple machines: a lever and a wheel and axle. Many compound machines are much more complex and consist of many simple machines. Examples include washing machines and cars.



[Figure 5]

Watch this video to learn more about simple machines:



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Summary

- A machine is any device that makes work easier by changing a force.
- Machines may increase the strength of the force, increase the distance over which the force is applied, or change the direction in which the force is applied.
- There are six types of simple machines. Machines that consist of two or more simple machines are called compound machines.

Review

1. What is a machine?
2. List three ways that machines may change a force.
3. Can a machine increase both the force and the distance over which the force is applied? Why or why not?
4. A broom is an example of a machine. Where are the input and output forces applied?
5. Look at the pictures of simple machines in the **Figure** above. Which type of simple machine is represented by each of the following tools?
   a. hammer
   b. ladder
   c. knife
   d. doorknob

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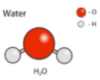	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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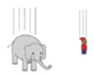	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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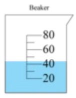
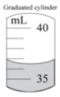
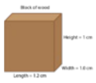
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 11

Introduction to Energy

Chapter Outline

11.1 Energy

FlexBooks® 2.0 > American HS Physical Science > Energy

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[Figure 1]

These young children are very active. They seem to be brimming with energy. You probably know that lots of things have energy—from batteries to the sun. But do you know what energy is? Read on to find out.

Defining Energy

Energy is defined in science as the ability to move matter or change matter in some other way. Energy can also be defined as the ability to do work, which means using force to move an object over a distance. When work is done, energy is transferred from one object to another. For example, when the boy in the **Figure** below uses force to swing the racket, he transfers some of his energy to the racket.

[Figure 2]

Q: It takes energy to play tennis. Where does this boy get his energy?

A: He gets energy from the food he eats.

SI Unit for Energy

Because energy is the ability to do work, it is expressed in the same unit that is used for work. The SI unit for both work and energy is the joule (J), or Newton · meter (N · m). One joule is the amount of energy needed to apply a force of 1 Newton over a distance of 1 meter. For example, suppose the boy in the **Figure** above applies 20 Newtons of force to his tennis racket over a distance of 1 meter. The energy needed to do this work is 20 N ·m, or 20 J.

Energy Has Many Forms

If you think about different sources of energy—such as batteries and the sun—you probably realize that energy can take different forms. For example, when the boy swings his tennis racket, the energy of the moving racket is an example of mechanical energy. To move his racket, the boy needs energy stored in food, which is an example of chemical energy. Other forms of energy include electrical, thermal, light, and sound energy. The different forms of energy can also be classified as either kinetic energy or potential energy. Kinetic energy is the energy of moving matter. Potential energy is energy that is stored in matter.

Q: Is the chemical energy in food kinetic energy or potential energy?

A: The chemical energy in food is potential energy. It is stored in the chemical bonds that make up food molecules. The stored energy is released when we digest food. Then we can use it for many purposes, such as moving (mechanical energy) or staying warm (thermal energy).

Q: What is an example of kinetic energy?

A: Anything that is moving has kinetic energy. An example is a moving tennis racket.

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Summary

- Energy is defined in science as the ability to move matter or change matter in some other way. Energy can also be defined as the ability to do work.
- The SI unit for energy as well as work is the joule (J), or Newton · meter (N · m).
- Energy exists in different forms, such as mechanical energy and chemical energy. Most forms of energy can also be classified as either kinetic energy or potential energy.

Review

1. How is energy defined in science?
2. What is the SI unit for energy?
3. Name two forms that energy may take.
4. Which type of energy is the energy of a moving tennis ball? Is it kinetic energy or potential energy?

11.2 Kinetic Energy

FlexBooks® 2.0 > American HS Physical Science > Kinetic Energy

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[Figure 1]

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** below 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:

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

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 2]

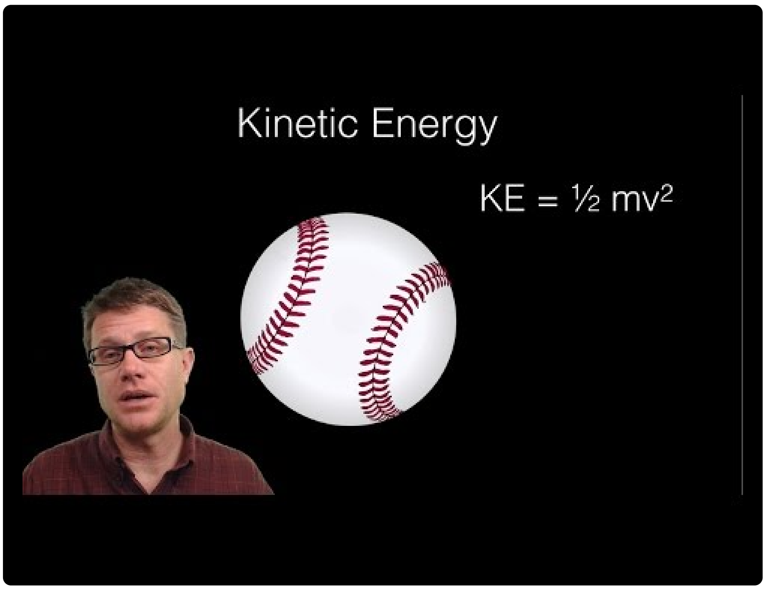
What about Juan's dad? His mass is 80 kg, and he's running at the same velocity as Juan (1 m/s). Because his mass is twice as great as Juan's, his kinetic energy is twice as great:

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

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:

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



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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: $\text{KE} = \frac{1}{2}\text{mass} \times \text{velocity}^2$.

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** below 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 3]

11.3 Potential Energy

FlexBooks® 2.0 > American HS Physical Science > Potential Energy

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[Figure 1]

This diver has just jumped up from the end of the diving board. After she dives down and is falling toward the water, she'll have kinetic energy, or the energy of moving matter. But even as she is momentarily stopped high above the water, she has energy. Do you know why?

Stored Energy

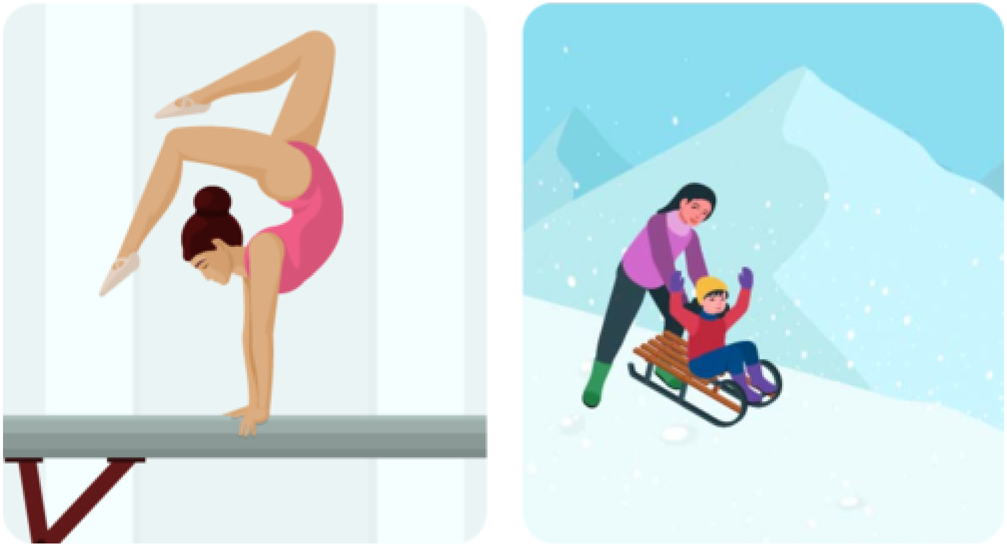
The diver has energy because of her position high above the pool. The type of energy she has is called potential energy. **Potential energy** is energy that is stored in a person or object. Often, the person or object has potential energy because of its position or shape.

Q: What is it about the diver's position that gives her potential energy?

A: Because the diver is high above the water, she has the potential to fall toward Earth because of gravity. This gives her potential energy.

Gravitational Potential Energy

Potential energy due to the position of an object above Earth's surface is called gravitational potential energy. Like the diver on the diving board, anything that is raised up above Earth's surface has the potential to fall because of gravity. You can see another example of people with gravitational potential energy in the **Figure** below.



[Figure 2]

Gravitational potential energy depends on an object's weight and its height above the ground. It can be calculated with the equation:

Gravitational potential energy (GPE) = weight × height

Consider the little girl on the sled, pictured in the **Figure** above. She weighs 140 Newtons, and the top of the hill is 4 meters higher than the bottom of the hill. As she sits at the top of the hill, the child's gravitational potential energy is:

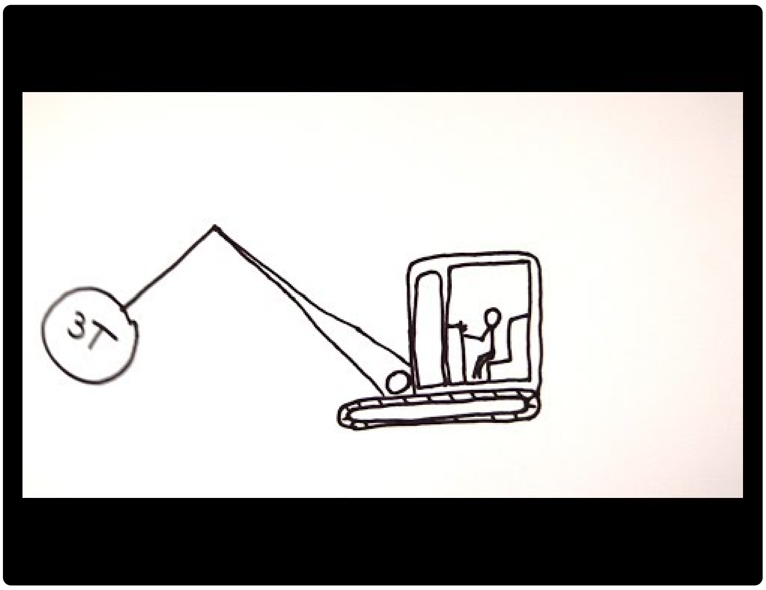
GPE = 140 N × 4 m = 560 N • m

Notice that the answer is given in Newton • meters (N • m), which is the SI unit for energy. A Newton · meter is the energy needed to move a weight of 1 Newton over a distance of 1 meter. A Newton • meter is also called a joule (J).

Q: The gymnast on the balance beam pictured in the **Figure** above weighs 360 Newtons. If the balance beam is 1.2 meters above the ground, what is the gymnast's gravitational potential energy?

A: Her gravitational potential energy is:

GPE = 360 N × 1.2 m = 432 N • m, or 432 J



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Elastic Potential Energy

Potential energy due to an object's shape is called elastic potential energy. This energy results when an elastic object is stretched or compressed. The farther the object is stretched or compressed, the greater its potential energy is. A point will be reached when the object can't be stretched or compressed any more. Then it will forcefully return to its original shape.

Look at the pogo stick in the **Figure** below. Its spring has elastic potential energy when it is pressed down by the boy's weight. When it can't be compressed any more, it will spring back to its original shape. The energy it releases will push the pogo stick—and the boy—off the ground.

[Figure 3]

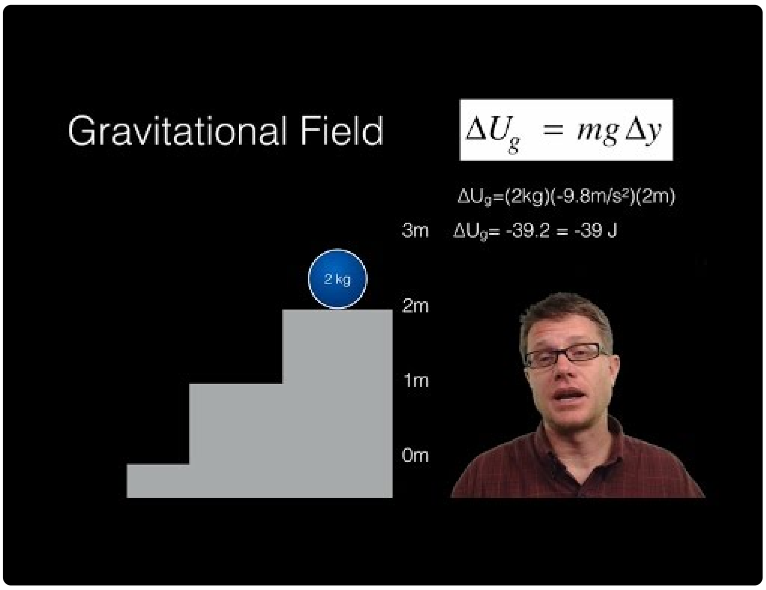
Q: The girl in the **Figure** below is giving the elastic band of her slingshot potential energy by stretching it. She's holding a small stone against the stretched band. What will happen when she releases the band?

A: The elastic band will spring back to its original shape. When that happens, watch out! Some of the band's elastic potential energy will be transferred to the stone, which will go flying through the air.

[Figure 4]

Other Forms of Potential Energy

All of the examples of potential energy described above involve movement or the potential to move. The form of energy that involves movement is called mechanical energy. Other forms of energy also involve potential energy, including chemical energy and nuclear energy. Chemical energy is stored in the bonds between the atoms of compounds. For example, food and batteries both contain chemical energy. Nuclear energy is stored in the nuclei of atoms because of the strong forces that hold the nucleus together. Nuclei of radioactive elements such as uranium are unstable, so they break apart and release the stored energy.



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Summary

- Potential energy is energy that is stored in a person or object.
- Gravitational potential energy is due to the position of an object above Earth's surface. The object has the potential to fall due to gravity. Gravitational potential energy depends on an object's weight and its height above the ground (GPE = weight x height).
- Elastic potential energy is due to an object's shape. It results when an elastic object is stretched or compressed. The more it is stretched or compressed, the greater its elastic potential energy is.
- Chemical energy and nuclear energy are other forms of potential energy.

Review

1. What is potential energy?
2. Compare and contrast gravitational and elastic potential energy, and give an example of each.
3. The diver on the diving board in the opening picture weighs 500 Newtons. The diving board is 5 meters above the ground. What is the diver's gravitational potential energy?
4. Why does food have potential energy?

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11.4 Energy Conversion

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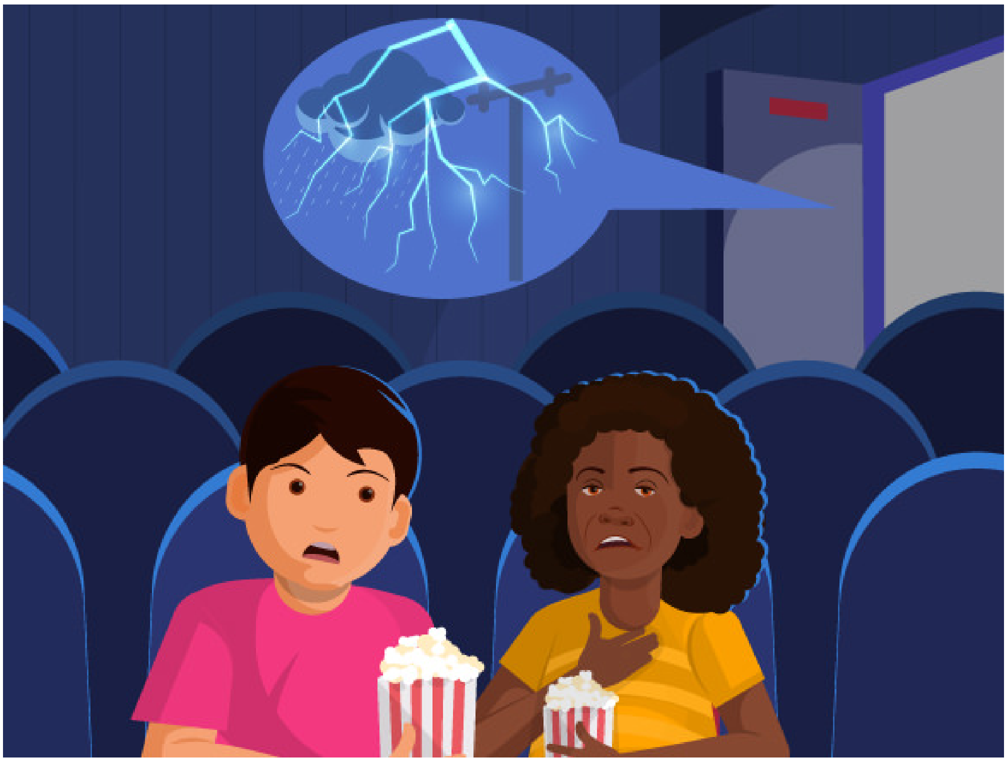


[Figure 1]

Sari and Daniel are spending a stormy Saturday afternoon with cartons of hot popcorn and a spellbinding movie. They are obviously too focused on the movie to wonder where all the energy comes from to power their weekend entertainment. They'll give it some thought halfway through the movie when the storm causes the power to go out!

Changing Energy

Watching movies, eating hot popcorn, and many other activities depend on electrical energy. Most electrical energy comes from the burning of fossil fuels, which contain stored chemical energy. When fossil fuels are burned, the chemical energy changes to thermal energy and the thermal energy is then used to generate electrical energy. These are all examples of energy conversion. **Energy conversion** is the process in which one kind of energy changes into another kind. When energy changes in this way, the energy isn't used up or lost. The same amount of energy exists after the conversion as before. Energy conversion obeys the law of conservation of energy, which states that energy cannot be created or destroyed.

How Energy Changes Form

Besides electrical, chemical, and thermal energy, some other forms of energy include mechanical and sound energy. Any of these forms of energy can change into any other form. Often, one form of energy changes into two or more different forms. For example, the popcorn machine below changes electrical energy to thermal energy. The thermal energy, in turn, changes to both mechanical energy and sound energy. You can read the **Figure** below how these changes happen.

Energy Conversions in a Popcorn Machine

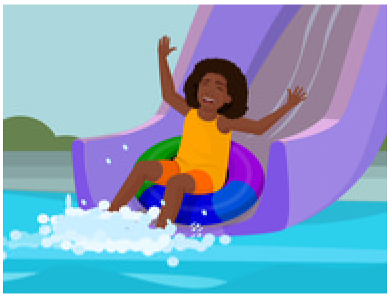
[Figure 2]

1. The popcorn machine changes electrical to thermal energy, which heats the popcorn. 2. The heat causes the popcorn to pop. You can see that the popping corn has mechanical energy (energy of movement). It overflows the pot and falls into the pile of popcorn at the bottom of the machine. 3. The popping corn also has energy. That's why it makes popping sounds.

Kinetic-Potential Energy Changes

Mechanical energy commonly changes between kinetic and potential energy. Kinetic energy is the energy of moving objects. Potential energy is energy that is stored in objects, typically because of their position or shape. Kinetic energy can be used to change the position or shape of an object, giving it potential energy. Potential energy gives the object the potential to move. If it does, the potential energy changes back to kinetic energy.

That's what happened to Sari. After she and Daniel left the theater, the storm cleared and they went for a swim. That's Sari in the **Figure** below coming down the water slide. When she was at the top of the slide, she had potential energy. Why? She had the potential to slide into the water because of the pull of gravity. As she moved down the slide, her potential energy changed to kinetic energy. By the time she reached the water, all the potential energy had changed to kinetic energy.



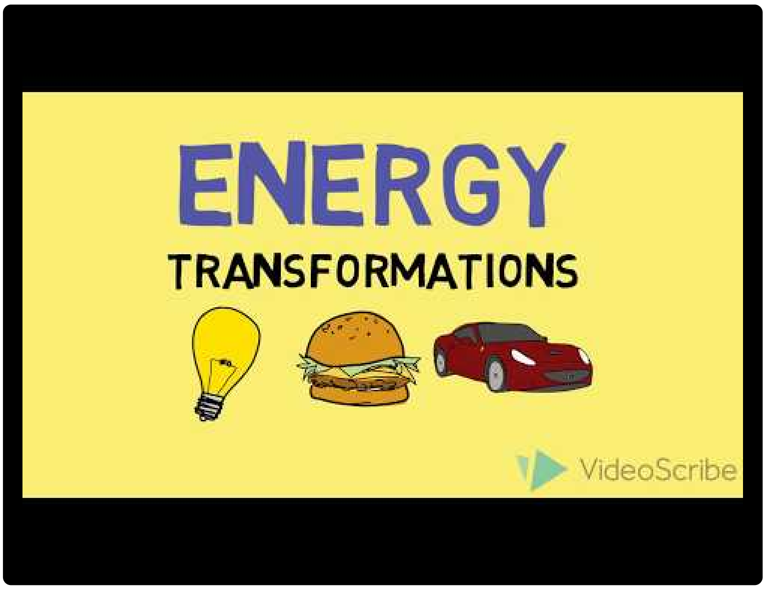
[Figure 3]

Q: How could Sari regain her potential energy?

A: Sari could climb up the steps to the top of the slide. It takes kinetic energy to climb the steps, and this energy would be stored in Sari as she climbed. By the time she got to the top of the slide, she would have the same amount of potential energy as before.

Q: Can you think of other fun examples of energy changing between kinetic and potential energy?

A: Playground equipment such as swings, slides, and trampolines involve these changes.



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Summary

- Energy conversion is the process in which energy changes from one form or type to another. Energy is always conserved in energy conversions.
- Different forms of energy—such as electrical, chemical, and thermal energy—often change to other forms of energy.
- Mechanical energy commonly changes back and forth between kinetic and potential energy.

Review

1. Define energy conversion.
2. Relate energy conversion to the law of conservation of energy.
3. Describe an original example of energy changing from one form to two other forms.
4. Explain how energy changes back and forth between kinetic and potential energy when you jump on a trampoline. Include a sketch to help explain the energy conversions.

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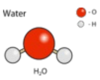	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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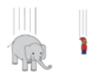	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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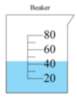
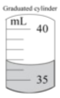
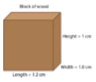
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 12

Waves

Chapter Outline

12.1 Mechanical Wave

FlexBooks® 2.0 > American HS Physical Science > Mechanical Wave

Last Modified: Sep 19, 2019

[Figure 1]

No doubt you've seen this happen. Droplets of water fall into a body of water, and concentric circles spread out through the water around the droplets. The concentric circles are waves moving through the water.

Waves in Matter

The waves in the picture above are examples of mechanical waves. A **mechanical wave** is a disturbance in matter that transfers energy through the matter. A mechanical wave starts when matter is disturbed. A source of energy is needed to disturb matter and start a mechanical wave.

Q: Where does the energy come from in the water wave pictured above?

A: The energy comes from the falling droplets of water, which have kinetic energy because of their motion.

The Medium

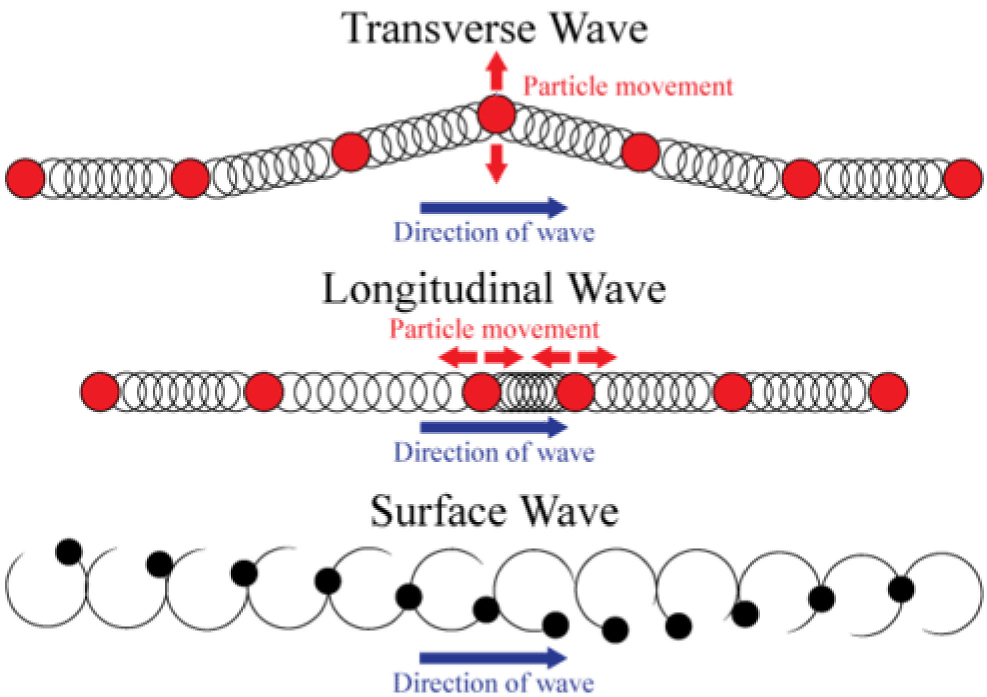
The energy of a mechanical wave can travel only through matter. The matter through which the wave travels is called the **medium** (*plural*, media). The medium in the water wave pictured above is water, a liquid. But the medium of a mechanical wave can be any state of matter, even a solid.

Q: How do the particles of the medium move when a wave passes through them?

A: The particles of the medium just vibrate in place. As they vibrate, they pass the energy of the disturbance to the particles next to them, which pass the energy to the particles next to them, and so on. Particles of the medium don't actually travel along with the wave. Only the energy of the wave travels through the medium.

Types of Mechanical Waves

There are three types of mechanical waves: transverse, longitudinal, and surface waves. They differ in how particles of the medium move. You can see this in the **Figure** below.



[Figure 2]

- In a transverse wave, particles of the medium vibrate up and down perpendicular to the direction of the wave.
- In a longitudinal wave, particles of the medium vibrate back and forth parallel to the direction of the wave.
- In a surface wave, particles of the medium vibrate both up and down and back and forth, so they end up moving in a circle.

Q: How do you think surface waves are related to transverse and longitudinal waves?

A: A surface wave is combination of a transverse wave and a longitudinal wave.

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Summary

- A mechanical wave is a disturbance in matter that transfers energy through the matter.
- The matter through which a mechanical wave travels is called the medium (*plural*, media).
- There are three types of mechanical waves: transverse, longitudinal, and surface waves. They differ in how particles of the medium move when the energy of the wave passes through.

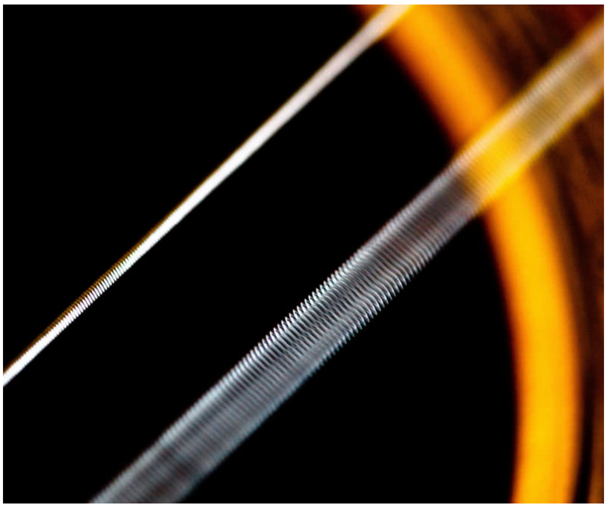
Review

1. Define mechanical wave.
2. What is the medium of a mechanical wave?
3. List three types of mechanical waves.
4. If you shake one end of a rope up and down, a wave passes through the rope. Which type of wave is it?

12.2 Transverse Wave

FlexBooks® 2.0 > American HS Physical Science > Transverse Wave

Last Modified: Sep 19, 2019



[Figure 1]

Can you guess what this picture shows? Here's a hint: the objects in the picture have been magnified, and one of them is moving rapidly. The objects are guitar strings, and the moving string is the one on the bottom right. The string is moving because it has just been plucked. Plucking the string gave it energy, which is moving through the string in a mechanical wave. A mechanical wave is a wave that travels through matter. The matter a mechanical wave travels through is called the medium. The type of mechanical wave passing through the vibrating guitar string is a transverse wave.

What Is a Transverse Wave?

A **transverse wave** is a wave in which particles of the medium vibrate at right angles, or perpendicular, to the direction that the wave travels. Another example of a transverse wave is the wave that passes through a rope with you shake one end of the rope up and down, as in the **Figure** below. The direction of the wave is down the length of the rope away from the hand. The rope itself moves up and down as the wave passes through it.

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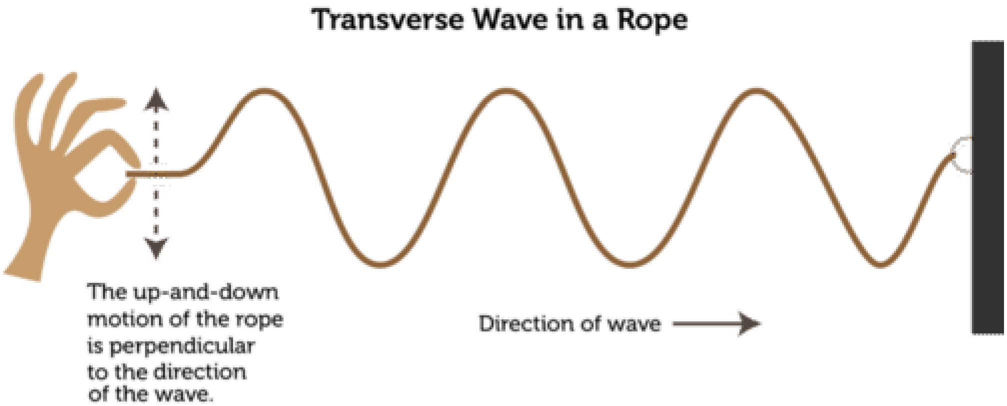


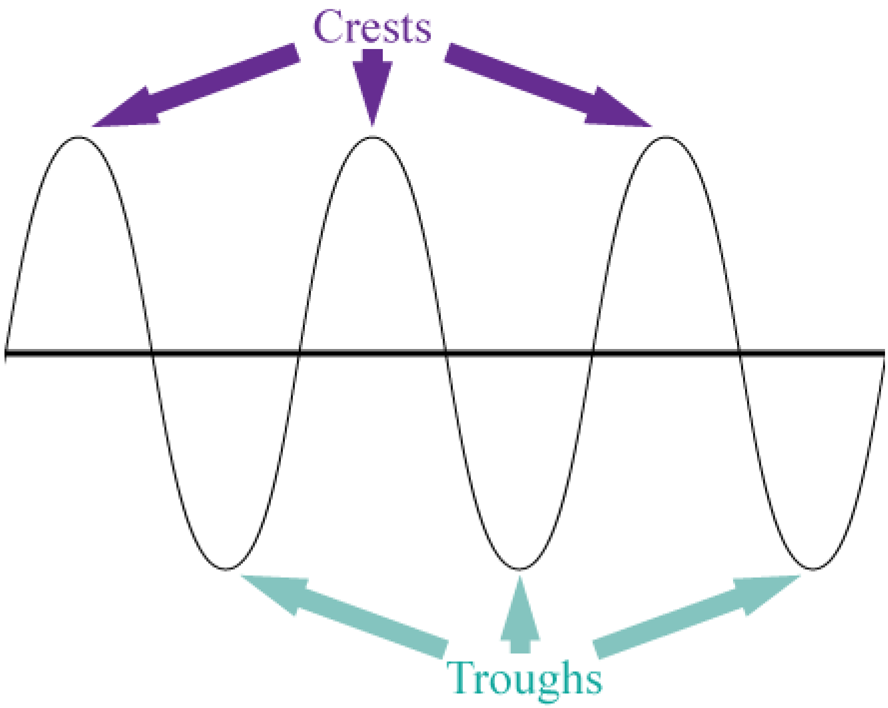
[Figure 2]

Q: When a guitar string is plucked, in what direction does the wave travel? In what directions does the string vibrate?

A: The wave travels down the string to the end. The string vibrates up and down at right angles to the direction of the wave.

Crests and Troughs

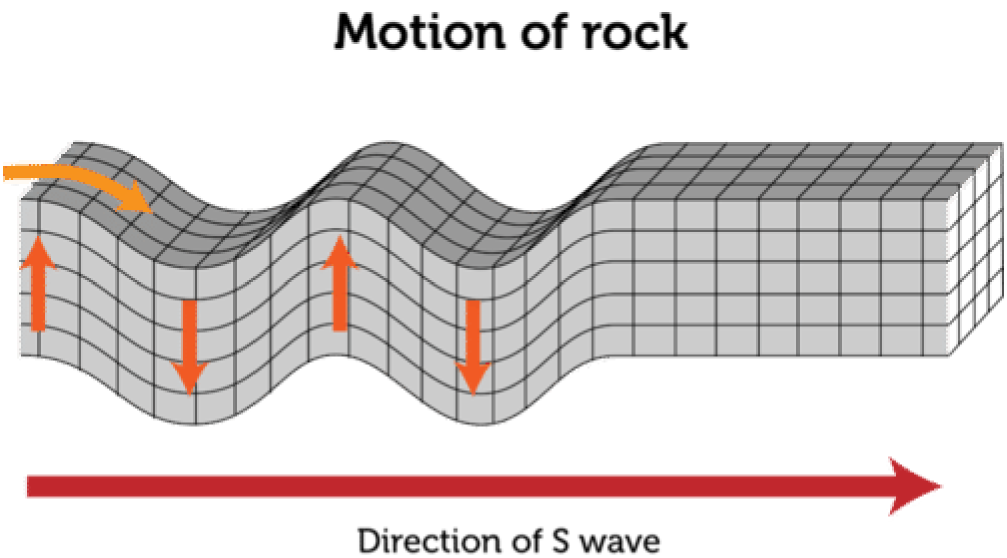
A transverse wave is characterized by the high and low points reached by particles of the medium as the wave passes through. The high points are called crests, and the low points are called troughs. You can see both in the **Figure** below.



[Figure 3]

S Waves

Transverse waves called S waves occur during earthquakes. The disturbance that causes an earthquake sends transverse waves through underground rocks in all directions away from the disturbance. S waves may travel for hundreds of miles. An S wave is modeled in the **Figure** below.



[Figure 4]

Summary

- A transverse wave is a wave in which particles of the medium vibrate perpendicular to the direction that the wave travels.
- The high points of a transverse wave are called crests, and the low points are called troughs.
- S waves are transverse waves that travel through underground rocks during earthquakes.

Review

1. What is a transverse wave?
2. Sketch a transverse wave and label the crests and troughs.
3. Infer how S waves might affect structures such as buildings.

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12.3 Longitudinal Wave

FlexBooks® 2.0 > American HS Physical Science > Longitudinal Wave

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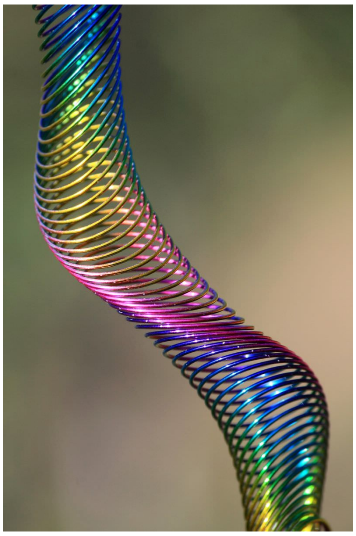

[Figure 1]

You've probably played with Slinky spring toys like these. They're simple toys, but they can move in very interesting ways. Pushing in on the end of a spring toy, for example, gives it energy that moves through the spring in a longitudinal wave.

What Is a Longitudinal Wave?

A **longitudinal wave** is a type of mechanical wave. A mechanical wave is a wave that travels through matter, called the medium. In a longitudinal wave, particles of the medium vibrate in a direction that is parallel to the direction that the wave travels. You can see this in the **Figure** below. The person's hand pushes and pulls on one end of the spring. The energy of this disturbance passes through the coils of the spring to the other end.

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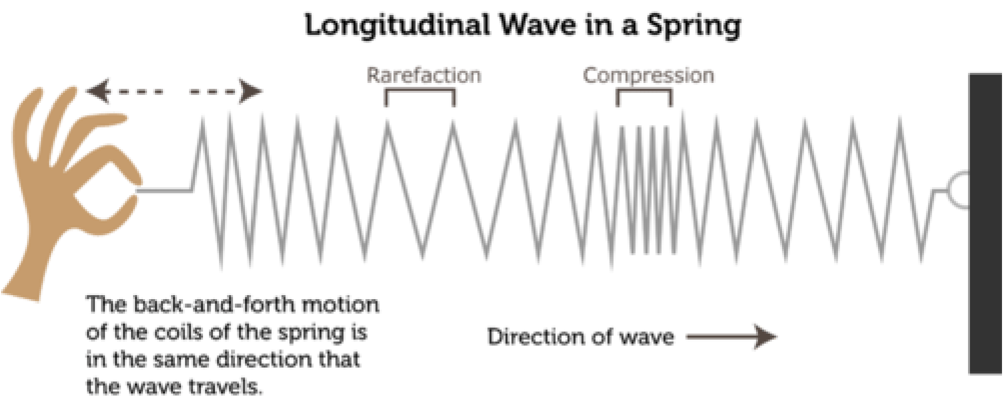


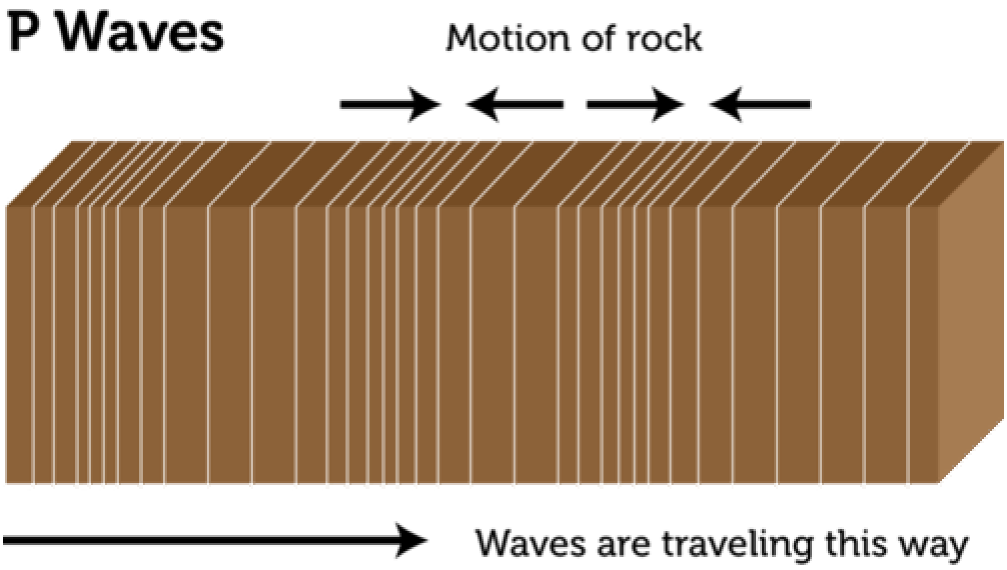
[Figure 2]

Compressions and Rarefactions

Notice in the **Figure** above that the coils of the spring first crowd closer together and then spread farther apart as the wave passes through them. Places where particles of a medium crowd closer together are called compressions, and places where the particles spread farther apart are called rarefactions. The more energy the wave has, the closer together the particles are in compressions and the farther apart they are in rarefactions.

P Waves

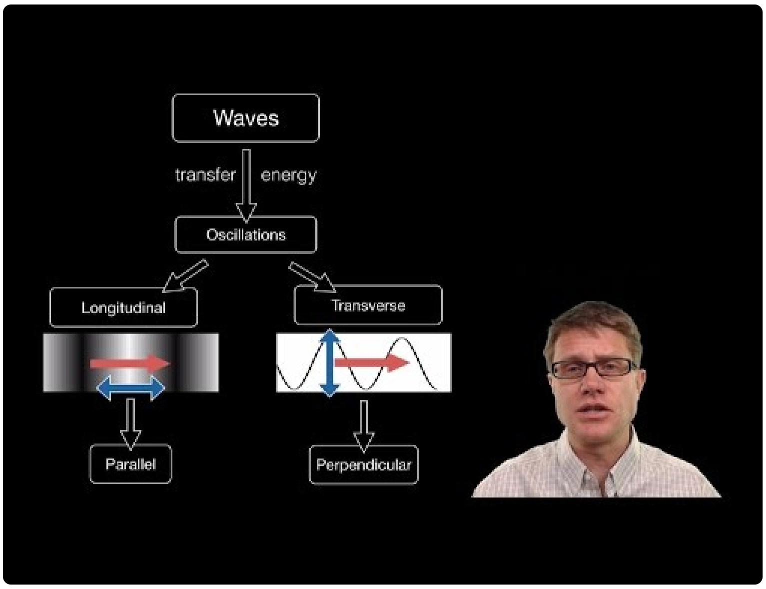
Earthquakes cause longitudinal waves called P waves. The disturbance that causes an earthquake sends longitudinal waves through underground rocks in all directions away from the disturbance. P waves are modeled in the **Figure** below.



[Figure 3]

Q: Where are the compressions and rarefactions of the medium in this model of P waves?

A: The compressions are the places where the vertical lines are closest together. The rarefactions are the places where the vertical lines are farthest apart.



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Summary

- A longitudinal wave is a type of mechanical wave, or wave that travels through matter, called the medium. In a longitudinal wave, particles of the medium vibrate in a direction that is parallel to the direction that the wave travels.
- Places where particles of the medium crowd closer together are called compressions. Places where particles of the medium spread farther apart are called rarefactions.

- Earthquakes cause longitudinal waves called P waves, which pass through underground rocks.

Review

1. What is a longitudinal wave?
2. Draw a sketch of a longitudinal wave. Use arrows to show the direction of the wave and the direction of the vibrating particles of the medium. Add labels to identify the compressions and rarefactions.
3. Describe P waves.

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12.4 Wavelength

FlexBooks® 2.0 > American HS Physical Science > Wavelength

Last Modified: Feb 19, 2021

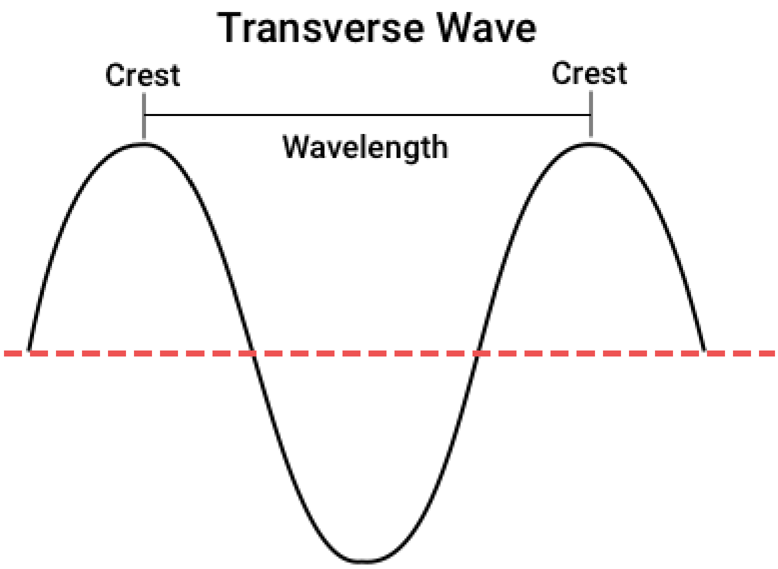
[Figure 1]

Nobody really has such colorful eyes! The colors were added digitally after the photo was taken. They represent all the different colors of light. Light is a form of energy that travels in waves. Light of different colors has different wavelengths.

Defining Wavelength

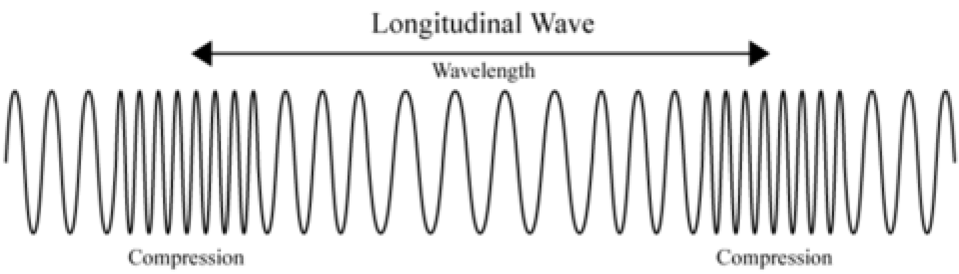
Wavelength is one way of measuring the size of waves. It is the distance between two corresponding points on adjacent waves, and it is usually measured in meters. How it is measured is a little different for transverse and longitudinal waves.

- In a transverse wave, particles of the medium vibrate up and down at right angles to the direction that the wave travels. The wavelength of a transverse wave can be measured as the distance between two adjacent crests, or high points, as shown in the **Figure** below.



[Figure 2]

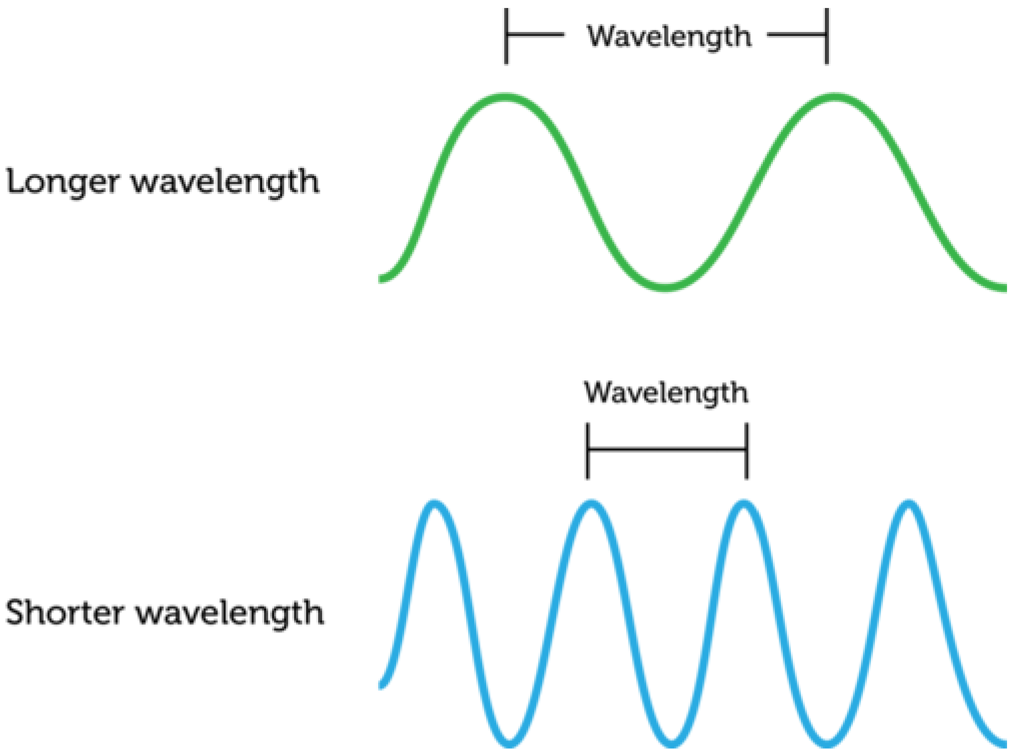
- In a longitudinal wave, particles of matter vibrate back and forth in the same direction that the wave travels. The wavelength of a longitudinal wave can be measured as the distance between two adjacent compressions, as shown in the **Figure** below. Compressions are the places where particles of the medium crowd close together as the energy of the wave passes through.



[Figure 3]

Wavelength and Wave Energy

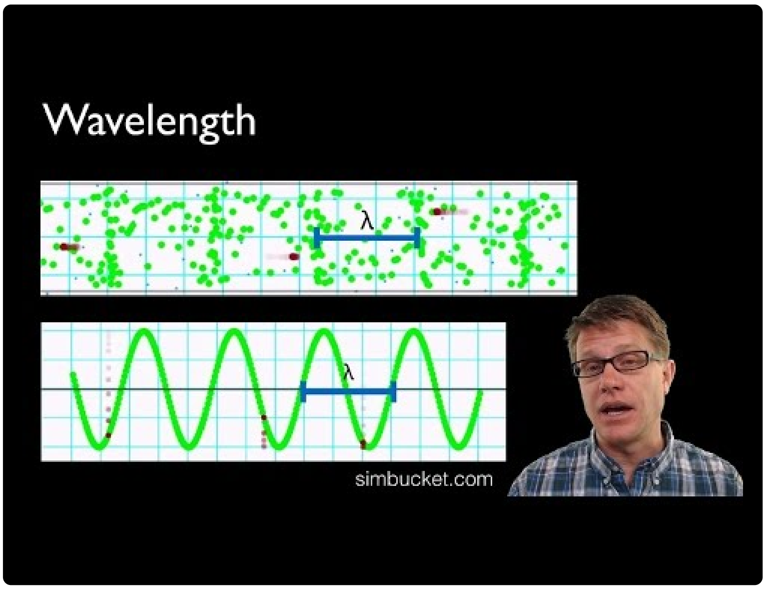
The wavelength of a wave is related to the wave's energy. Short-wavelength waves have more energy than long-wavelength waves of the same amplitude. (Amplitude is a measure of how far particles of the medium move up and down or back and forth when a wave passes through them.) You can see examples of transverse waves with shorter and longer wavelengths in the **Figure** below.



[Figure 4]

Q: Of all the colors of visible light, red light has the longest wavelength and violet light has the shortest wavelength. Which color of light has the greatest energy?

A: Violet light has the greatest energy because it has the shortest wavelength.



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Summary

- Wavelength is one way of measuring the size of waves. It is the distance between two corresponding points on adjacent waves, usually measured in meters.

- The wavelength of a transverse wave can be measured as the distance between two adjacent crests. The wavelength of a longitudinal wave can be measured as the distance between two adjacent compressions.
- Short-wavelength waves have more energy than long-wavelength waves of the same amplitude.

Review

1. What is the wavelength of a wave?
2. Draw a simple transverse wave and label the wavelength.

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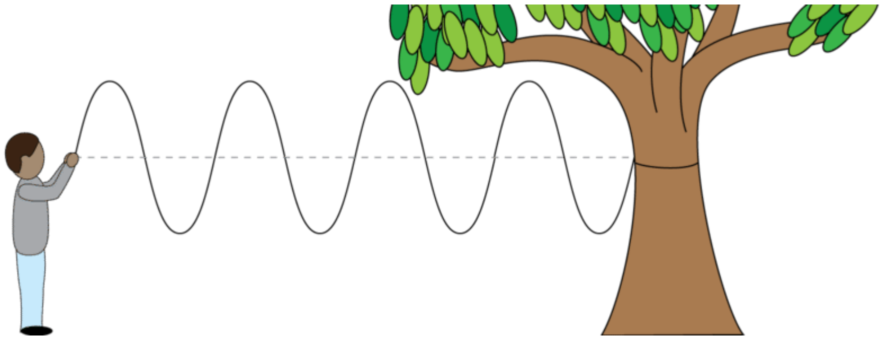
12.5 Wave Frequency

FlexBooks® 2.0 > American HS Physical Science > Wave Frequency

Last Modified: Sep 19, 2019

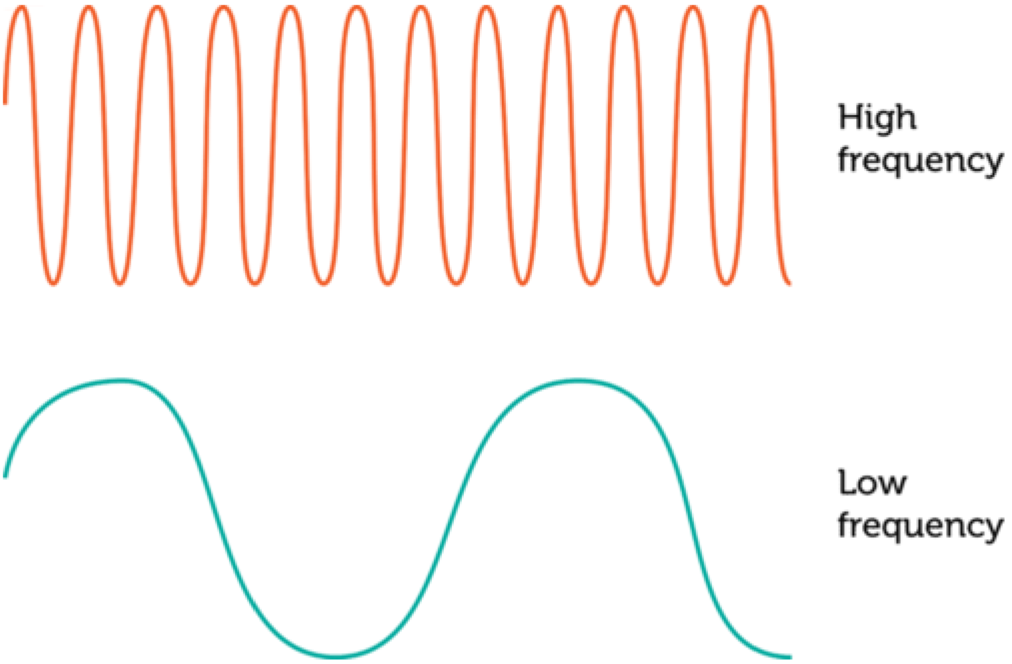


[Figure 1]

Imagine making transverse waves in a rope, like the person in the sketch above. You tie one end of the rope to a tree or other fixed point, and then you shake the other end of the rope up and down with your hand. You can move the rope up and down slowly or quickly. How quickly you move the rope determines the frequency of the waves.

What Is Wave Frequency?

The number of waves that pass a fixed point in a given amount of time is **wave frequency**. Wave frequency can be measured by counting the number of crests (high points) of waves that pass the fixed point in 1 second or some other time period. The higher the number is, the greater the frequency of the waves. The SI unit for wave frequency is the **hertz (Hz)**, where 1 hertz equals 1 wave passing a fixed point in 1 second. The **Figure** below shows high-frequency and low-frequency transverse waves.



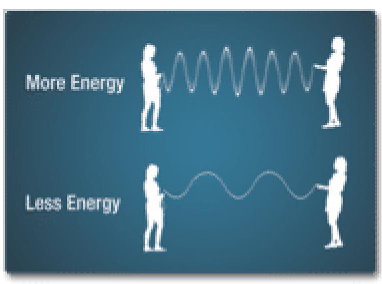
[Figure 2]

Q: The wavelength of a wave is the distance between corresponding points on adjacent waves. For example, it is the distance between two adjacent crests in the transverse waves in the diagram. Infer how wave frequency is related to wavelength.

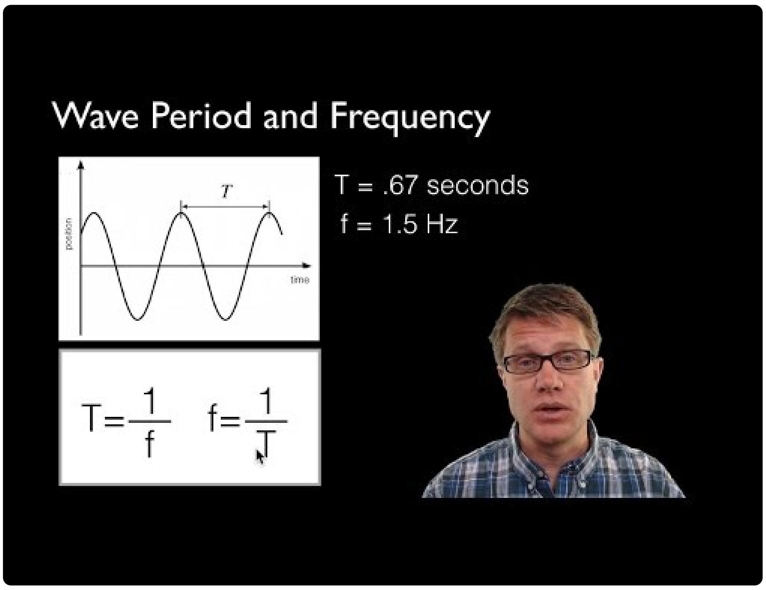
A: Waves with a higher frequency have crests that are closer together, so higher frequency waves have shorter wavelengths.

Wave Frequency and Energy

The frequency of a wave is the same as the frequency of the vibrations that caused the wave. For example, to generate a higher-frequency wave in a rope, you must move the rope up and down more quickly. This takes more energy, so a higher-frequency wave has more energy than a lower-frequency wave with the same amplitude. You can see examples of different frequencies in the **Figure** below (Amplitude is the distance that particles of the medium move when the energy of a wave passes through them.)



[Figure 3]



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Summary

- Wave frequency is the number of waves that pass a fixed point in a given amount of time.
- The SI unit for wave frequency is the hertz (Hz), where 1 hertz equals 1 wave passing a fixed point in 1 second.
- A higher-frequency wave has more energy than a lower-frequency wave with the same amplitude.

Review

1. What is wave frequency?
2. What is the SI unit for wave frequency?
3. Assume that 10 waves pass a fixed point in 5 seconds. What is the frequency of the waves in hertz?
4. Relate wave frequency to the energy of waves.

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12.6 Wave Speed

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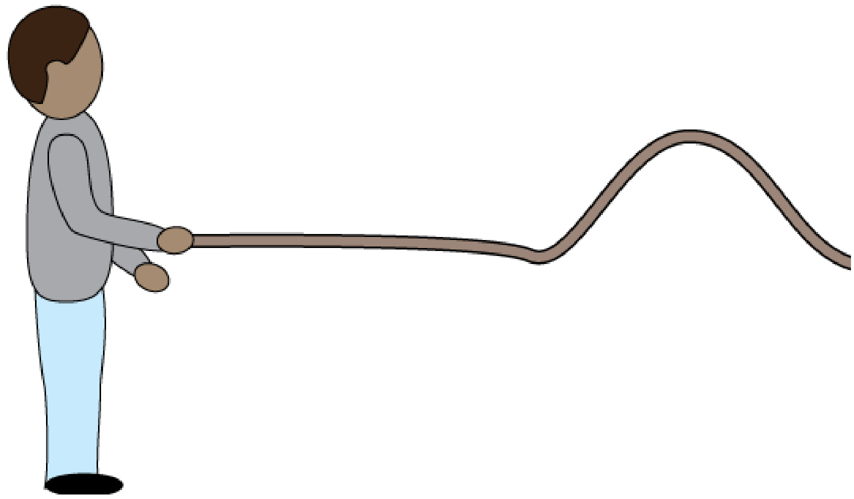


[Figure 1]

Assume that you move one end of a rope up and down just once to generate a wave in the rope. How long will take the wave to travel down the rope to the other end? It depends on the speed of the wave.

The Speed of a Wave

Wave speed is the distance a wave travels in a given amount of time, such as the number of meters it travels per second. Wave speed (and speed in general) can be represented by the equation:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Wave Speed, Wavelength, and Wave Frequency

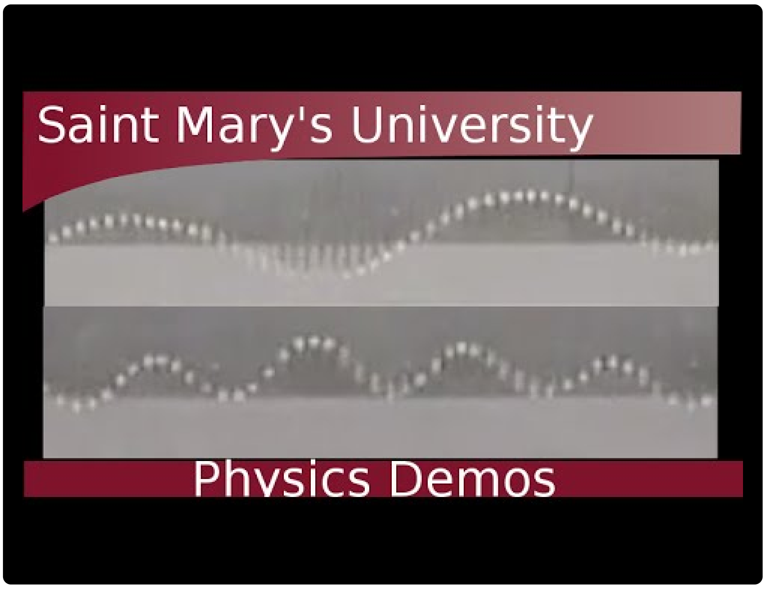
Wave speed is related to both wavelength and wave frequency. Wavelength is the distance between two corresponding points on adjacent waves. Wave frequency is the number of waves that pass a fixed point in a given amount of time. This equation shows how the three factors are related:

Speed = Wavelength x Wave Frequency

In this equation, wavelength is measured in meters and frequency is measured in hertz (Hz), or number of waves per second. Therefore, wave speed is given in meters per second, which is the SI unit for speed.

Q: If you increase the wavelength of a wave, does the speed of the wave increase as well?

A: Increasing the wavelength of a wave doesn't change its speed. That's because when wavelength increases, wave frequency decreases. As a result, the product of wavelength and wave frequency is still the same speed.



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Calculating Wave Speed from Wavelength and Wave Frequency

The equation for wave speed can be used to calculate the speed of a wave when both wavelength and wave frequency are known. Consider an ocean wave with a wavelength of 3 meters and a frequency of 1 hertz. The speed of the wave is:

Speed = 3 m x 1 wave/s = 3 m/s

Q: Kim made a wave in a spring by pushing and pulling on one end. The wavelength is 0.1 m, and the wave frequency is 2 hertz. What is the speed of the wave?

A: Substitute these values into the equation for speed:

Speed = 0.1 m x 2 waves/s = 0.2 m/s

Calculating Wave Frequency or Wavelength from Wave Speed

The equation for wave speed (above) can be rewritten as:

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

Therefore, if you know the speed of a wave and either the wavelength or wave frequency, you can calculate the missing value. For example, suppose that a wave is traveling at a speed of 2 meters per second and has a wavelength of 1 meter. Then the frequency of the wave is:

$$\text{Frequency} = \frac{2\text{m/s}}{1\text{m}} = 2 \text{ waves/s, or } 2 \text{ Hz}$$

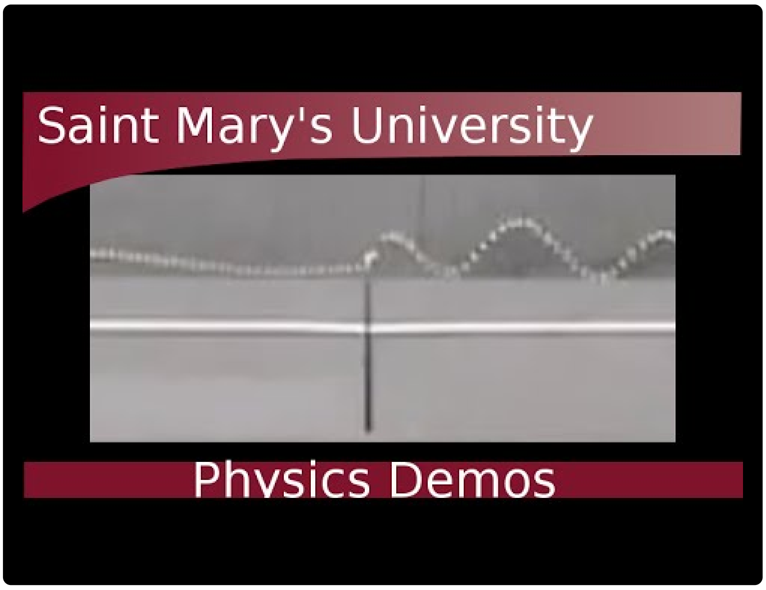
Q: A wave is traveling at a speed of 2 m/s and has a frequency of 2 Hz. What is its wavelength?

A: Substitute these values into the equation for wavelength:

$$\text{Wavelength} = \frac{2\text{m/s}}{2\text{waves/s}} = 1 \text{ m}$$

The Medium Matters

The speed of most waves depends on the medium, or the matter through which the waves are traveling. Generally, waves travel fastest through solids and slowest through gases. That's because particles are closest together in solids and farthest apart in gases. When particles are farther apart, it takes longer for the energy of the disturbance to pass from particle to particle through the medium.



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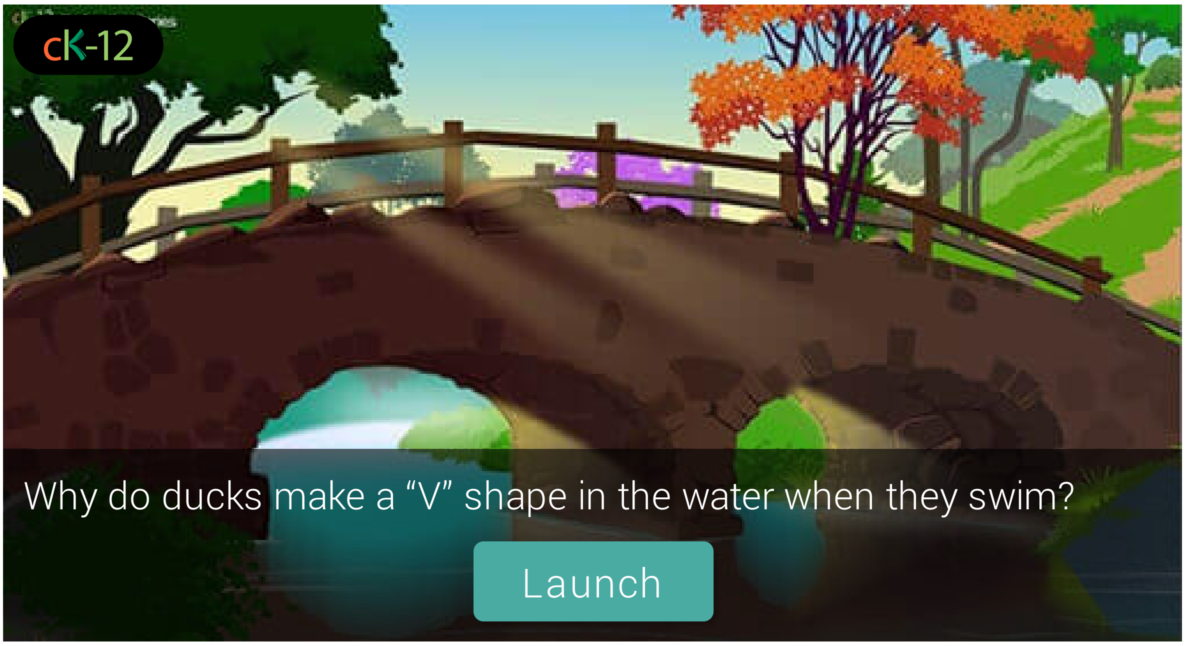
Launch the Doppler Ducks simulation below to visualize how wave speed is related to both wavelength and wave frequency. Adjust the duck velocity slider to change how quickly the duck moves through the water. Remember that positive velocities are rightward and negative velocities are leftward. Try playing around with having the duck go faster or slower than the wave speed, or towards or away from the boat.



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Further Reading

- Wave Equation
- Types of Waves
- Mechanical Wave
- Surface Wave

Summary

- Wave speed is the distance a wave travels in a given amount of time, such as the number of meters it travels per second.
- Wave speed is related to wavelength and wave frequency by the equation: Speed = Wavelength x Frequency. This equation can be used to calculate wave speed when wavelength and frequency are known.
- The equation for wave speed can be written to solve for wavelength or frequency if the speed and the other value are known.
- The speed of most waves depends on the medium, or the matter through which they are traveling. Generally, waves travel fastest through solids and slowest through gases.

Review

1. What is wave speed?
2. What is the speed of a wave that has a wavelength of 2 m and a frequency of 1.5 Hz?

3. Calculate the frequency of a wave that is traveling at a speed of 3.0 m/s and has a wavelength of 1.2 m.
4. Sound energy travels through matter in waves. Do sound waves travel faster through air or water? Explain your answer.

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12.7 References

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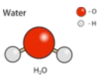	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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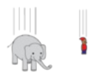	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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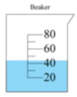
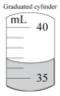
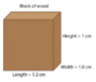
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 13

Sound

Chapter Outline

13.1 Sound Wave

FlexBooks® 2.0 > American HS Physical Science > Sound Wave

Last Modified: Sep 26, 2019

[Figure 1]

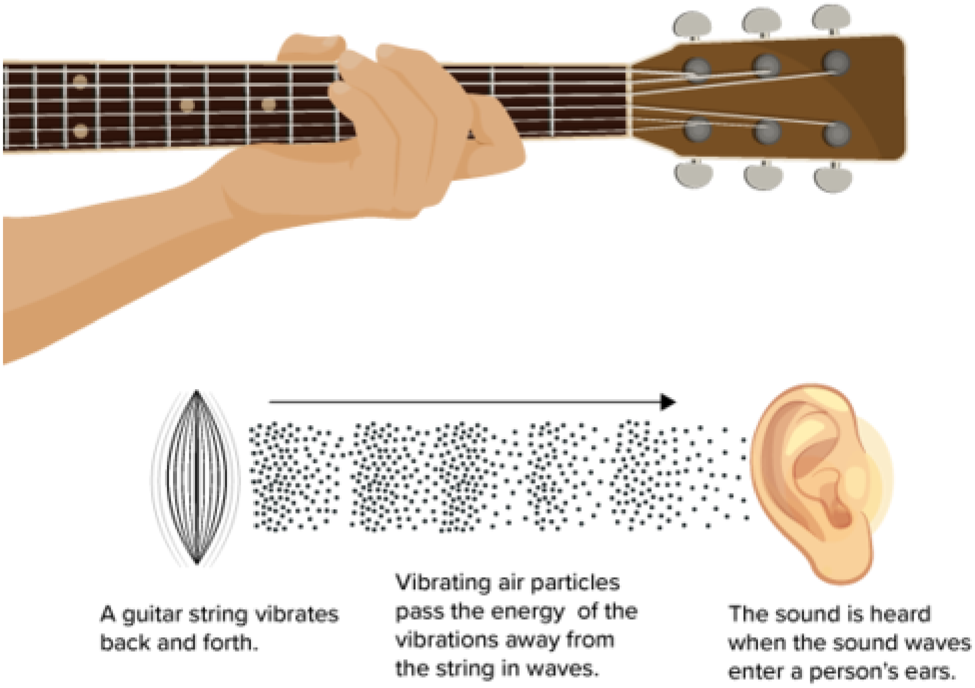
Crack! Crash! Thud! That's what you'd hear if you were in the forest when this old tree cracked and came crashing down to the ground. But what if there was nobody there to hear the tree fall? Would it still make these sounds? This is an old riddle. To answer the riddle correctly, you need to know the scientific definition of sound.

Defining Sound

In science, **sound** is defined as the transfer of energy from a vibrating object in waves that travel through matter. Most people commonly use the term sound to mean what they hear when sound waves enter their ears. The tree above generated sound waves when it fell to the ground, so it made sound according to the scientific definition. But the sound wasn't detected by a person's ears if there was nobody in the forest. So the answer to the riddle is both yes and no!

How Sound Waves Begin

All sound waves begin with vibrating matter. Look at the first guitar string on the left in the **Figure** below. Plucking the string makes it vibrate. The diagram below the figure shows the wave generated by the vibrating string. The moving string repeatedly pushes against the air particles next to it, which causes the air particles to vibrate. The vibrations spread through the air in all directions away from the guitar string as longitudinal waves. In longitudinal waves, particles of the medium vibrate back and forth parallel to the direction that the waves travel.

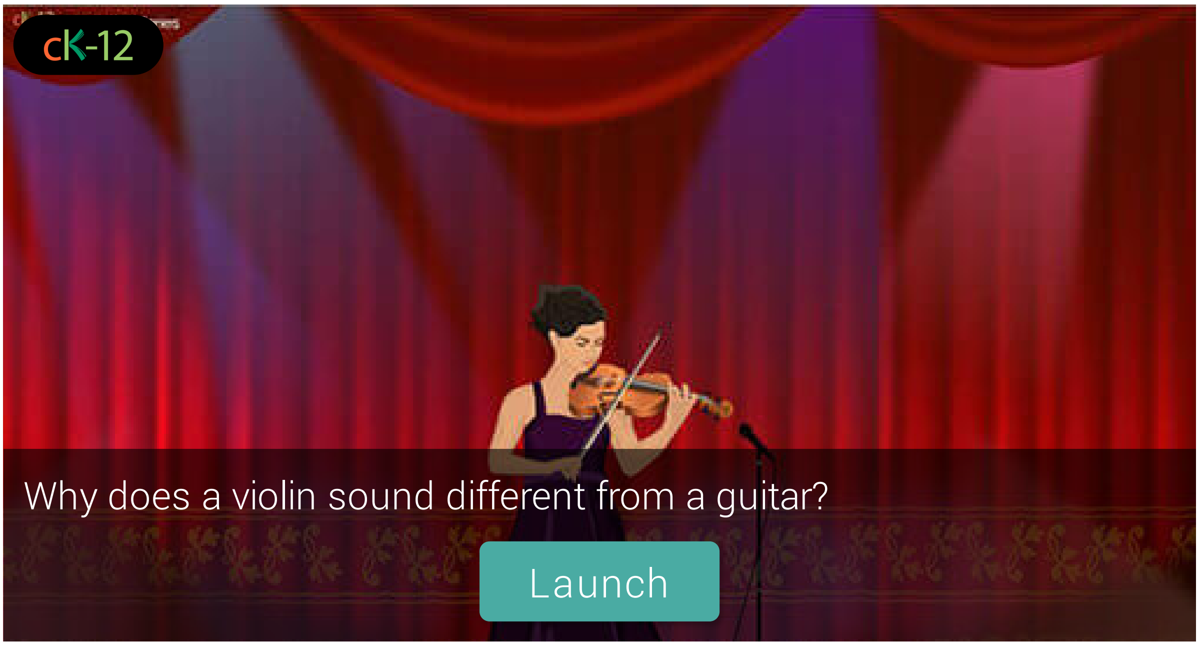


[Figure 2]

Q: If there were no air particles to carry the vibrations away from the guitar string, how would sound reach the ear?

A: It wouldn't unless the vibrations were carried by another medium. Sound waves are mechanical waves, so they can travel only though matter and not through empty space.

What about the sound waves created by other instruments? Why does the same musical note on different instruments, such as a guitar and violin, sound different? Begin your exploration of sound by exploring the different types of sound waves produced by string instruments in the Violin SIM below:



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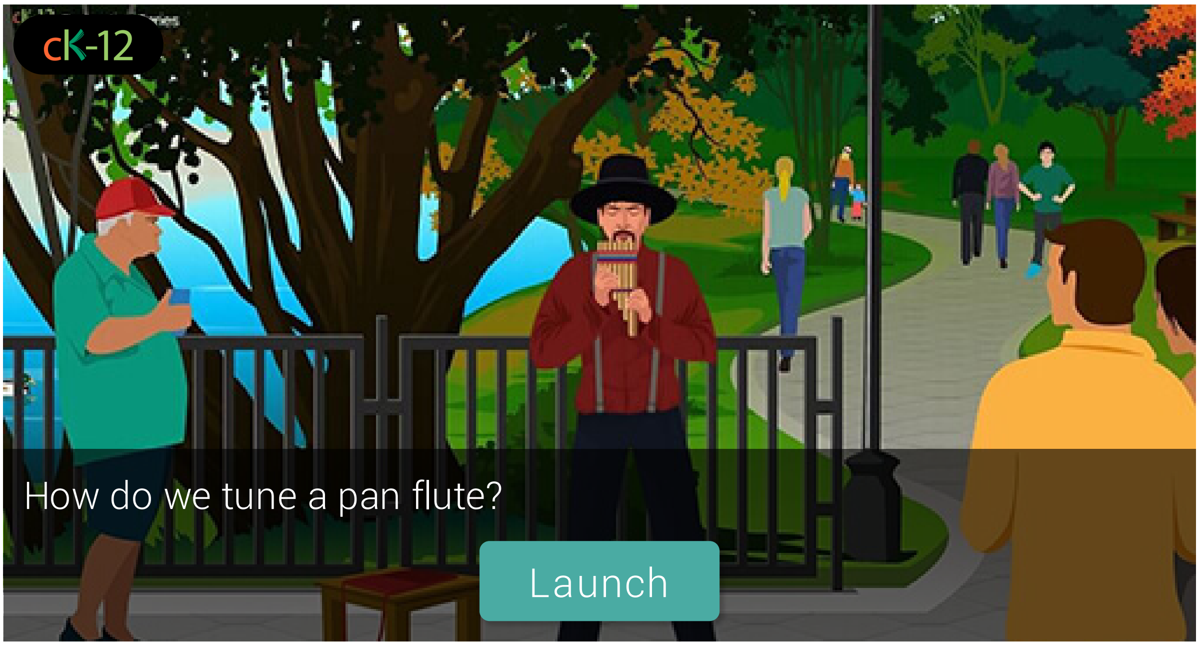
A pan flute is another example of a musical instrument that depends on the vibration of air particles. Use the simulation below to visualize how the movement of invisible air molecules inside the tubes produces musical notes:



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A Ticking Clock

The fact that sound cannot travel through empty space was first demonstrated in the 1600s by a scientist named Robert Boyle. Boyle placed a ticking clock in a sealed glass jar. The clock could be heard ticking through the air and glass of the jar. Then Boyle pumped the air out of the jar. The clock was still ticking, but the ticking sound could no longer be heard. That's because the sound couldn't travel away from the clock without air particles to pass the sound energy along.

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Sound Waves and Matter

Most of the sounds we hear reach our ears through the air, but sounds can also travel through liquids and solids. If you swim underwater—or even submerge your ears in bathwater—any sounds you hear have traveled to your ears through the water. Some solids, including glass and metals, are very good at transmitting sounds. Foam rubber and heavy fabrics, on the other hand, tend to muffle sounds. They absorb rather than pass on the sound energy.

Q: How can you tell that sounds travel through solids?

A: One way is that you can hear loud outdoor sounds such as sirens through closed windows and doors. You can also hear sounds through the inside walls of a house. For example, if you put your ear against a wall, you may be able to eavesdrop on a conversation in the next room—not that you would, of course.

Summary

- In science, sound is defined as the transfer of energy from a vibrating object in waves that travel through matter.
- All sound waves begin with vibrating matter. The vibrations generate longitudinal waves that travel through matter in all directions.
- Most sounds we hear travel through air, but sounds can also travel through liquids and solids.

Review

1. How is sound defined in science? How does this definition differ from the common meaning of the word?
2. Hitting a drum, as shown in the **Figure** below, generates sound waves. Create a diagram to show how the sound waves begin and how they reach a person's ears.

[Figure 3]

3. How do you think earplugs work?

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13.2 Speed of Sound

FlexBooks® 2.0 > American HS Physical Science > Speed of Sound

Last Modified: Sep 26, 2019

[Figure 1]

Has this ever happened to you? You see a flash of lightning on the horizon, but several seconds pass before you hear the rumble of thunder. The reason? The speed of light is much faster than the speed of sound.

What Is the Speed of Sound?

The **speed of sound** is the distance that sound waves travel in a given amount of time. You'll often see the speed of sound given as 343 meters per second. But that's just the speed of sound under a certain set of conditions, specifically, through dry air at 20 °C. The speed of sound may be very different through other matter or at other temperatures.

Speed of Sound in Different Media

Sound waves are mechanical waves, and mechanical waves can only travel through matter. The matter through which the waves travel is called the medium (plural, media). The **Table** below gives the speed of sound in several different media. Generally, sound waves travel most quickly through solids, followed by liquids, and then by gases. Particles of matter are closest together in solids and farthest apart in gases. When particles are closer together, they can more quickly pass the energy of vibrations to nearby particles.

Medium (20 °C)	Speed of Sound Waves (m/s)
Dry Air	343
Water	1437
Wood	3850
Glass	4540
Aluminum	6320

Q: The table gives the speed of sound in dry air. Do you think that sound travels more or less quickly through air that contains water vapor? (Hint: Compare the speed of sound in water and air in the table.)

A: Sound travels at a higher speed through water than air, so it travels more quickly through air that contains water vapor than it does through dry air.

Temperature and Speed of Sound

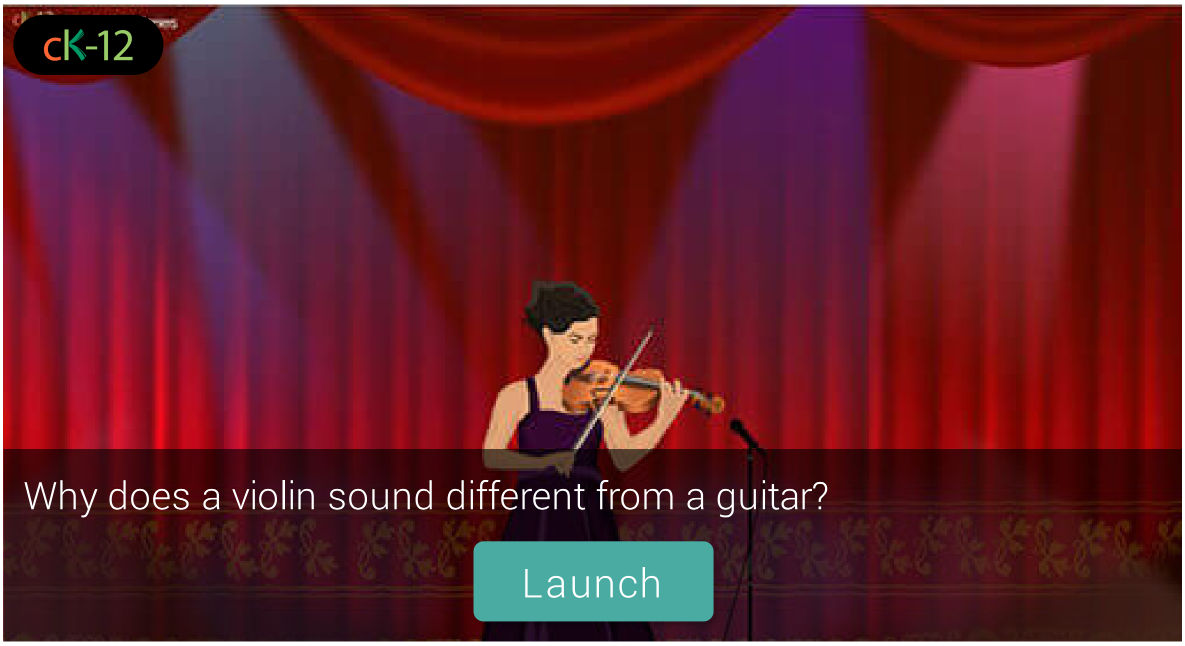
The speed of sound also depends on the temperature of the medium. For a given medium, sound has a slower speed at lower temperatures. You can compare the speed of sound in dry air at different temperatures in the following **Table** below. At a lower temperature, particles of the medium are moving more slowly, so it takes them longer to transfer the energy of the sound waves.

Temperature of Air	Speed of Sound Waves (m/s)
0 °C	331
20 °C	343
100 °C	386

Q: What do you think the speed of sound might be in dry air at a temperature of -20 °C?

A: For each 1 degree Celsius that temperature decreases, the speed of sound decreases by 0.6 m/s. So sound travels through dry, -20 °C air at a speed of 319 m/s.

Can you calculate the speed of sound in air and the wave speed on the string in the Violin simulation below? Use the Wavelength vs Frequency graph on the top left to analyze the waves produced by the violin. The product of the wavelength and frequency can be used to determine the speed of sound in air and wave speed on the violin string:



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Summary

- The speed of sound is the distance that sound waves travel in a given amount of time. The speed of sound in dry air at 20 °C is 343 meters per second.
- Generally, sound waves travel most quickly through solids, followed by liquids, and then by gases.
- For a given medium, sound waves travel more slowly at lower temperatures.

Review

1. What is the speed of sound in dry air at 20 °C?
2. Describe variation in the speed of sound through various media.
3. Explain how temperature affects the speed of sound.

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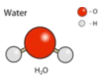	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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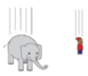
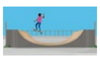
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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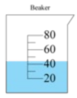
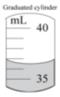
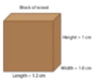
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 14

Electromagnetic Radiation

Chapter Outline

14.1 Properties of Electromagnetic Waves

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Last Modified: May 23, 2019

[Figure 1]

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.

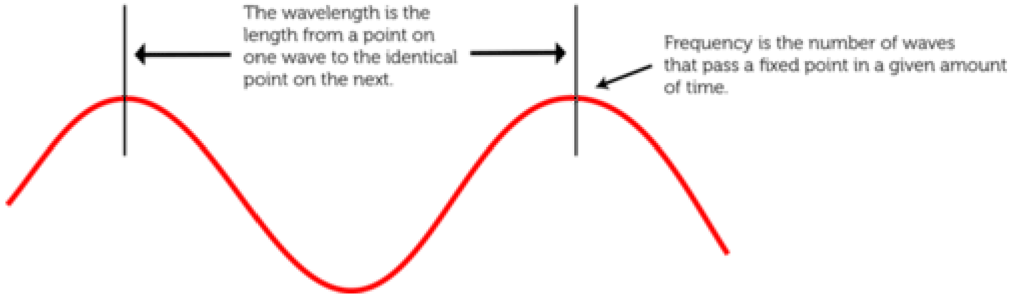
Speed of Electromagnetic Waves

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 (3.0×10^8 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** below). 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 2]

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:

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

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 × 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 × 10^8 Hz

Q: What is the wavelength of an electromagnetic wave that has a frequency of 3.0 × 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 × 10^8 Hz, what is its wavelength?

14.2 Electromagnetic Spectrum

FlexBooks® 2.0 > American HS Physical Science > Electromagnetic Spectrum

Last Modified: Oct 01, 2019

[Figure 1]

It's a warm sunny Saturday, and Michael and Lavar have a big day planned. They're going to ride across town to meet their friends and then go to the zoo. The boys may not realize it, but they will be bombarded by electromagnetic radiation as they ride their bikes and walk around the zoo grounds. The only kinds of radiation they can detect are visible light, which allows them to see, and infrared light, which they feel as warmth on their skin.

Q: Besides visible light and infrared light, what other kinds of electromagnetic radiation will the boys be exposed to in sunlight?

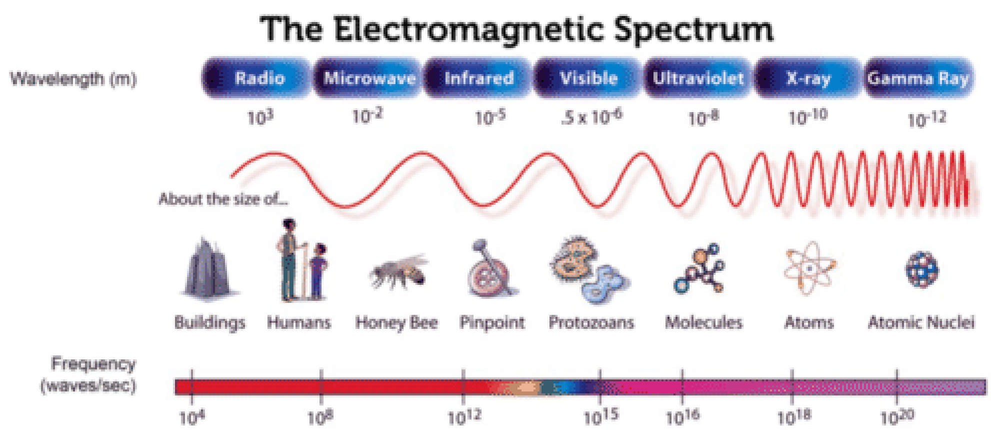
A: Sunlight consists of all the different kinds of electromagnetic radiation, from harmless radio waves to deadly gamma rays. Fortunately, Earth's atmosphere prevents most of the harmful radiation from reaching Earth's surface. You can read about the different kinds of electromagnetic radiation in this article.

Electromagnetic Radiation

Electromagnetic radiation is energy that travels in waves across space as well as through matter. Most of the electromagnetic radiation on Earth comes from the sun. Like other waves, electromagnetic waves are characterized by certain wavelengths and wave frequencies. Wavelength is the distance between two corresponding points on adjacent waves. Wave frequency is the number of waves that pass a fixed point in a given amount of time. Electromagnetic waves with shorter wavelengths have higher frequencies and more energy.

A Spectrum of Electromagnetic Waves

Visible light and infrared light are just a small part of the full range of electromagnetic radiation, which is called the **electromagnetic spectrum**. You can see the waves of the electromagnetic spectrum in the **Figure** below. At the top of the diagram, the wavelengths of the waves are given. Also included are objects that are about the same size as the corresponding wavelengths. The frequencies and energy levels of the waves are shown at the bottom of the diagram. Some sources of the waves are also given.



[Figure 2]

- On the left side of the electromagnetic spectrum diagram are radio waves and microwaves. Radio waves have the longest wavelengths and lowest frequencies of all electromagnetic waves. They also have the least amount of energy.
- On the right side of the diagram are X rays and gamma rays. They have the shortest wavelengths and highest frequencies of all electromagnetic waves. They also have the most energy.
- Between these two extremes are waves that are commonly called light. Light includes infrared light, visible light, and ultraviolet light. The wavelengths, frequencies, and energy levels of light fall in between those of radio waves on the left and X rays and gamma rays on the right.

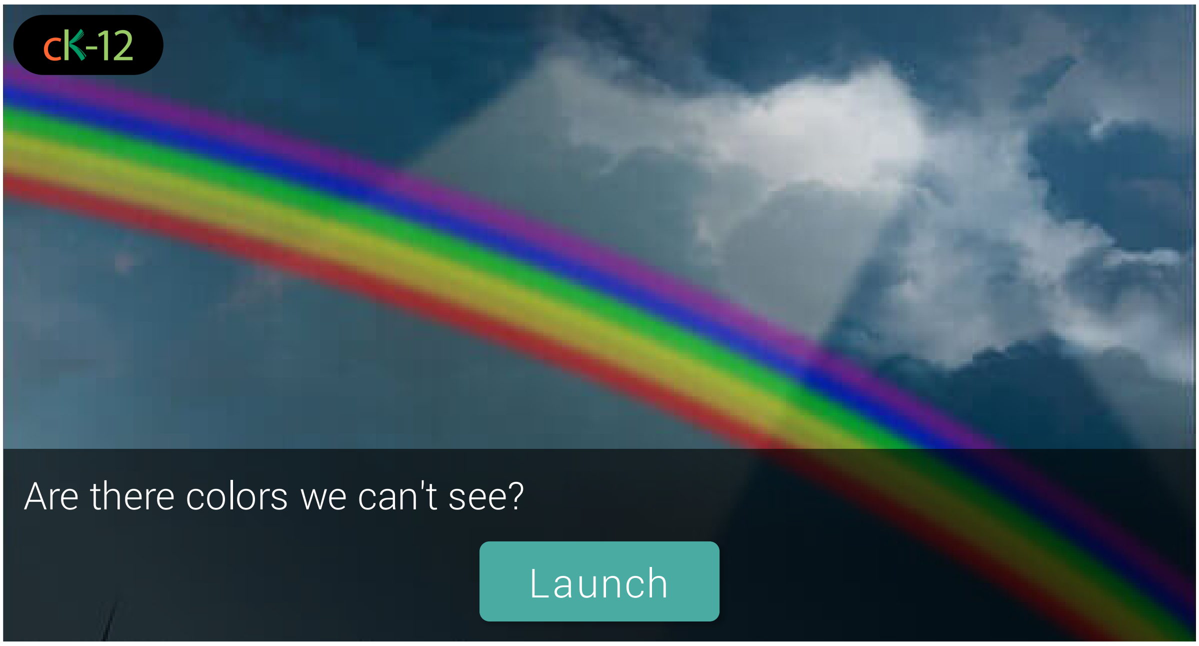
Q: Which type of light has the longest wavelengths?

A: Infrared light has the longest wavelengths.

Q: What sources of infrared light are shown in the diagram?

A: The sources in the diagram are people and light bulbs, but all living things and most other objects give off infrared light.

Launch the Light Wave simulation below to visualize the different types of light waves. Be sure to check out the objects of comparable size next to the Electromagnetic Spectrum to help you grasp just how big or small different waves of light can be:



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Summary

- Electromagnetic radiation travels in waves through space or matter. Electromagnetic waves with shorter wavelengths have higher frequencies and more energy.
- The full range of electromagnetic radiation is called the electromagnetic spectrum. From longest to shortest wavelengths, it includes radio waves, microwaves, infrared light, visible light, ultraviolet light, X rays, and gamma rays.

Review

1. Describe the relationship between the wavelength and frequency of electromagnetic waves.
2. What is the electromagnetic spectrum?
3. Which electromagnetic waves have the longest wavelengths?
4. Identify a source of microwaves.
5. Which type of light has the highest frequencies?
6. Explain why gamma rays are the most dangerous of all electromagnetic waves.

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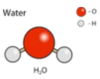	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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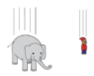
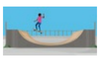
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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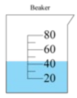
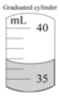
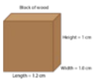
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 15

Visible Light

Chapter Outline

15.1 Light and Color

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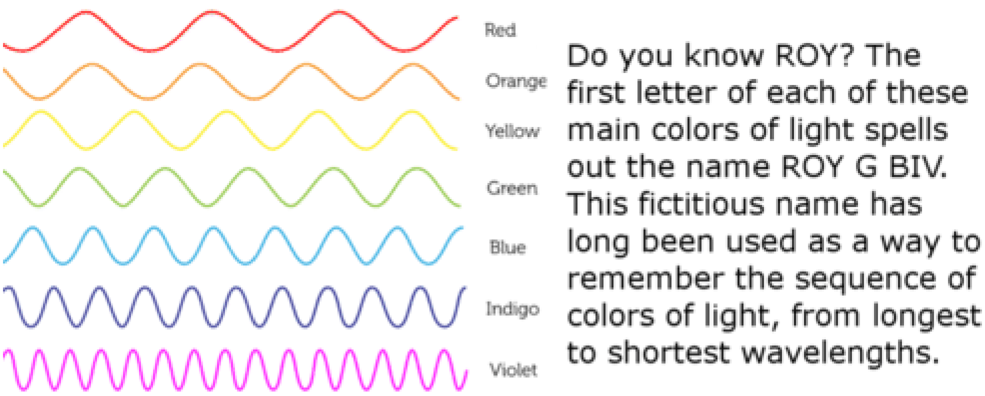
Last Modified: Aug 13, 2021

[Figure 1]

This rainbow contains all the colors that you can see in the land below it—the yellow of the hills, the green of the leaves and grasses. It contains other colors as well. In fact, a rainbow contains all of the colors of visible light.

Wavelength and Color

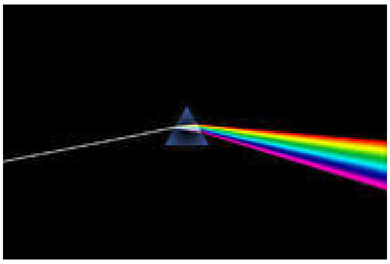
Visible light is light that has wavelengths that can be detected by the human eye. The wavelength of visible light determines the color that the light appears. As you can see in the **Figure** below, light with the longest wavelength appears red, and light with the shortest wavelength appears violet. In between are all the other colors of light that we can see. Only seven main colors of light are actually represented in the diagram.



[Figure 2]

Separating Colors of Light

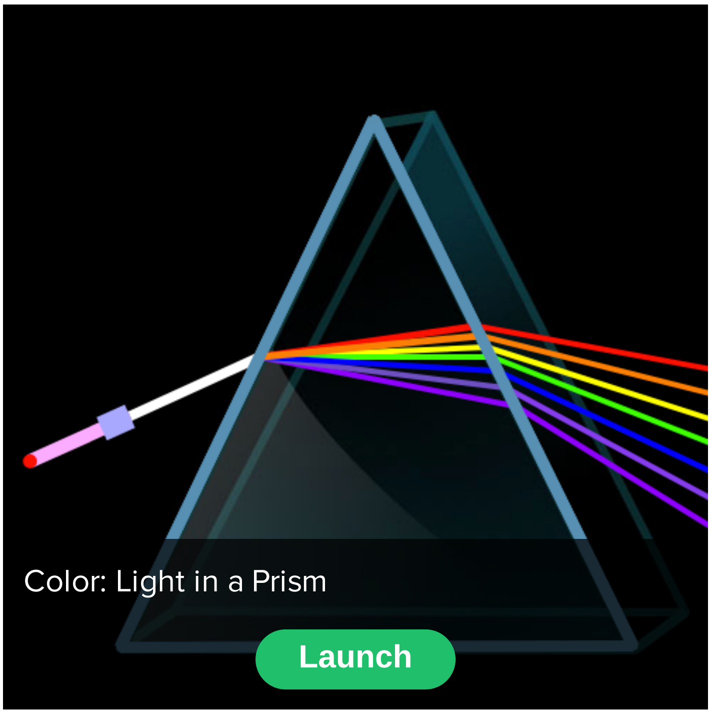
A prism, like the one in the **Figure** below, can be used to separate visible light into its different colors. A prism is a pyramid-shaped object made of transparent matter, usually clear glass or plastic. Matter that is transparent allows light to pass through it. A prism transmits light but slows it down. When light passes from air to the glass of the prism, the change in speed causes the light to change direction and bend. Different wavelengths of light bend at different angles. This makes the beam of light separate into light of different wavelengths. What we see is a rainbow of colors.



[Figure 3]

Q: Look back at the rainbow that opened this article. Do you see all the different colors of light, from red at the top to violet at the bottom? What causes a rainbow to form? **A:** Individual raindrops act as tiny prisms. They separate sunlight into its different wavelengths and create a rainbow of colors.

Launch the PLIX Interactive below to observe the refraction of white light through a prism. You can adjust the angle of the white light shining on the prism and observe its effect on how each color of light refracts (or bends):



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Colors of Objects

An opaque object is one that doesn't let light pass through it. Instead, it reflects or absorbs the light that strikes it. Many objects, such as the leaves pictured in the **Figure** below, reflect just one or a few wavelengths of visible light and absorb the rest. The wavelengths that are reflected determine the color that an object appears to the human eye. For example, the leaves appear green because they reflect green light and absorb light of other wavelengths.

[Figure 4]

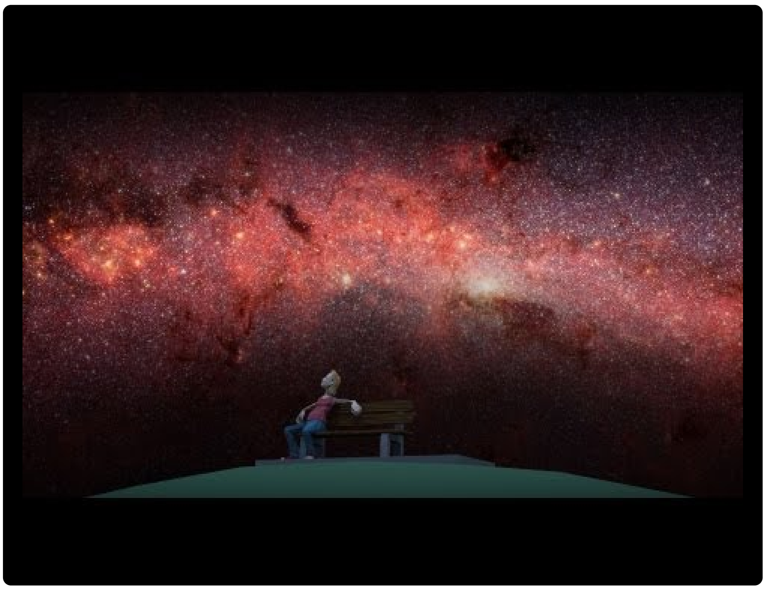
A transparent or translucent material, such as window glass, transmits some or all of the light that strikes it. This means that the light passes through the material rather than being reflected by it. In this case, we see the material because of the transmitted light. Therefore, the wavelength of the transmitted light determines the color that the object appears. Look at the beautiful stained glass windows in the **Figure** below. The different colors of glass transmit light of different colors.

[Figure 5]

The color of light that strikes an object may also affect the color that the object appears. For example, if only blue light strikes green leaves, the blue light is absorbed and no light is reflected.

Q: What color do you see if an object absorbs all of the light that strikes it?

A: When all of the light is absorbed, none is reflected, so the object looks black. But black isn't a color of light. Black is the absence of light.



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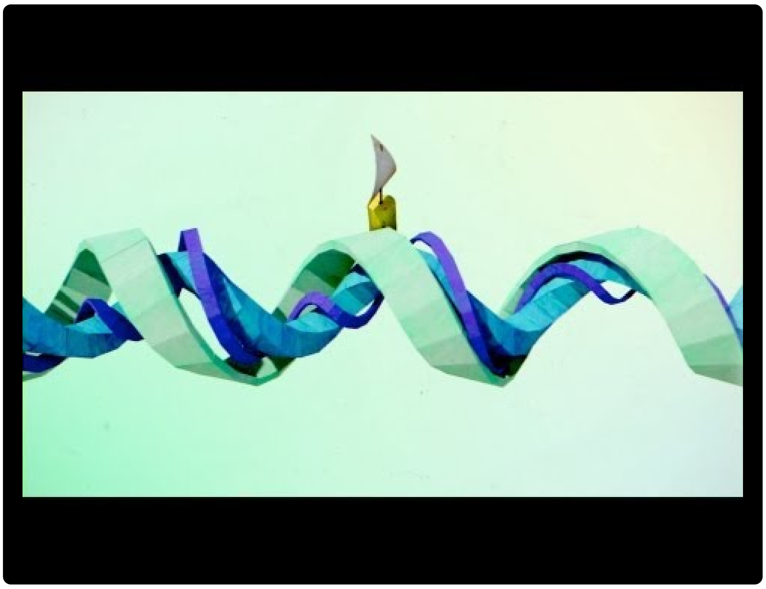
The Colors We See

The human eye can distinguish only red, green, and blue light. These three colors are called the **primary colors** of light. All other colors of light can be created by combining the primary colors. Look at the Venn diagram below. Red and green light combine to form yellow light. Red and blue light combine to form magenta light, and blue and green light combine to form cyan light. Yellow, magenta, and cyan are called the secondary colors of light. Look at the center of the diagram, where all three primary colors of light combine. The result is white light.

[Figure 6]

Have you ever wondered why we see the colors we do? Watch the video below to discover more about the science behind visible colors:



https://flexbooks.ck12.org/flx/render/embeddedobject/257743

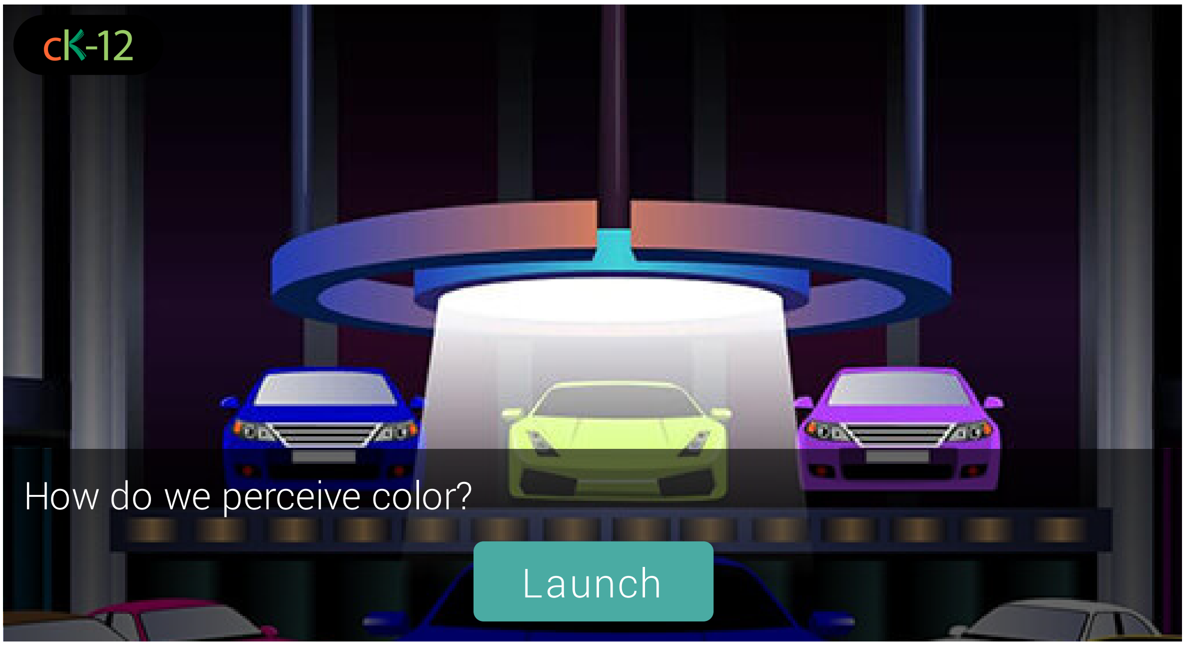
Pigments

Many objects have color because they contain pigments. A **pigment** is a substance that colors materials by reflecting light of certain wavelengths and absorbing light of other wavelengths. A very common pigment is the dark green pigment called chlorophyll, which is found in plants. Chlorophyll absorbs all but green wavelengths of visible light. Pigments are also found in many manufactured products. They are used to color paints, inks, and dyes. Just three pigments, called primary pigments, can be combined to produce all other colors. The primary colors of pigments are the same as the secondary colors of light: cyan, magenta, and yellow.

Q: A color printer needs just three colors of ink to print all of the colors that we can see. Which colors are they?

A: The three colors of ink in a color printer are the three primary pigment colors: cyan, magenta, and yellow. These three colors can be combined in different ratios to produce all other colors, so they are the only colors needed for full-color printing.

What color would a white car appear under yellow light? What would you see when you look at an orange car through green glasses? Why? Use the sliders in the Rose-Colored Glasses simulation below and play around with setting different colors for the light source, the car, and the glasses to answer these questions and learn more about the light and color:



https://flexbooks.ck12.org/flx/show/interactive/user:ck12science/http://www.ck12.org/embed/#module=launcher&artifactID=1916733&nochrome=true?hash=c88165707f92aa0176304287ef88fe28

Summary

- The wavelength of visible light determines the color that the light appears. Light with the longest wavelength appears red, and light with the shortest wavelength appears violet. In between are the wavelengths of all the other colors of light.
- A prism separates visible light into its different colors. As light passes through the prism, it slows and bends, but different wavelengths bend at different angles. This separates light into different wavelengths, forming a rainbow of colors.
- The wavelengths of visible light that an object reflects or transmits determine the color that the object appears to the human eye.
- The human eye can distinguish only red, green, and blue light. These three colors are the primary colors of light. All other colors of light can be created by combining the primary colors. Secondary colors of light—cyan, yellow, and magenta—form when two primary colors combine equally.
- Pigments are substances that color materials by reflecting light of certain wavelengths and absorbing light of other wavelengths. The primary pigment colors are cyan, yellow, and magenta. They can be combined to produce all other colors.

Review

1. What determines the color of visible light?

2. Which color of light has the longest wavelength? Which color has the shortest wavelength?
3. How does a prism separate visible light into its different colors?
4. To a person with normal vision, the apple in the **Figure** below appears green. Explain why.

[Figure 7]

5. The human eye can detect only three colors of light. What three colors are they? How can we perceive other colors of light?
6. What are pigments? Identify the primary colors of pigments. If you combined the three primary pigment colors, what color would you get?

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15.2 Reflection

FlexBooks® 2.0 > American HS Physical Science > Reflection

Last Modified: Jun 18, 2020

[Figure 1]

This dancer is practicing in front of a mirror so she can see how she looks as she performs. She's watching her image in the mirror as she dances. What is an image, and how does it get “inside” a mirror? In this article, you’ll find out.

Reflected Light and Images

Reflection is one of several ways that light can interact with matter. Light reflects off surfaces such as mirrors that do not transmit or absorb light. When light is reflected from a smooth surface, it may form an image. An **image** is a copy of an object that is formed by reflected (or refracted) light.

Q: Is an image an actual object? If not, what is it?

A: No, an image isn’t an actual object. It is focused rays of light that make a copy of an object, like a picture projected on a screen.

Regular and Diffuse Reflection

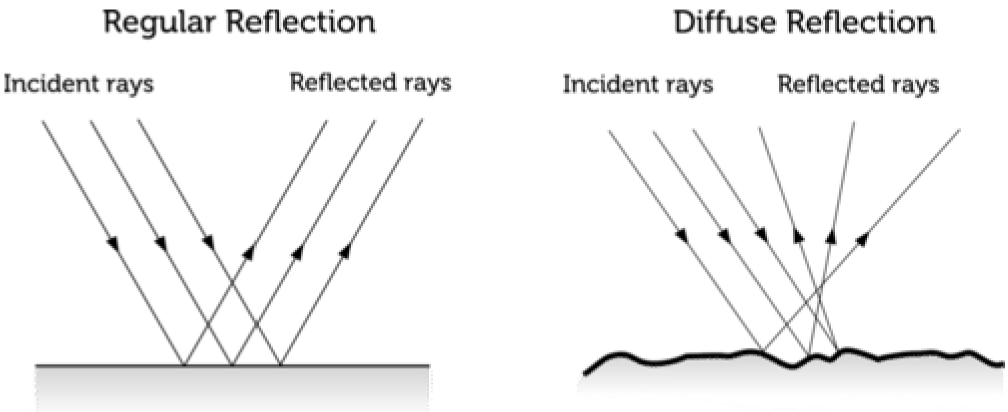
If a surface is extremely smooth, as it is in a mirror, then the image formed by reflection is sharp and clear. This is called regular reflection (also called specular reflection). However, if the surface is even slightly rough or bumpy, an image may not form, or if there is an image, it is blurry or fuzzy. This is called diffuse reflection.

Q: Look at the boats and their images in the **Figure** below. Which one represents regular reflection, and which one represents diffuse reflection?

A: Reflection of the boat on the left is regular reflection. The water is smooth and the image is sharp and clear. Reflection of the boat on the right is diffuse reflection. The water has ripples and the image is blurry and wavy.

[Figure 2]

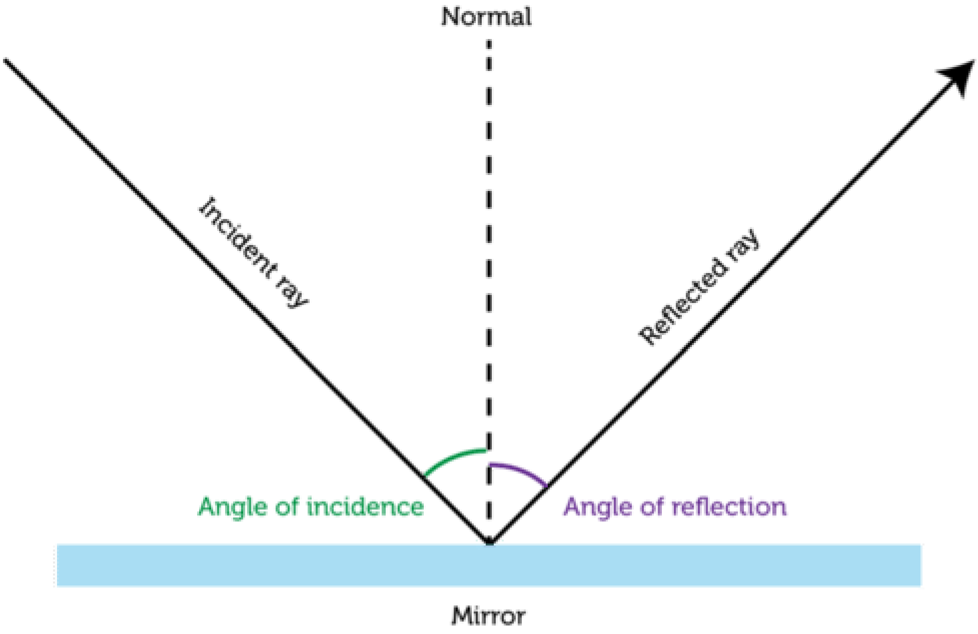
In the **Figure** below, you can see how both types of reflection occur. Waves of light are represented by arrows called rays. Rays that strike the surface are referred to as incident rays, and rays that reflect off the surface are known as reflected rays. In regular reflection, all the rays are reflected in the same direction. This explains why regular reflection forms a clear image. In diffuse reflection, the rays are reflected in many different directions. This is why diffuse reflection forms, at best, a blurry image.



[Figure 3]

Law of Reflection

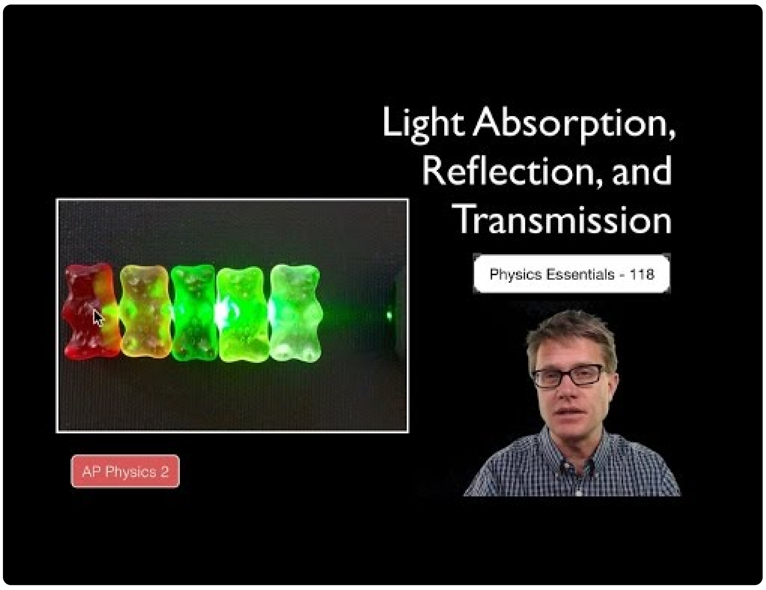
One thing is true of both regular and diffuse reflection. The angle at which the reflected rays leave the surface is equal to the angle at which the incident rays strike the surface. This is known as the **law of reflection**. The law is illustrated in the **Figure** below.



[Figure 4]

According to the law of reflection, the angle of reflection always equals the angle of incidence. The angles of both reflected and incident light are measured relative to an imaginary line, called normal, that is perpendicular (at right angles) to the reflective surface.

Watch this video to learn more about reflection:



https://flexbooks.ck12.org/flx/render/embeddedobject/275869

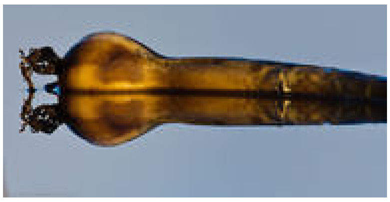
Summary

- Reflection is one of several ways that light can interact with matter. When light is reflected from a smooth surface, it may form an image. An image is a copy of an object that is formed by reflected (or refracted) light.

- Regular reflection occurs when light reflects off a very smooth surface and forms a clear image. Diffuse reflection occurs when light reflects off a rough surface and forms a blurry image or no image at all.
- According to the law of reflection, the angle at which light rays reflect off a surface is equal to the angle at which the incident rays strike the surface.

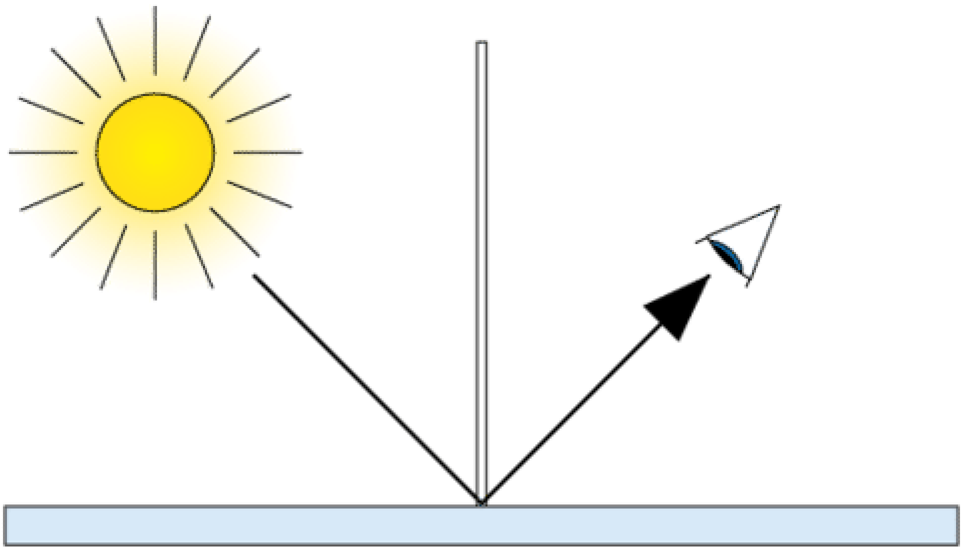
Review

1. What is an image?
2. Identify the object and the image in the **Figure** below. Which type of reflection formed the image: regular reflection or diffuse reflection? How do you know?



[Figure 5]

3. What is the law of reflection?
4. Label the angle of incidence and the angle of reflection in the **Figure** below.



[Figure 6]

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15.3 Mirrors

FlexBooks® 2.0 > American HS Physical Science > Mirrors

Last Modified: May 26, 2021

[Figure 1]

What does this picture show? Is it a photo of identical twin sisters, or is it just one girl looking in a mirror? The picture shows a single girl and her mirror image.

How Mirrors Form Images

A mirror is typically made of glass with a shiny metal backing that reflects all the light that strikes it. When a mirror reflects light, it forms an image. An image is a copy of an object that is formed by reflection or refraction. Mirrors may have flat or curved surfaces. The shape of a mirror's surface determines the type of image it forms. For example, some mirrors form real images, and other mirrors form virtual images. What's the difference between real and virtual images?

- A real image forms in front of a mirror where reflected light rays actually meet. It is a true image that could be projected on a screen.
- A virtual image appears to be on the other side of the mirror. Of course, reflected rays don't actually go through the mirror to the other side, so a virtual image doesn't really exist. It just appears to exist to the human brain.

Q: Look back at the image of the girl pointing at her image in the mirror. Which type of image is it, real or virtual?

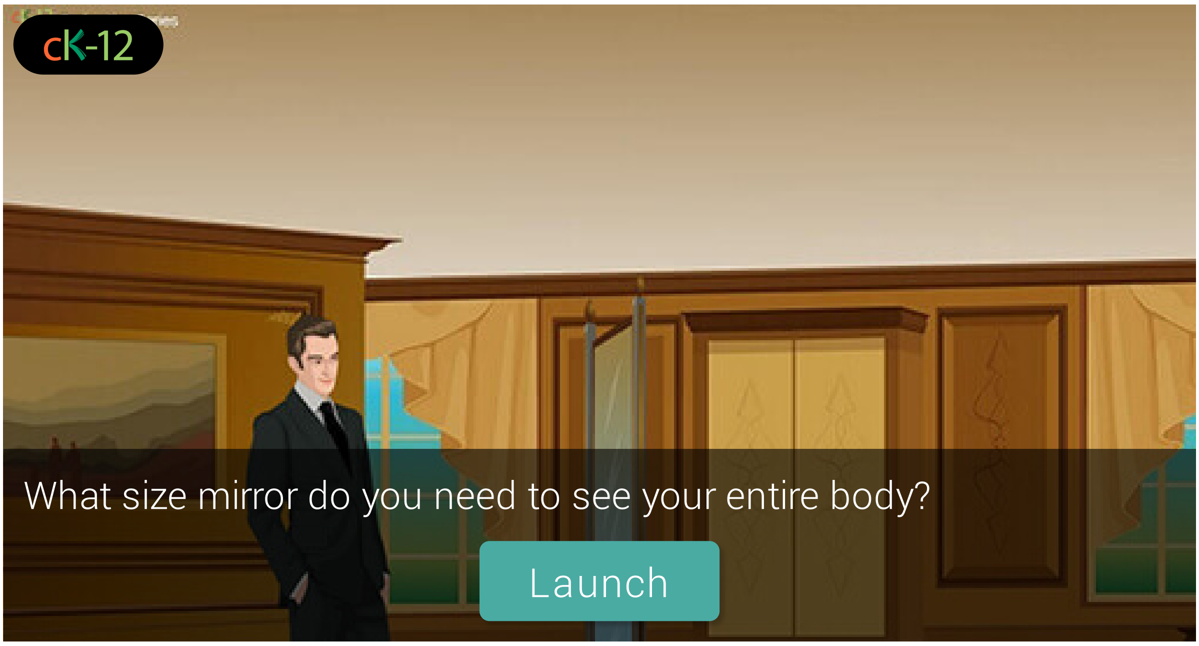
A: The image of the girl is a virtual image. It appears to be on the other side of the mirror from the girl.

Plane Mirror

The mirror in the opening photo is a plane mirror. This is the most common type of mirror. It has a flat reflective surface and forms only virtual images. The image formed by a plane mirror is also right-side up and life sized. But something is different about the image compared with the real object in front of the mirror. Left and right are reversed. Look at the girl brushing her teeth in the **Figure** below. She is using her right hand to brush her teeth, but her image (on the left) appears to be brushing her teeth with the left hand. All plane mirrors reverse left and right in this way. The term *mirror image* refers to how left and right are reversed in an image compared with the object.

[Figure 2]

In the simulation below, the young man is getting ready for the Prom. He needs to stand at a particular distance and have the mirror be a particular length to be able to view his entire body. Rays of light are emerging from various light sources in the room and bouncing off him into the mirror. Play around with rays from different locations, try different mirror lengths, and see what you can discover about the reflection of light in a plane mirror:



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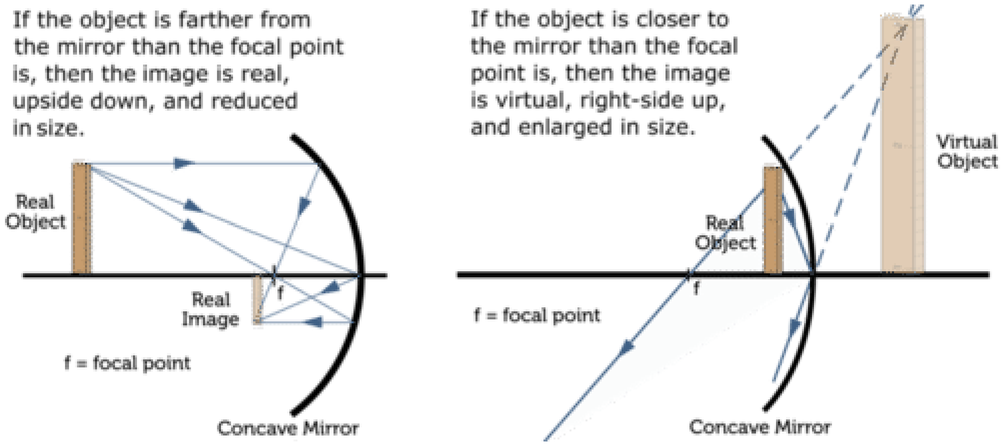
Concave Mirror

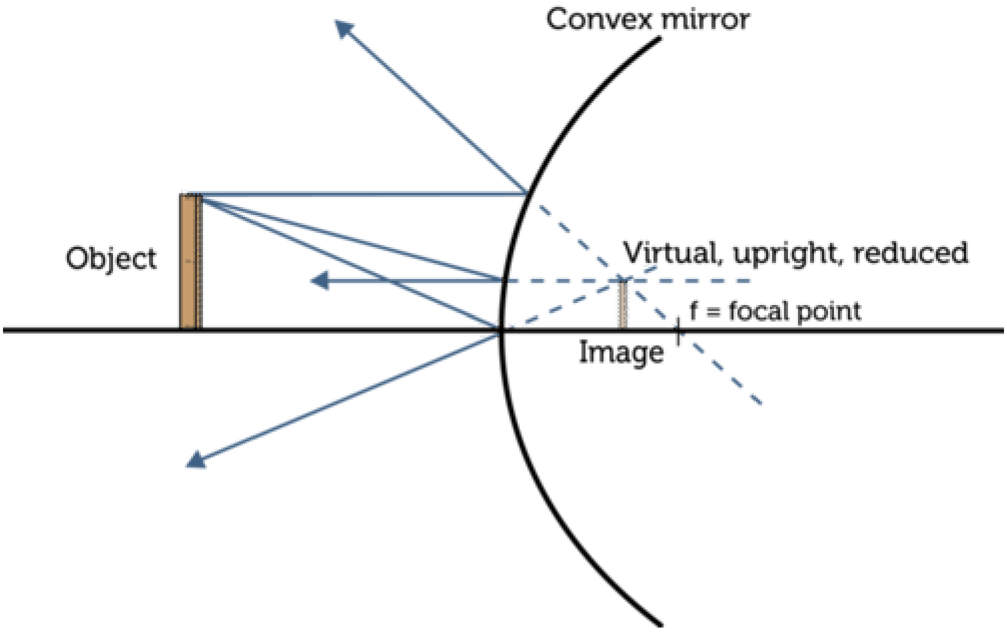
Some mirrors have a curved rather than flat surface. Curved mirrors can be concave or convex. A **concave** mirror is shaped like the inside of a bowl. This type of mirror forms either real or virtual images, depending on where the object is placed relative to the focal point. The focal point is the point in front of the mirror where the reflected rays meet. You can see how concave mirrors form images in the **Figure** below. Concave mirrors are used behind car headlights. They focus the light and make it brighter. Concave mirrors are also used in some telescopes.



[Figure 3]

Convex Mirror

The other type of curved mirror, a **convex** mirror, is shaped like the outside of a bowl. Because of its shape, it can gather and reflect light from a wide area. As you can see in the **Figure** below, a convex mirror forms only virtual images that are right-side up and smaller than the actual object.



[Figure 4]

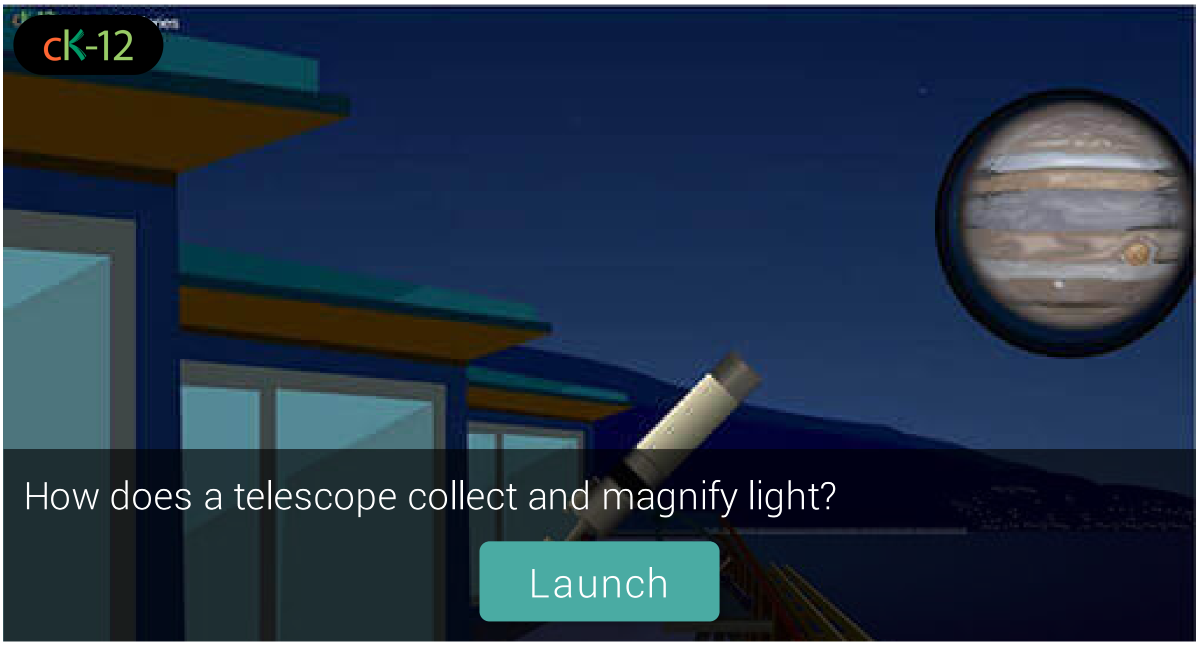
Q: Convex mirrors are used as side mirrors on cars. You can see one in the **Figure** below. Why is a convex mirror good for this purpose?

A: Because it gathers light over a wide area, a convex mirror gives the driver a wider view of the area around the vehicle than a plane mirror would.

[Figure 5]

When light enters a Cassegrain telescope from a distant planet, first it bounces off a concave primary mirror and then off a secondary convex mirror. Play around with a

Cassegrain Telescope in the simulation below and see if you can until you get a clear view of Jupiter in the eyepiece:



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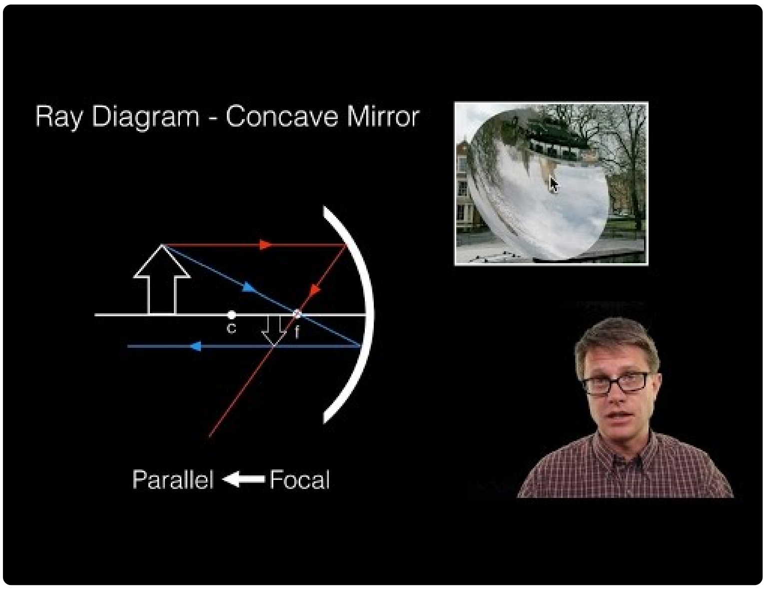
Watch the video below to learn more about how ray diagrams can be used to predict how an the image of an object will appear when reflected in a mirror:



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Summary

- When a mirror reflects light, it forms an image. An image is a copy of an object formed by reflection (or refraction). A real image is a true image that forms in front of a mirror where reflected light rays actually meet. A virtual image appears to be on the other side of the mirror and doesn't really exist.

- Most mirrors are plane mirrors that have a flat reflective surface. A plane mirror forms only virtual, right-side up, and life-sized images.
- A concave mirror is shaped like the inside of a bowl. The type of image it forms depends on where the object is relative to the focal point. The image may be real, upside down, and reduced in size; or it may be virtual, right-side up, and enlarged.
- A convex mirror is shaped like the outside of a bowl. It forms only virtual images that are right-side up and reduced in size relative to the object.

Review

1. What is an image? How do real and virtual images differ?
2. Define the focal point of a mirror.
3. Describe the image formed by a plane mirror.
4. What type of image is formed by a concave mirror if the object is between the mirror and the focal point?
5. Mirrors like the one in the **Figure** below are sometimes placed at street intersections so drivers can see around blind corners. What type of mirror is used for this purpose? What type of image does it form?

[Figure 6]

15.4 Refraction

FlexBooks® 2.0 > American HS Physical Science > Refraction

Last Modified: Oct 01, 2019

[Figure 1]

Is this some kind of magic trick? Or is this straw really broken where it enters the water? The answer to both questions is no. There's nothing wrong with the straw, and no magic is involved. It's simply how light may behave when it enters a new medium.

Speed of Light and Matter

Light always travels at the same speed across space. That speed, represented by the letter c, is about 300 million meters per second. However, when light travels through a medium, it travels more slowly. The speed varies for different kinds of matter. The **Table** below gives the speed of visible light in six different materials.

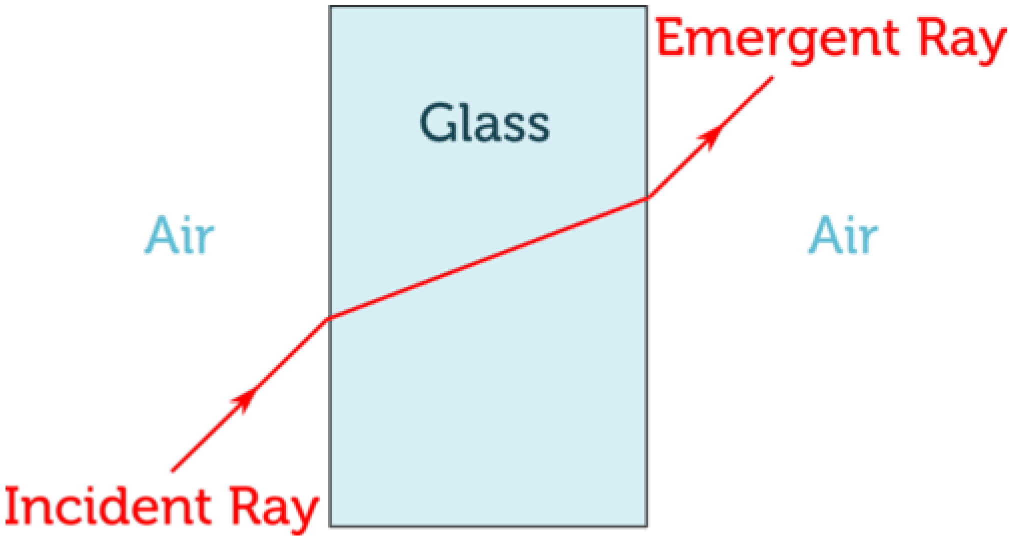
Material	Speed of Visible Light (m/s)
Air	299 million
Water	231 million
Glass	200 million
Vegetable oil	150 million
Alcohol	140 million
Diamond	125 million

Q: Predict the speed of visible light through vinegar.

A: Vinegar is mostly water, so if you predicted that the speed of light through vinegar would be close to its speed through water, you are correct. The speed of visible light through Heinz® vinegar is about 230 million m/s.

Bending Light

When light passes from one medium to another, it changes speed. For example, when light passes from air to glass, it slows down. If light strikes a sheet of glass at a 90° angle, or perpendicular to the glass, it slows down but still passes straight through the glass. However, if light enters the glass at an angle other than 90°, the light bends as it slows down. The bending of light as it changes speed in a new medium is called **refraction**. The **Figure** below shows how refraction occurs. Notice that the speed of light changes again as it passes from the glass back to the air. In this case, the speed increases, and the ray of light resumes its initial direction.



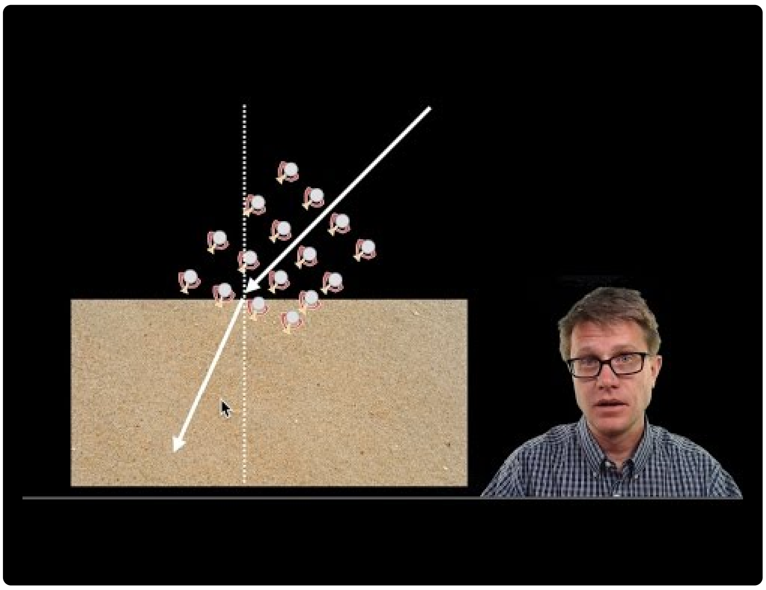
[Figure 2]

What's Your Angle?

The angle at which light bends when it enters a different medium depends on its change in speed. The greater the change in speed, the greater the angle of refraction is. For example, light refracts more when it passes from air to diamond than it does when it passes from air to water. That's because the speed of light is slower in diamond than it is in water.

Q: Now can you explain why the straw in the opening image appears to be broken where it enters the water?

A: The straw appears to be broken because of refraction. Light slows down and bends when it passes from the water in the glass to the air on its way to your eyes.



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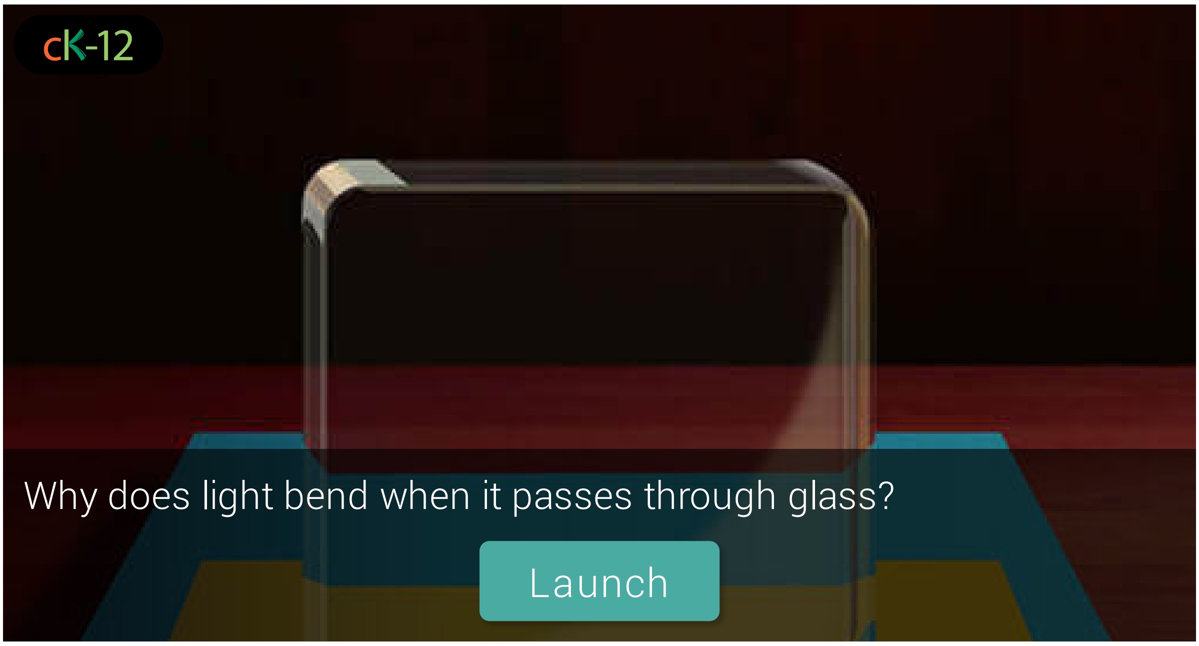
In the Least Time simulation below, you can adjust the sliders so that light travels from air to a denser material like glass or diamond. Then, drag the incident ray and refracted rays to the correct angles according to Snell's Law. When you have found the path of least time - a red light ray will shoot out across the both materials! Very exciting!



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Summary

- Light always travels at the same speed through empty space. That speed, represented by the letter c, is about 300 million meters per second. However, when light travels through a medium, it travels more slowly.

- If light passes from one medium to another at an angle other than 90 °, the light changes speed and bends. This bending of light is called refraction.
- The angle at which light refracts when it enters a different medium depends on its change in speed. The greater the change in speed, the greater the angle of refraction is.

Review

1. You may have heard that the speed of light is constant. Is this true? Why or why not?
2. What is the refraction of light? When and why does it occur?
3. Draw a diagram to show how visible light refracts when it passes from air to diamond.

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15.5 Lenses

FlexBooks® 2.0 > American HS Physical Science > Lenses

Last Modified: Oct 01, 2019

[Figure 1]

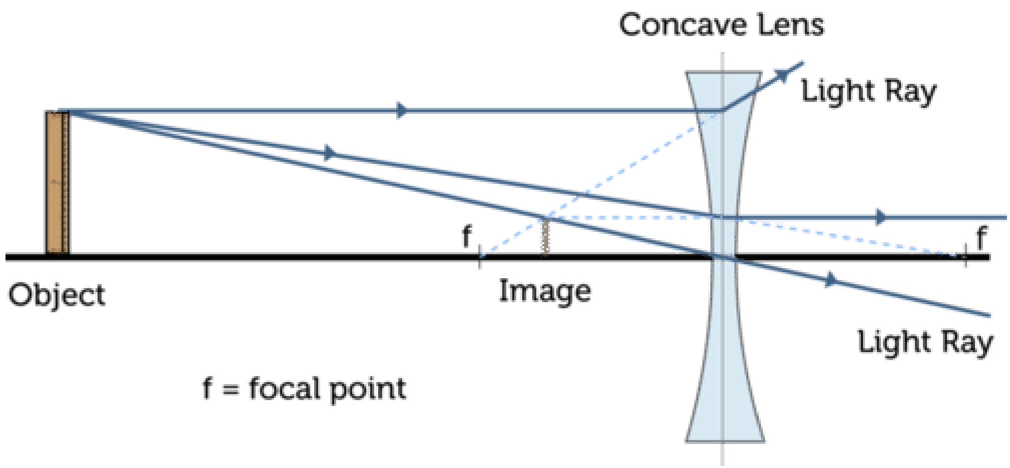
The tiny object on this woman's finger is life-changing for her. It lets her see clearly without wearing glasses. You probably recognize the object as a contact lens. You may even wear contact lenses yourself.

What Is a Lens?

A **lens** is a transparent object with one or two curved surfaces. It is typically made of glass (or clear plastic in the case of a contact lens). A lens refracts, or bends, light and forms an image. An image is a copy of an objected formed by the refraction (or reflection) of visible light. The more curved the surface of a lens is, the more it refracts the light that passes through it. There are two basic types of lenses: concave and convex. The two types of lenses have different shapes, so they bend light and form images in different ways.

Concave Lens

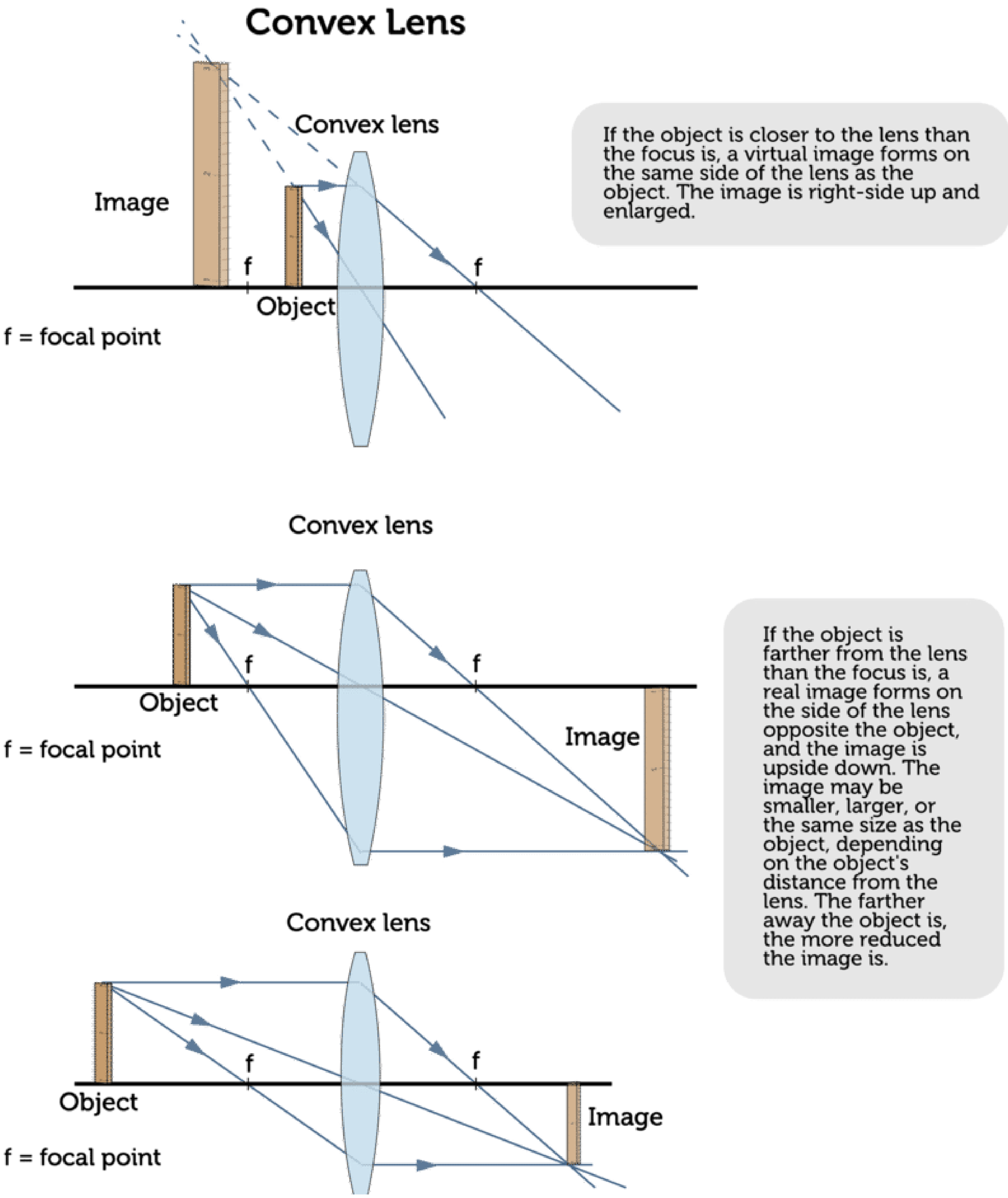
A concave lens is thicker at the edges than it is in the middle. You can see the shape of a concave lens in the **Figure** below. From the diagram, it's clear that the lens causes rays of light to diverge, or spread apart, as they pass through it. Note that the image formed by a concave lens is on the same side of the lens as the object. It is also smaller than the object and right-side up. However, it isn't a real image. It is a virtual image. Your brain "tricks" you into seeing an image there. The light rays actually pass through the glass to the other side and spread out in all directions.



[Figure 2]

Convex Lens

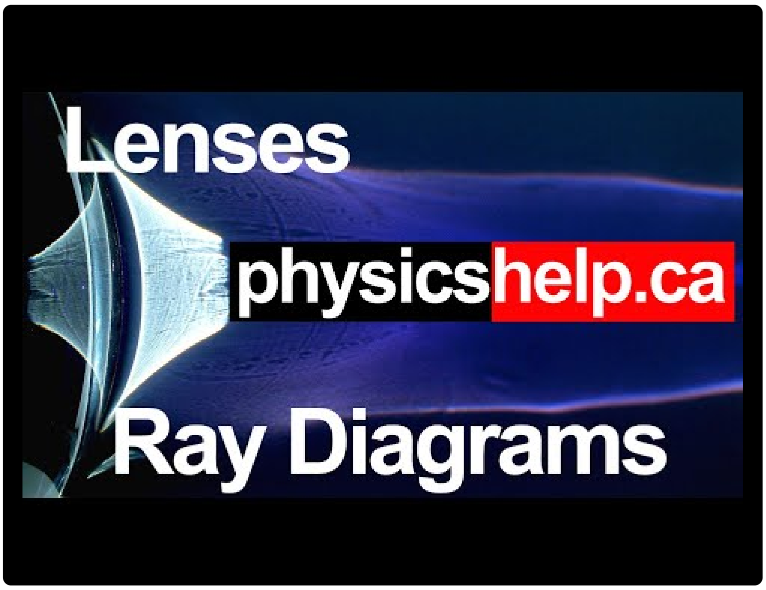
A convex lens is thicker in the middle than at the edges. You can see the shape of a convex lens in the **Figure** below. A convex lens causes rays of light to converge, or meet, at a point called the focus (F). A convex lens forms either a real or virtual image. It depends on how close the object is to the lens relative to the focus.



[Figure 3]

Q: An example of a convex lens is a hand lens. Which of the three convex lens diagrams in the **Figure** above shows how a hand lens makes an image?

A: You've probably looked through a hand lens before. If you have, then you know that the image it produces is right-side up. Therefore, the first diagram must show how a hand lens makes an image. It's the only one that produces a right-side up image.



https://flexbooks.ck12.org/flx/render/embeddedobject/257740

Summary

- A lens is a transparent object, typically made of glass, with one or two curved surfaces. A lens refracts light and forms an image.
- A concave lens is thicker at the edges than it is in the middle. This causes rays of light to diverge. The light forms a virtual image that is right-side up and smaller than the object.
- A convex lens is thicker in the middle than at the edges. This causes rays of light to converge. The light forms a real or virtual image depending on the distance of the object from the lens.

Review

1. What is a lens? What does it do?
2. Describe the image formed by a concave lens.
3. Explain how a hand lens forms an enlarged image of an object.

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15.6 REFERENCES

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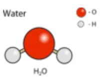	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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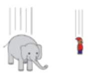
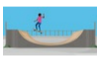
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** CK-12 Foundation **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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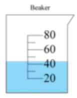
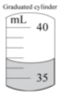
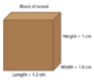
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 16

Electricity

Chapter Outline

16.1 Electric Charge and Electric Force

FlexBooks® 2.0 > American HS Physical Science > Electric Charge and Electric Force

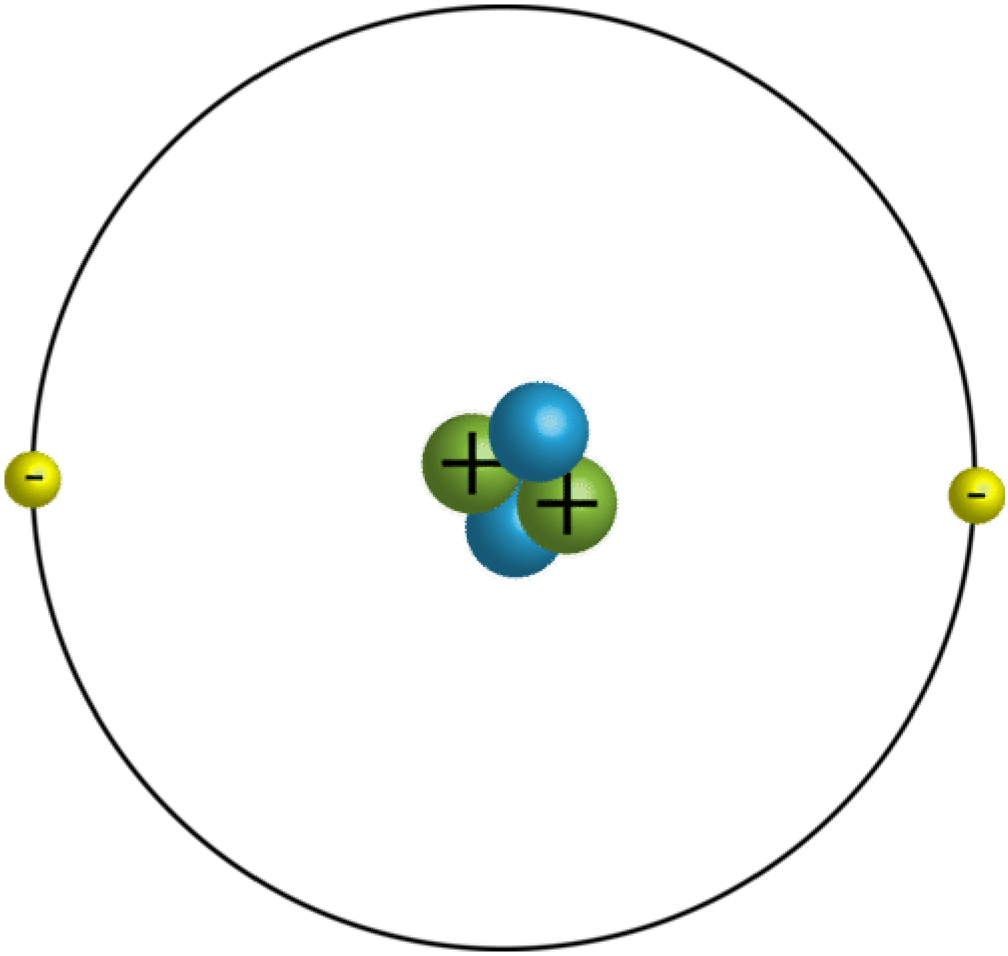
Last Modified: Oct 15, 2019

[Figure 1]

A lightning bolt is like the spark that gives you a shock when you touch a metal doorknob. Of course, the lightning bolt is on a *much* larger scale. But both the lightning bolt and spark are a sudden transfer of electric charge.

Introducing Electric Charge

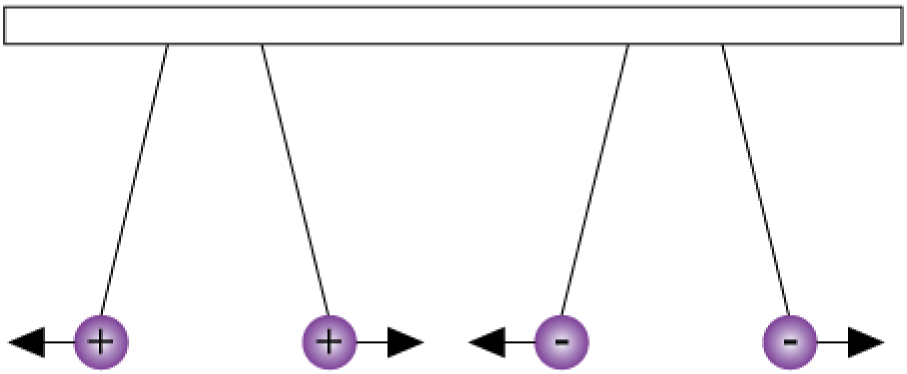
Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge. In the **Figure** below, you can see that positively charged protons (+) are located in the nucleus of the atom, while negatively charged electrons (-) move around the nucleus.



[Figure 2]

Electric Force

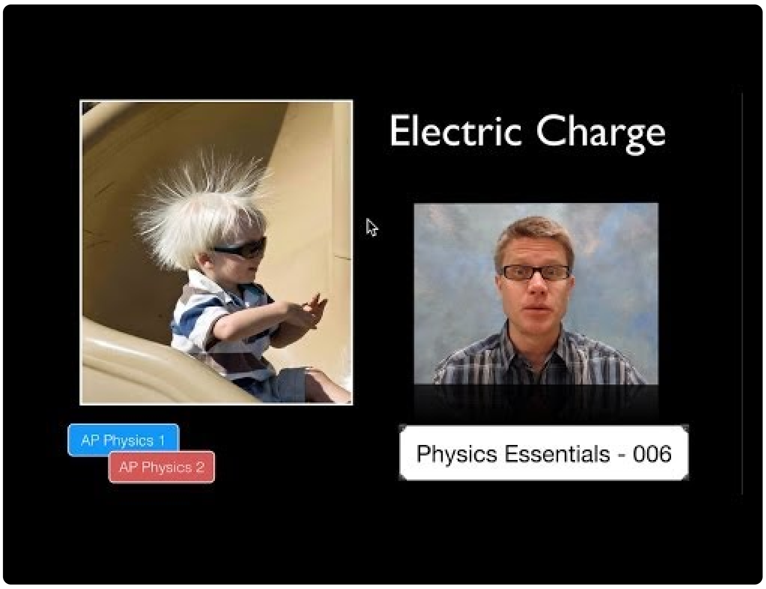
When it comes to electric charges, opposites attract, so positive and negative particles attract each other. You can see this in the **Figure** below. This attraction explains why negative electrons keep moving around the positive nucleus of the atom. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart. This is also shown in the diagram. The attraction or repulsion between charged particles is called **electric force**. The strength of electric force depends on the amount of electric charge on the particles and the distance between them. Larger charges or shorter distances result in greater force.



[Figure 3]

Q: How do positive protons stay close together inside the nucleus of the atom if like charges repel each other?

A: Other, stronger forces in the nucleus hold the protons together.



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Summary

- Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching.
- Particles that have opposite charges attract each other. Particles that have like charges repel each other. The force of attraction or repulsion is called electric force.

Review

1. What is electric charge?
2. Make a simple table summarizing electric forces between charged particles.

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16.2 Static Electricity and Static Discharge

FlexBooks® 2.0 > American HS Physical Science > Static Electricity and Static Discharge

Last Modified: May 29, 2019

[Figure 1]

You're a thoughtful visitor, so you wipe your feet on the welcome mat before you reach out to touch the brass knocker on the door. Ouch! A spark suddenly jumps between your hand and the metal, and you feel an electric shock.

Q: Why do you think an electric shock occurs?

A: An electric shock occurs when there is a sudden discharge of static electricity.

What Is Static Electricity?

Static electricity is a buildup of electric charges on objects. Charges build up when negative electrons are transferred from one object to another. The object that gives up electrons becomes positively charged, and the object that accepts the electrons becomes negatively charged. This can happen in several ways.

One way electric charges can build up is through friction between materials that differ in their ability to give up or accept electrons. When you wipe your rubber-soled shoes on the wool mat, for example, electrons rub off the mat onto your shoes. As a result of this transfer of electrons, positive charges build up on the mat and negative charges build up on you.

Once an object becomes electrically charged, it is likely to remain charged until it touches another object or at least comes very close to another object. That's because electric charges cannot travel easily through air, especially if the air is dry.

Q: You're more likely to get a shock in the winter when the air is very dry. Can you explain why?

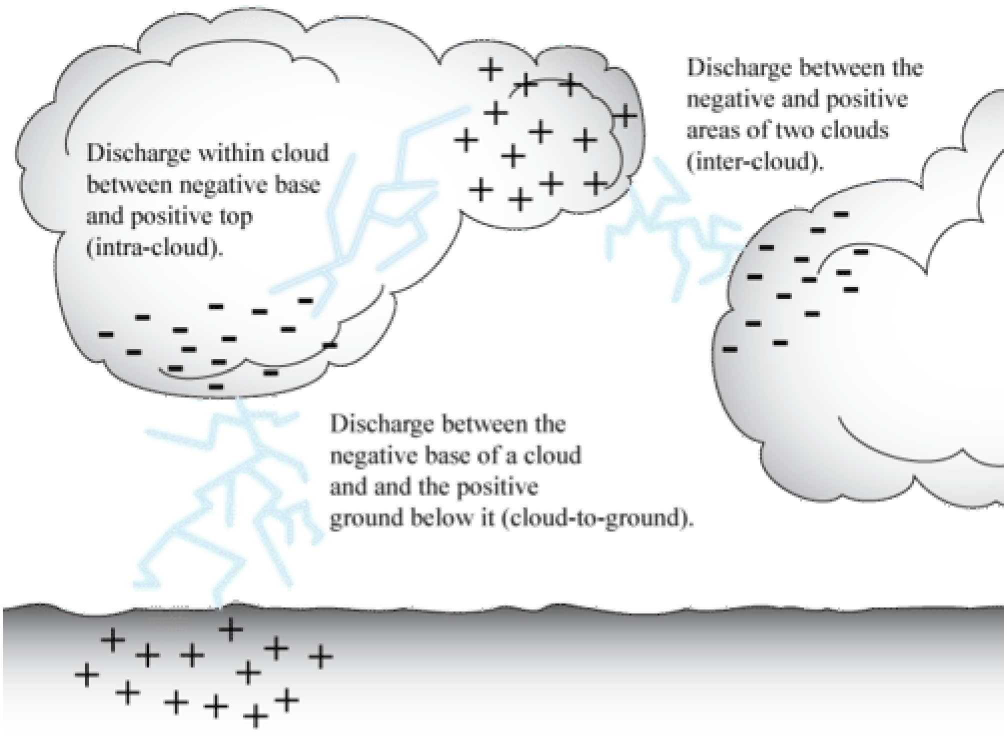
A: When the air is very dry, electric charges are more likely to build up objects because they cannot travel easily through the dry air. This makes a shock more likely when you touch another object.

Static Discharge

What happens when you have become negatively charged and your hand approaches the metal doorknocker? Your negatively charged hand repels electrons in the metal, so the electrons move to the other side of the knocker. This makes the side of the knocker closest to your hand positively charged. As your negatively charged hand gets very close to the positively charged side of the metal, the air between your hand and the knocker also becomes electrically charged. This allows electrons to suddenly flow from your hand to the knocker. The sudden flow of electrons is **static discharge**. The discharge of electrons is the spark you see and the shock you feel.

How Lightning Occurs

Another example of static discharge, but on a much larger scale, is lightning. You can see how it occurs in the following diagram (**Figure** below).

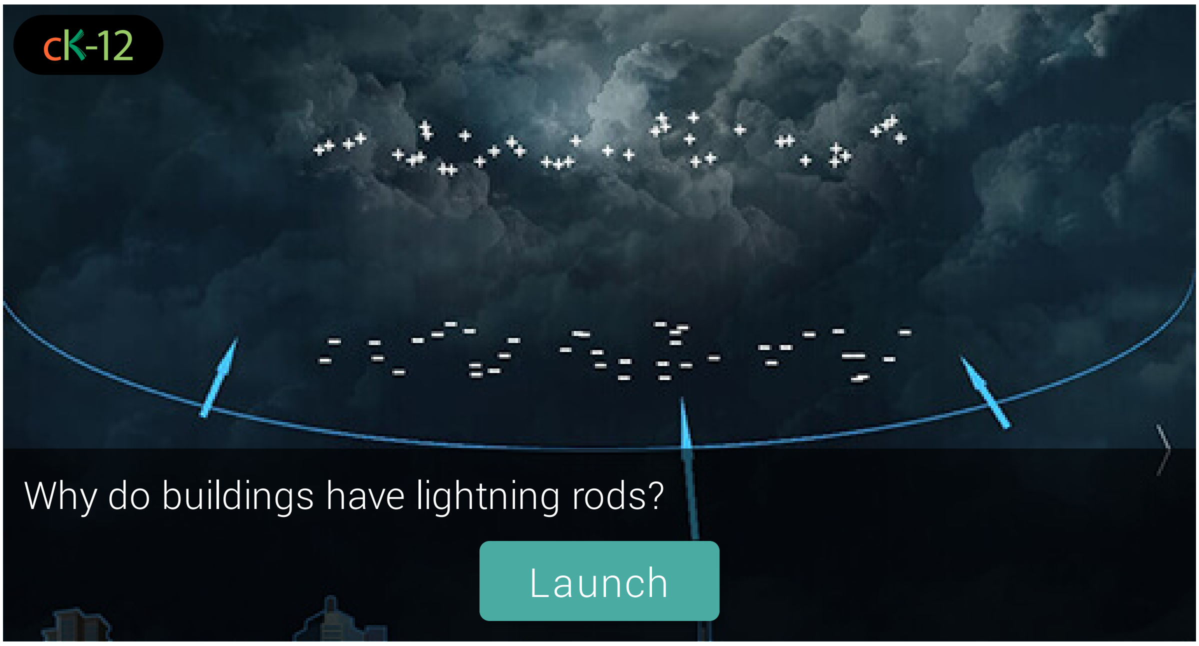


[Figure 2]

During a rainstorm, clouds develop regions of positive and negative charge due to the movement of air molecules, water drops, and ice particles. The negative charges are concentrated at the base of the clouds, and the positive charges are concentrated at the top. The negative charges repel electrons on the ground beneath them, so the ground below the clouds becomes positively charged. At first, the atmosphere prevents electrons from flowing away from areas of negative charge and toward areas of positive charge. As more charges build up, however, the air between the oppositely charged areas also becomes charged. When this happens, static electricity is discharged as bolts of lightning.

https://flexbooks.ck12.org/flx/render/embeddedobject/177735

To learn more about lightning, launch the Lightning Rod simulation below. Adjust the Charge Separation slider to high, the Cloud Separation slider to low, and be sure to turn the Lightning Rod on (to protect the people in the building). Then, press play and see what happens:



https://flexbooks.ck12.org/flx/show/interactive/https://interactives.ck12.org/simulations/embed.html?embeded=true&interactive=lightning-rod&subject=physics&lang=en&assignment=true&hash=09bb2ed50fe15836062074ccfd85d0b6

Summary

- Static electricity is a buildup of electric charges on objects. It occurs when electrons are transferred from one object to another.
- A sudden flow of electrons from one charged object to another is called static discharge.
- Examples of static discharge include lightning and the shock you sometimes feel when you touch another object.

Review

1. What is static electricity?
2. How does static discharge occur?
3. Explain why a bolt of lightning is like the spark you might see when you touch a metal object and get a shock.

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16.3 Current

FlexBooks® 2.0 > American HS Physical Science > Current

Last Modified: Jun 07, 2021

[Figure 1]

Emily's dad is giving his car battery a "jump" because the battery "died" overnight. He's attaching cables to the terminals of the car battery. Then he will connect the other ends of the cables to the terminals of a "live" battery. The cables will carry electric current to the dead battery, providing the energy needed for the car to start.

Flowing Charges

Electric current is a continuous flow of electric charges (electrons). Current is measured as the amount of charge that flows past a given point in a certain amount of time. The SI unit for electric current is the ampere (A), or amp. Electric current may flow in just one direction (direct current), or it may keep reversing direction (alternating current).

Q: Why do you think charges flow in an electric current?

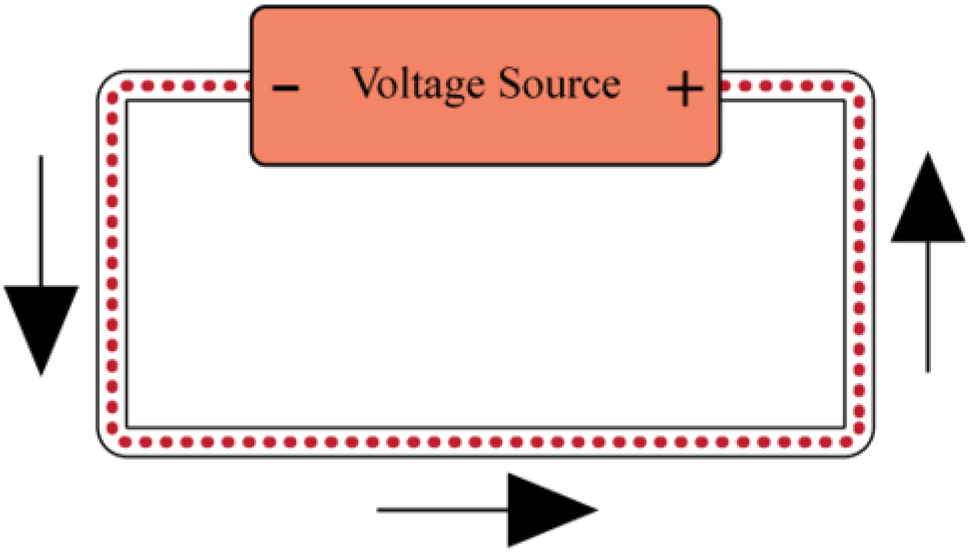
A: Electric charges flow when they have electric potential energy. Potential energy is stored energy that an object has due to its position or shape.

Electric Potential Energy

Electric potential energy comes from the position of a charged particle in an electric field. For example, when two negative charges are close together, they have potential energy because they repel each other and have the potential to push apart. If the charges actually move apart, their potential energy decreases. Electric charges always move spontaneously from a position where they have higher potential energy to a position where they have lower potential energy. This is like water falling over a dam from an area of higher to lower potential energy due to gravity.

Voltage

For an electric charge to move from one position to another, there must be a difference in electric potential energy between the two positions. A difference in electric potential energy is called **voltage**. The SI unit for voltage is the volt (V). Look at the **Figure** below. It shows a simple circuit. The source of voltage in the circuit is a 1.5-volt battery. The difference of 1.5 volts between the two battery terminals results in a spontaneous flow of charges, or electric current, between them. Notice that the current flows from the negative terminal to the positive terminal, because electric current is a flow of electrons.



[Figure 2]

Q: You might put a 1.5-volt battery in a TV remote. The battery in a car is a 12-volt battery. How do you think the current of a 12-volt battery compares to the current of a 1.5-volt battery?

A: Greater voltage means a greater difference in potential energy, so the 12-volt battery can produce more current than the 1.5-volt battery.

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Summary

- Electric current is a continuous flow of electric charges. The SI unit for electric current is the ampere (A).
- An electric charge flows when it has electric potential energy due to its position in an electric field. An electric charge always moves spontaneously from a position of higher to lower potential energy.
- For an electric charge to move from one position to another, there must be a difference in electric potential energy between the two positions. This difference is called voltage. The SI unit for voltage is the volt (V).

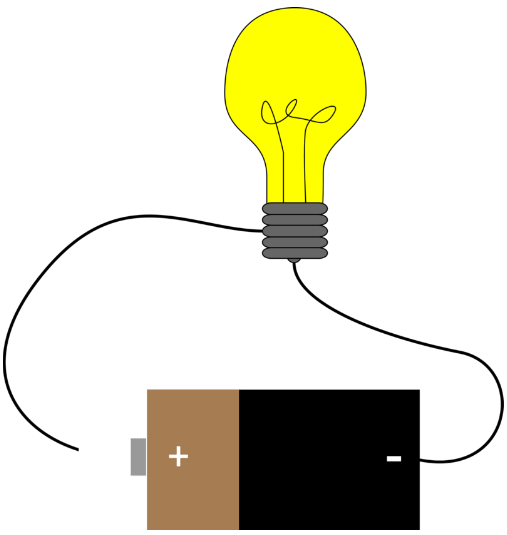
Review

1. What is electric current? Name the SI unit for electric current.
2. Explain what gives a charge electric potential energy. Describe an example.
3. How is electric potential energy related to the direction an electric charge spontaneously moves?
4. What is voltage, and why is it needed for charges to flow in an electric current?

16.4 Circuit

FlexBooks® 2.0 > American HS Physical Science > Circuit

Last Modified: Oct 15, 2019



[Figure 1]

Jose made this sketch of a battery and light bulb for science class. If this were a real set up, the light bulb wouldn't work. The problem is the loose wire on the left. It must be connected to the positive terminal of the battery in order for the bulb to light up.

Q: Why does the light bulb need to be connected to both battery terminals?

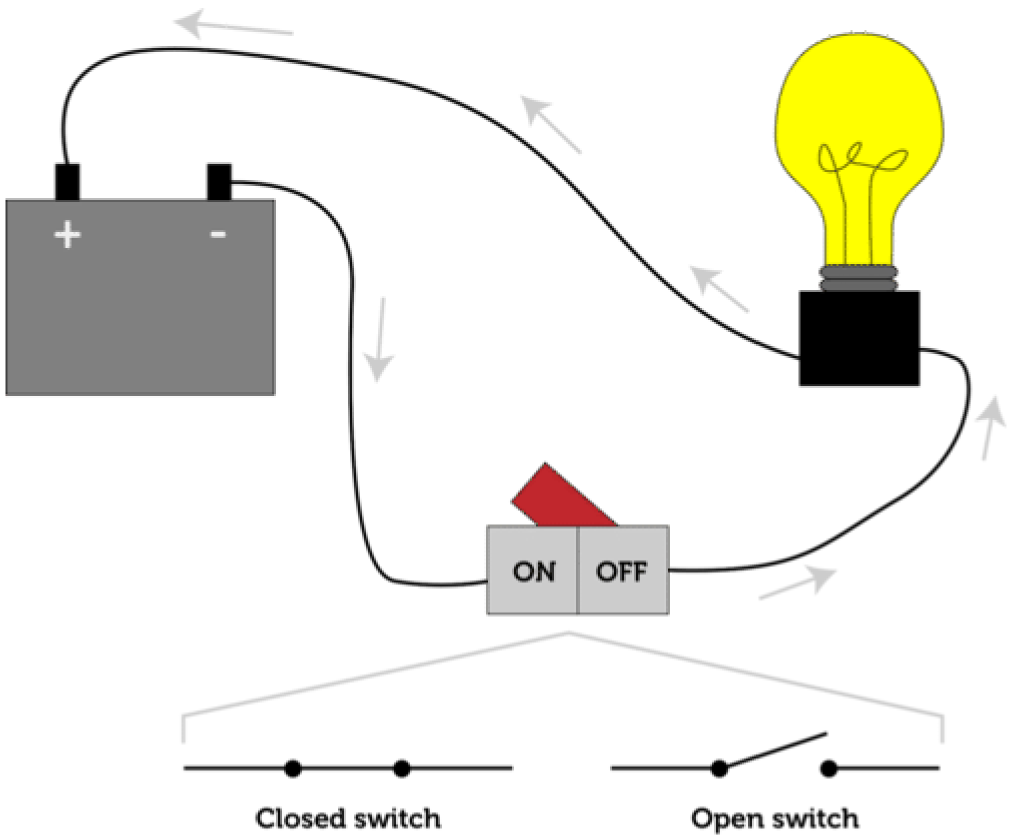
A: Electric current can flow through a wire only if it forms a closed loop. Charges must have an unbroken path to follow between the positively and negatively charged parts of the voltage source, in this case, the battery.

Electric Circuit Basics

A closed loop through which current can flow is called an **electric circuit**. In homes in the U.S., most electric circuits have a voltage of 120 volts. The amount of current (amps) a circuit carries depends on the number and power of electrical devices connected to the circuit. Home circuits generally have a safe upper limit of about 20 or 30 amps.

Parts of an Electric Circuit

All electric circuits have at least two parts: a voltage source and a conductor. They may have other parts as well, such as light bulbs and switches, as in the simple circuit seen in the **Figure** below.

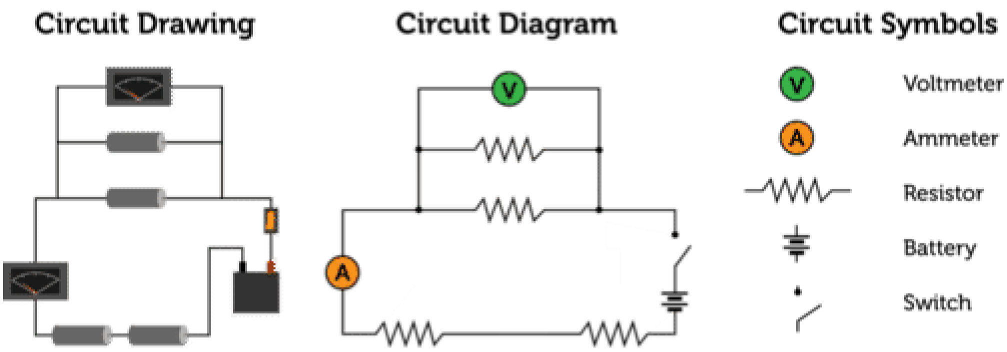


[Figure 2]

- The voltage source of this simple circuit is a battery. In a home circuit, the source of voltage is an electric power plant, which may supply electric current to many homes and businesses in a community or even to many communities.
- The conductor in most circuits consists of one or more wires. The conductor must form a closed loop from the source of voltage and back again. In the **Figure** above, the wires are connected to both terminals of the battery, so they form a closed loop.
- Most circuits have devices such as light bulbs that convert electrical energy to other forms of energy. In the case of a light bulb, electrical energy is converted to light and thermal energy.
- Many circuits have switches to control the flow of current. When the switch is turned on, the circuit is closed and current can flow through it. When the switch is turned off, the circuit is open and current cannot flow through it.

Circuit Diagrams

When a contractor builds a new home, she uses a set of plans called blueprints that show her how to build the house. The blueprints include circuit diagrams. The diagrams show how the wiring and other electrical components are to be installed in order to supply current to appliances, lights, and other electric devices. You can see an example of a very simple circuit in the **Figure** below. Different parts of the circuit are represented by standard circuit symbols. An ammeter measures the flow of current through the circuit, and a voltmeter measures the voltage. A resistor is any device that converts some of the electricity to other forms of energy. For example, a resistor might be a light bulb or doorbell.



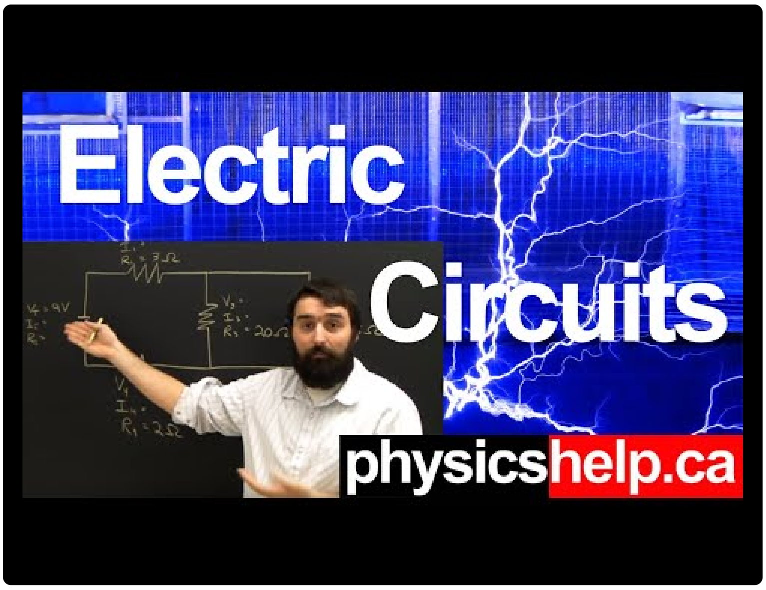
[Figure 3]

The circuit diagram in the middle represents the circuit drawing on the left. On the right are some of the standard symbols used in circuit diagrams.

Q: Only one of the circuit symbols in the **Figure** above must be included in every circuit. Which symbol is it?

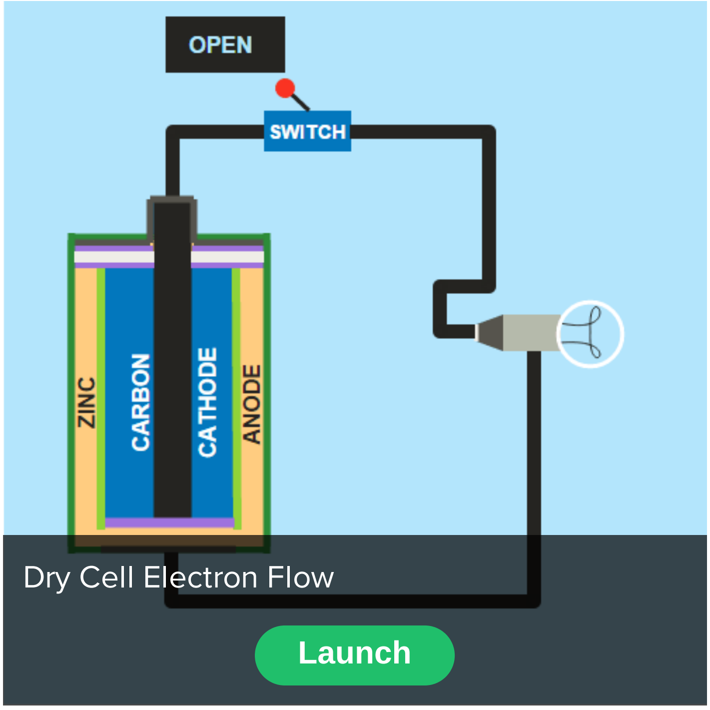
A: The battery symbol (or a symbol for some other voltage source) must be included in every circuit. Without a source of voltage, there is no electric current.

Watch the video below to learn more about how to draw circuit diagrams:



https://www.youtube.com/embed/52JoONLGl2s

Launch the PLIX Interactive below to see how electrons flow through a dry cell battery and the circuit connected to it:



https://flexbooks.ck12.org/assessment/tools/geometry-tool/fullscreen.html?qID=565623aa8e0e082bc356b512

Summary

- An electric circuit is a closed loop through which current can flow.
- All electric circuits must have a voltage source, such as a battery, and a conductor, which is usually wire. They may have one or more electric devices as well.
- An electric circuit can be represented by a circuit diagram, which uses standard symbols to represent the parts of the circuit.

Review

1. What is an electric circuit?
2. Which two parts must all electric circuits contain?
3. Sketch a simple circuit that includes a battery, switch, and light bulb. Then make a circuit diagram to represent your circuit, using standard circuit symbols.

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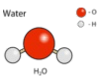	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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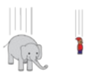	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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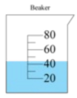
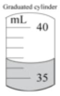
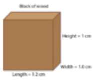
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License

CHAPTER 17

Magnetism

Chapter Outline

17.1 Magnet

FlexBooks® 2.0 > American HS Physical Science > Magnet

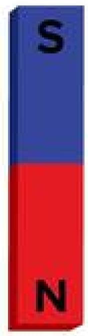
Last Modified: Oct 15, 2019

[Figure 1]

The train in this photo is called a maglev train. The word *maglev* stands for "magnetic levitation." Magnets push the train upward so it hovers, or levitates, above the track without actually touching it. This eliminates most of the friction acting against the train when it moves. Other magnets pull the train forward along the track. Because of all the magnets, the train can go very fast. It can fly over the tracks at speeds up to 480 kilometers (300 miles) per hour! What are magnets and how do they exert such force? In this article, you'll find out.

Magnetic Poles

A **magnet** is an object that attracts certain materials such as iron. You're probably familiar with common bar magnets, like the one shown in the **Figure** below. Like all magnets, this bar magnet has north and south **magnetic poles**. The red end of the magnet is the north pole and the blue end is the south pole. The poles are regions where the magnet is strongest. The poles are called north and south because they always line up with Earth's north-south axis if the magnet is allowed to move freely. (Earth's axis is the imaginary line around which the planet rotates.)



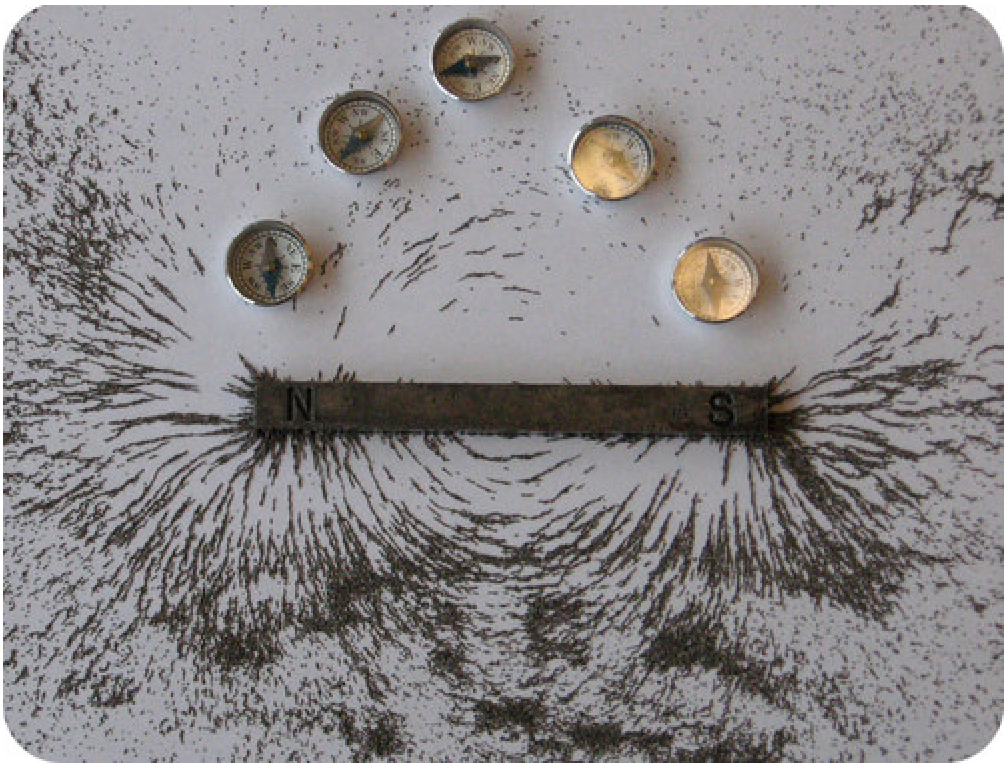
[Figure 2]

Q: What do you suppose would happen if you cut the bar magnet pictured in the **Figure** above along the line between the north and south poles?

A: Both halves of the magnet would also have north and south poles. If you cut each of the halves in half, all those pieces would have north and south poles as well. Pieces of a magnet always have both north and south poles no matter how many times you cut the magnet.

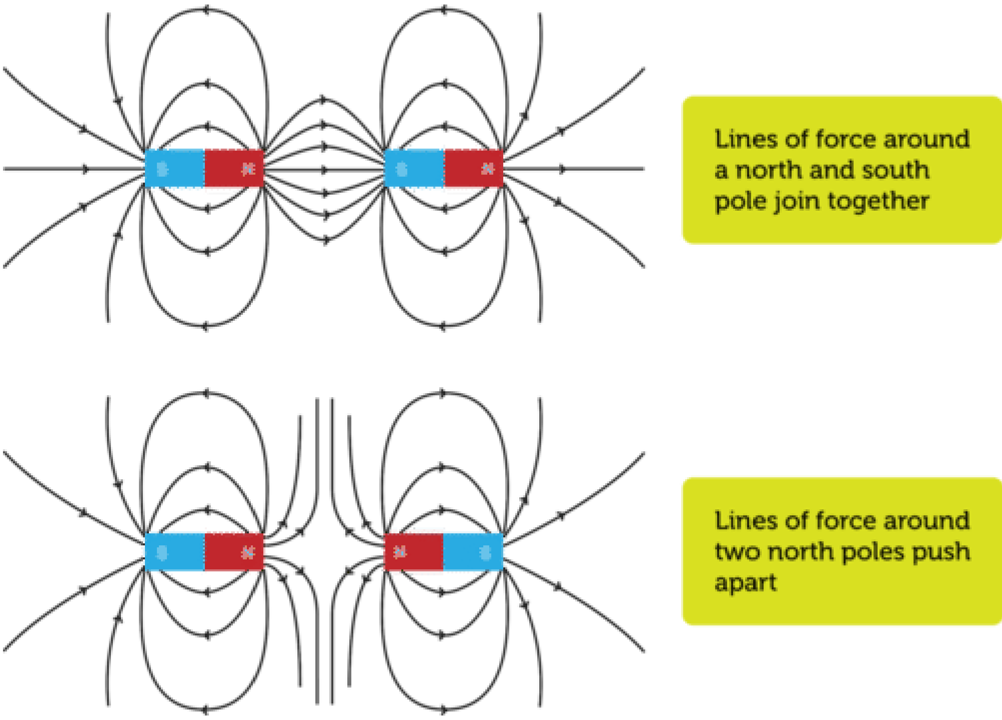
Magnetic Force and Magnetic Field

The force that a magnet exerts on certain materials, including other magnets, is called **magnetic force**. The force is exerted over a distance and includes forces of attraction and repulsion. North and south poles of two magnets attract each other, while two north poles or two south poles repel each other. A magnet can exert force over a distance because the magnet is surrounded by a **magnetic field**. In the **Figure** below, you can see the magnetic field surrounding a bar magnet. Tiny bits of iron, called iron filings, were placed under a sheet of glass. When the magnet was placed on the glass, it attracted the iron filings. The pattern of the iron filings shows the lines of force that make up the magnetic field of the magnet. The concentration of iron filings near the poles indicates that these areas exert the strongest force. You can also see how the magnetic field affects the compasses placed above the magnet.



[Figure 3]

When two magnets are brought close together, their magnetic fields interact. You can see how they interact in the **Figure** below. The lines of force of north and south poles attract each other whereas those of two north poles repel each other.



[Figure 4]

Watch the video below to learn more about how magnets work:

https://flexbooks.ck12.org/flx/render/embeddedobject/258454

Summary

- A magnet is an object that attracts certain materials such as iron. All magnets have north and south magnetic poles. The poles are regions where the magnet is strongest.
- The force that a magnet exerts is called magnetic force. The force is exerted over a distance and includes forces of attraction and repulsion. A magnet can exert force over a distance because the magnet is surrounded by a magnetic field.

Review

1. What is a magnet?
2. Describe the magnetic poles of a bar magnet.
3. Explain why a magnet can exert force over a distance.
4. Sketch two bar magnets that are arranged so their magnetic fields attract each other. Label the magnetic poles, and add arrows to represent lines of force between the two magnets.

17.2 Earth as a Magnet

FlexBooks® 2.0 > American HS Physical Science > Earth as a Magnet

Last Modified: May 29, 2019

[Figure 1]

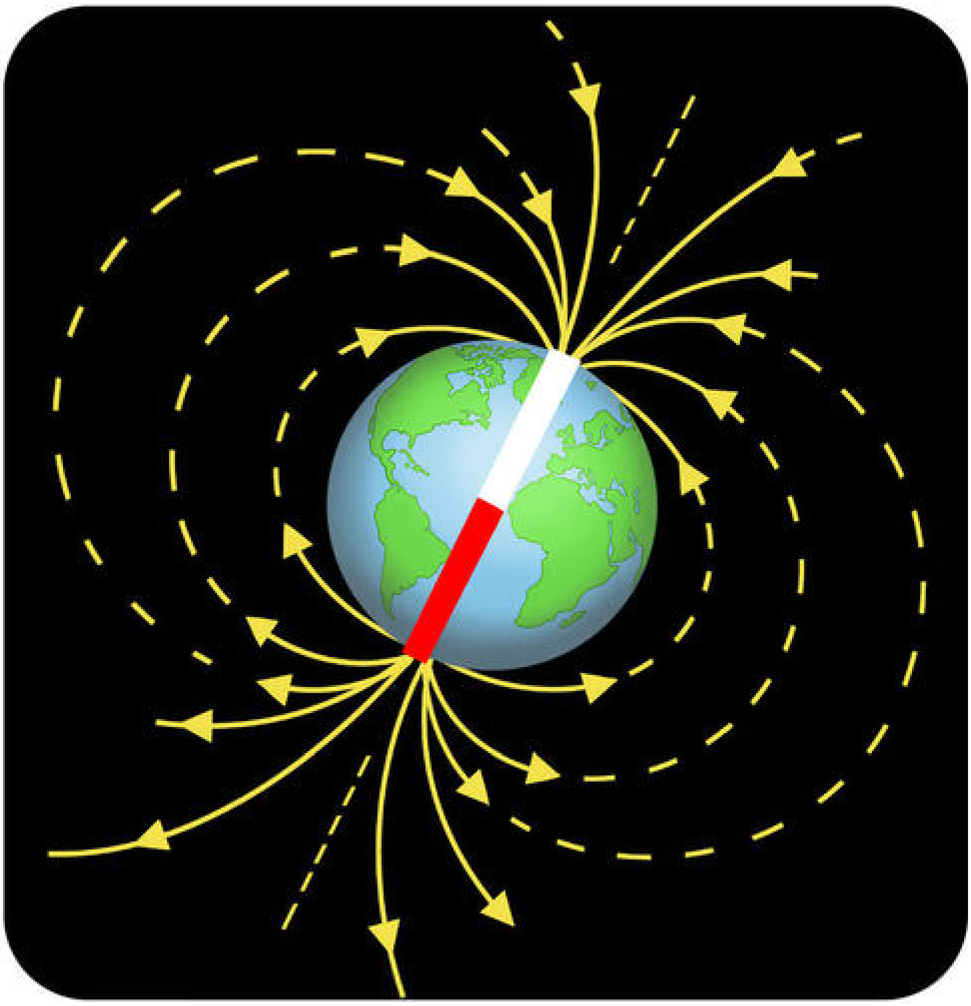
Did you ever use a compass like the one in this picture? Even if you've never used a compass, you probably know that the needle of a compass always points north. That's because a compass needle is magnetized, so it is attracted by a magnet.

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

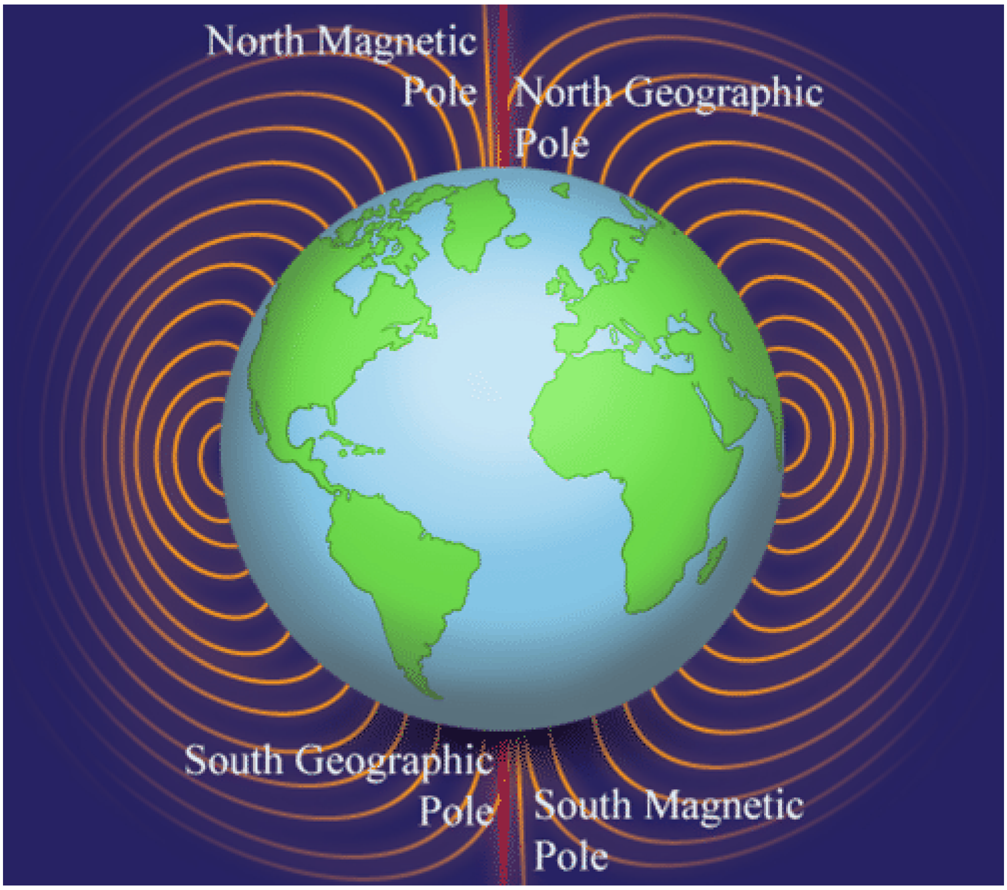
Imagine a huge bar magnet passing through Earth's axis, as in the **Figure** below. This is a good representation of Earth as a magnet. Like a bar magnet, Earth has north and south magnetic poles. A **magnetic pole** is the north or south end of a magnet, where the magnet exerts the most force.



[Figure 2]

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** below. 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.



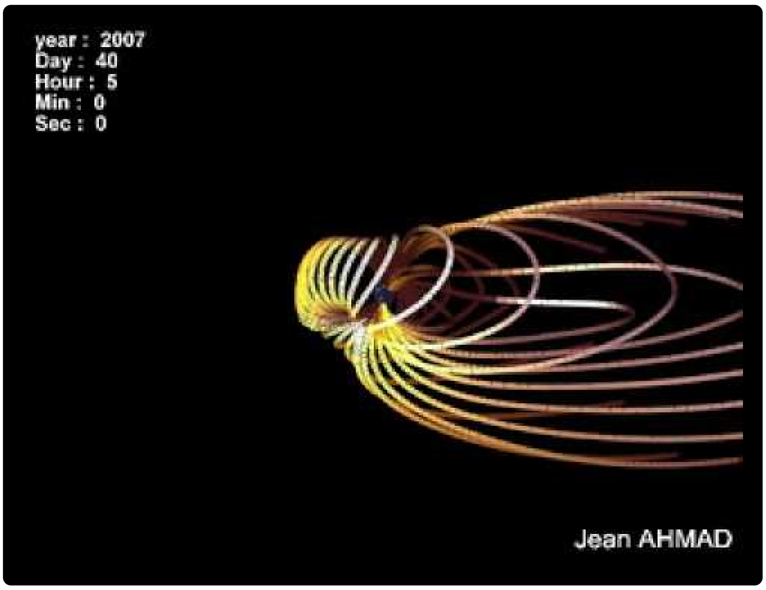
[Figure 3]

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** below. 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.



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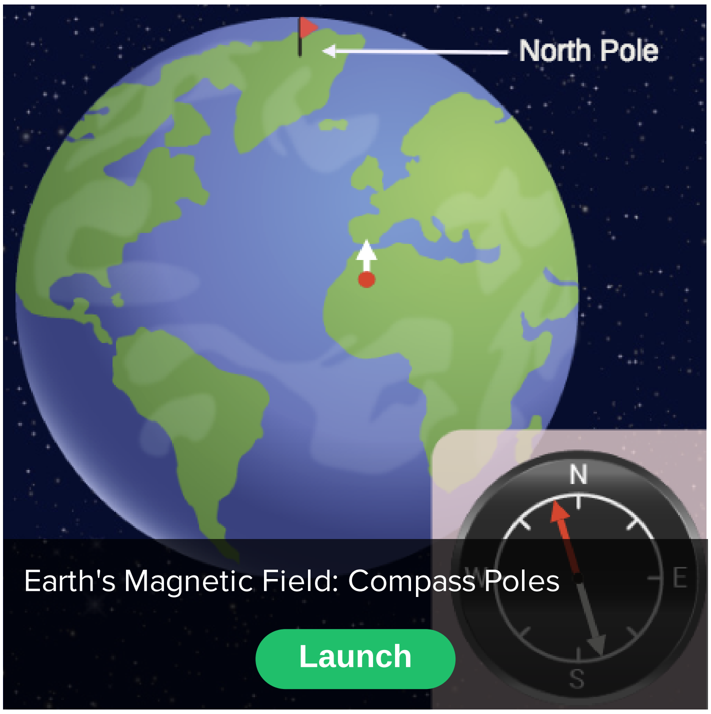
Launch the PLIX Interactive below to learn more about how a compass utilizes the Earth's magnetic field and observe what happens to a compass as you change positions on Earth:



https://flexbooks.ck12.org/assessment/tools/geometry-tool/fullscreen.html?qID=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.

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17.3 REFERENCES

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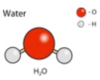	**Credit:** Chrklr, modified by CK-12 Foundation **Source:** http://commons.wikimedia.org/wiki/File:Wasserstoffbr%C3%BCckenbindungen-Wasser.svg **License:** Public Domain
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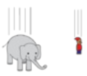	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
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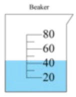
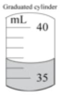
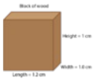
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License
	**Credit:** Zachary Wilson **Source:** CK-12 Foundation **License:** CK-12 Curriculum Materials License