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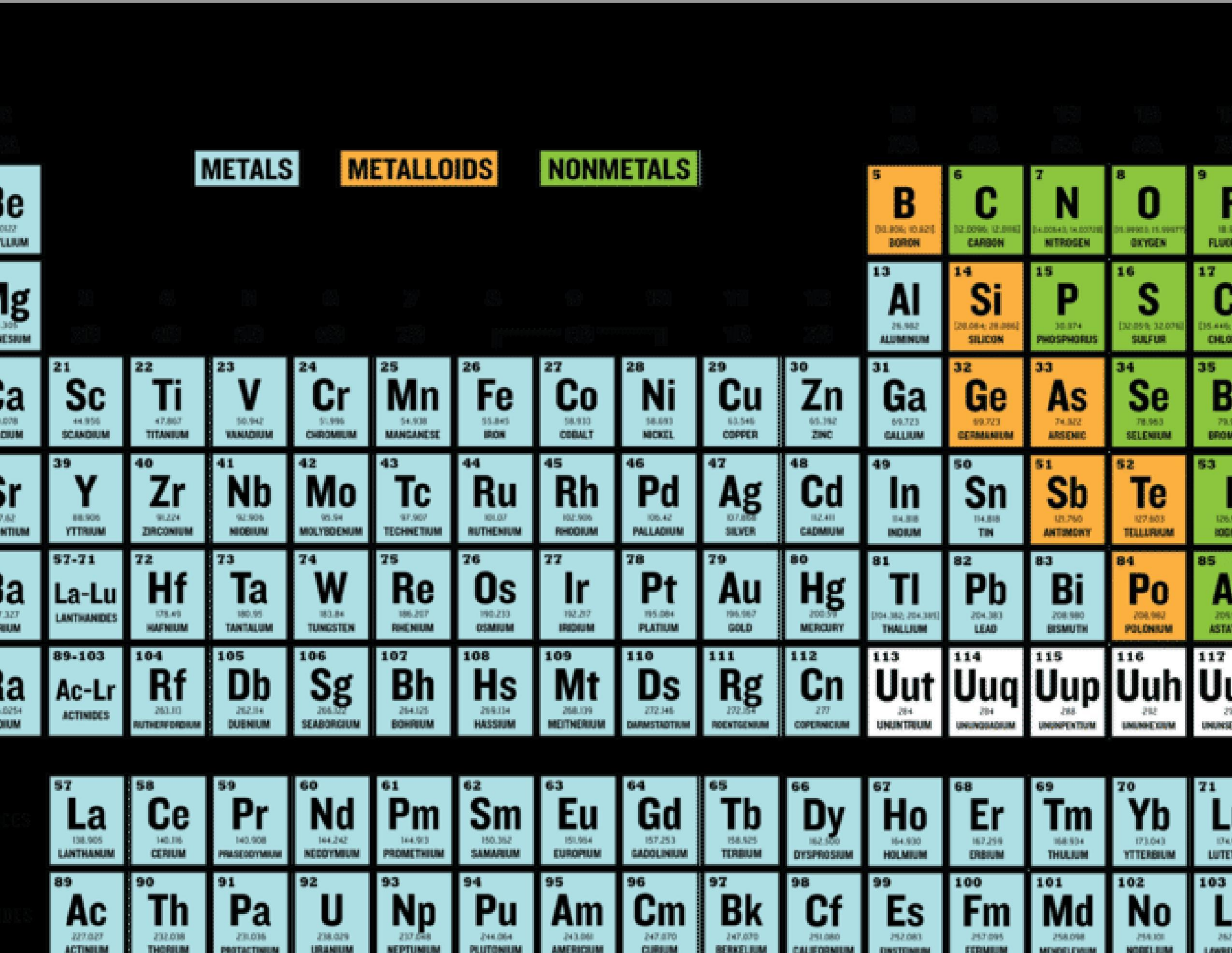
Science 9: Atoms & Elements



Science 9: Atoms & Elements

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Contents

CONCEPT 1 Scope of Chemistry

- Define chemistry.
- Give examples of chemistry in everyday life.

The Statue of Liberty, pictured above, is an icon of America and freedom. The statue is made of steel and covered with a thin layer of copper, the same type of matter that pennies are made of. Copper is a brownish red metal, so why is the statue green? Chemistry, which is a branch of physical science, has the answer.

What Is Chemistry?

Chemistry is the study of matter and energy and how they interact, mainly at the level of atoms and molecules. Basic concepts in chemistry include chemicals, which are specific types of matter, and chemical reactions. In a chemical reaction, atoms or molecules of certain types of matter combine chemically to form other types of matter. All chemical reactions involve energy.

Q: How do you think chemistry explains why the copper on the Statue of Liberty is green instead of brownish red?

A: The copper has become tarnished. The tarnish—also called patina—is a compound called copper carbonate, which is green. Copper carbonate forms when copper undergoes a chemical reaction with carbon dioxide in moist air. The green patina that forms on copper actually preserves the underlying metal. That's why it's not removed from the statue. Some people also think that the patina looks attractive.

Chemistry and You

Chemistry can help you understand the world around you. Everything you touch, taste, or smell is made of chemicals, and chemical reactions underlie many common changes. For example, chemistry explains how food cooks, why laundry detergent cleans your clothes, and why antacid tablets relieve an upset stomach. Other examples are illustrated in the **Figure** 1.1. Chemistry even explains you! Your body is made of chemicals, and chemical changes constantly take place within it.

The burning of matter such as wood is a chemical reaction. When it occurs, a lot of heat is released. What happens to the wood? It changes to different types of matter, including ashes and gases such as carbon dioxide and water vapor.

You can tell by the expression on this man's face that the milk smells spoiled. Milk souring is a chemical reaction. As milk spoils, new compounds form in the milk, giving it a sour smell and taste. The reactions can be slowed down by keeping the milk cold.

Batteries contain chemicals that undergo chemical reactions. When the reactions occur, electrons flow from one end of the battery to the other. Flowing electrons form electric current. That's why batteries can power electric devices such as flashlights and CD players.

FIGURE 1.1
Each of these pictures represents a way that chemicals and chemical reactions affect our lives.

Summary

- Chemistry is the study of matter and energy and how they interact, mainly at the level of atoms and molecules. Basic concepts in chemistry include chemicals and chemical reactions.
- Chemistry can help you understand the world around you. Everything you touch, taste, or smell is a chemical, and chemical reactions underlie many common changes.

Review

1. What is chemistry?
2. Describe three ways that chemistry is important in your life.

Resources

MEDIA

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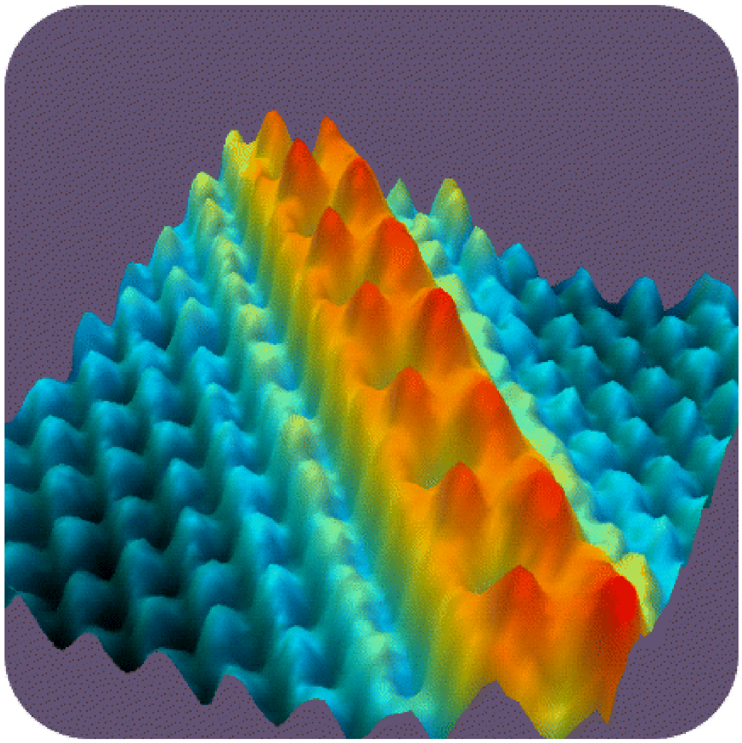
URL: https://www.ck12.org/flx/render/embeddedobject/184252

References

1. Fire: Wonderlane; Sour smell: Image copyright dragon_fang, 2013; Batteries: User:Asim18/Wikimedia Commons. How chemicals and chemical reactions affect our lives . Fire: CC BY 2.0; Sour smell: Used under license from Shutterstock.com; Batteries: CC BY 3.0

CONCEPT 2 Matter, Mass, and Volume

- Define matter.
- State what mass measures.
- State what volume measures.



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 the only type of microscope that can make images of things as small as 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.

Q: 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 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 with 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:

$$10 \times 2.2 \text{ lb} = 22 \text{ lb}$$

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.

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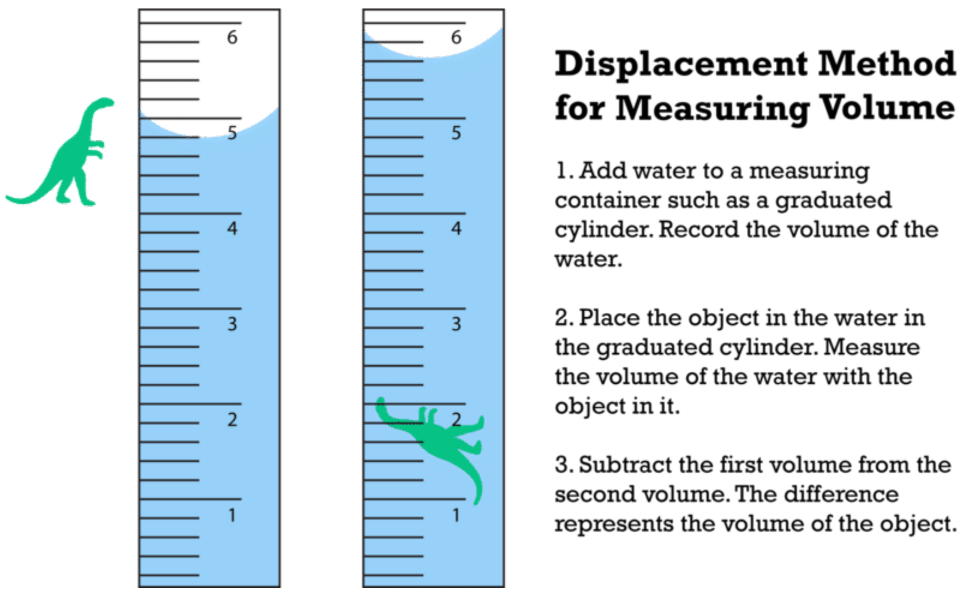
Q: How could you find the volume of air in an otherwise empty room?

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:

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

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:

$$\text{Volume} = 5.0\text{ m} \times 3.0\text{ m} \times 2.5\text{ m} = 37.5\text{ m}^3$$



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

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.

Concept 3 Physical Properties of Matter

- Define physical property.
- Give examples of physical properties of matter.


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** 3.1, 3.2, 3.3, and 3.4.

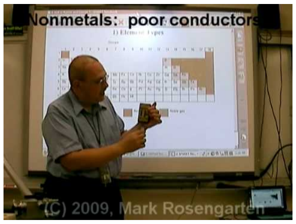


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FIGURE 3.1
The strong smell of swimming pool water is the odor of chlorine, which is added to the water to kill germs and algae. In contrast, bottled spring water, which contains no chlorine, does not have an odor.

FIGURE 3.2
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.

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.

FIGURE 3.3
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.

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.

References

1. Swimmer: Patrick Fitzgerald; Water bottle: Steven Depolo. Odor of water . CC BY 2.0
2. Flickr: EvelynGiggles, modified by CK-12 Foundation. Antifreeze raises the boiling point of coolant . CC BY 2.0
3. Jim D (Flickr: jkdevleer04). Plastic and aluminum in a kettle conduct heat differently . CC BY 2.0

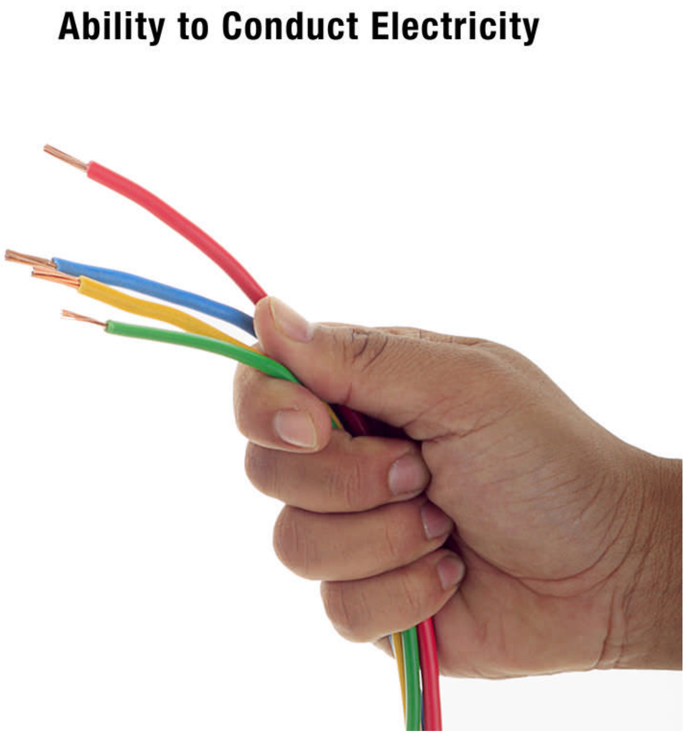

FIGURE 3.4
Copper is a good conductor of electricity. That's why electric wires are often made of copper. They are covered with a protective coating of plastic, which does not conduct electricity.

4. Image copyright pokchu, 2013. Copper wires can conduct electricity well . Used under license from Shutterstock.com

CONCEPT 4 Chemical Properties of Matter

- Define chemical property.
- Describe examples of chemical properties of matter.

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.

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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** 4.1.

FIGURE 4.1
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

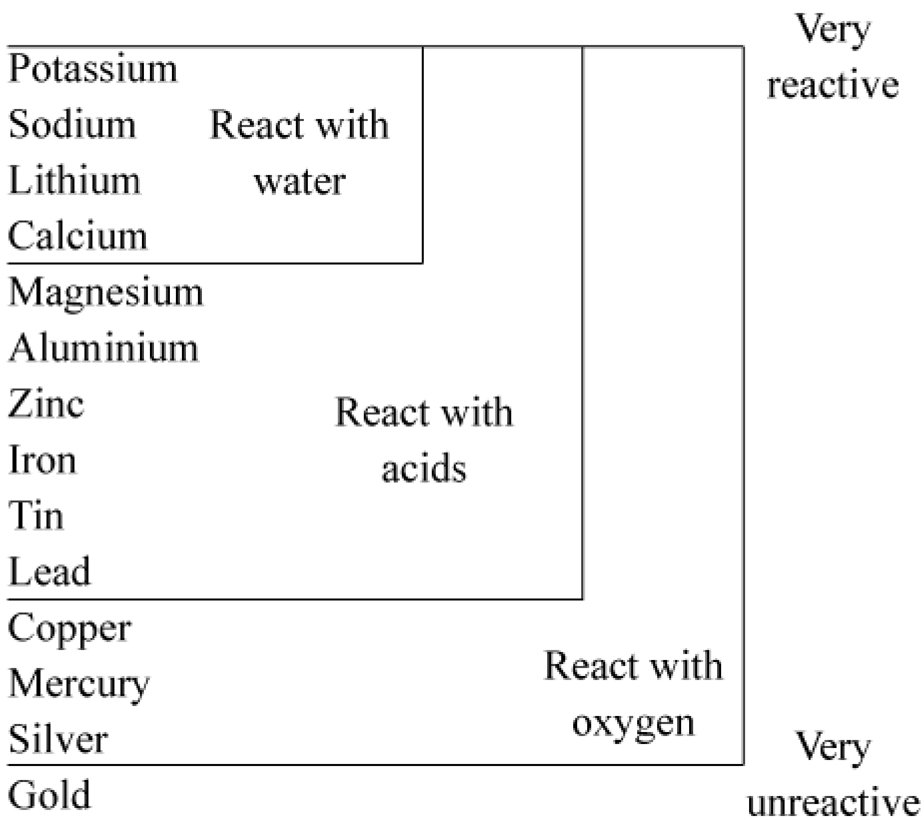
- Chemical properties are properties that can be measured or observed only when matter undergoes a change to become an entirely different kind of matter. They include reactivity, flammability, and the ability to rust.
- Reactivity is the ability of matter to react chemically with other substances.
-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



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 not with water?
   a. calcium
   b. magnesium
   c. copper

References

1. James Thompson. Wood burning in a fire . CC BY 2.0

CONCEPT 5 Physical Change

- Define physical change, and give examples of physical change.
- Explain how physical changes can be reversed.

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** 5.1.

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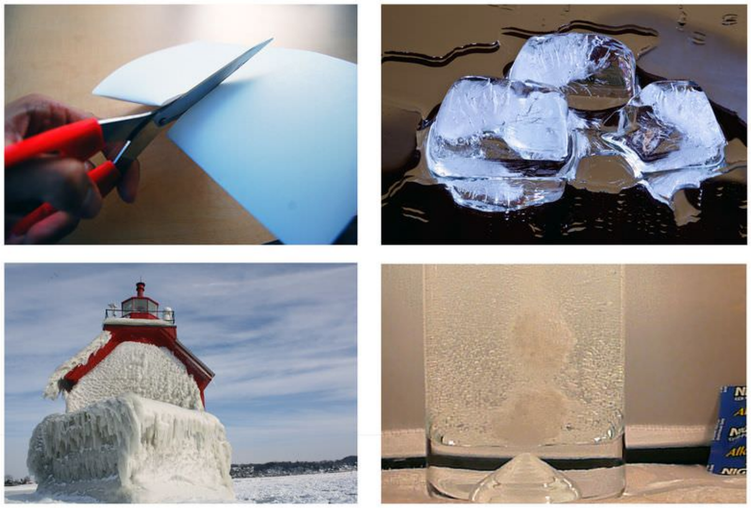


FIGURE 5.1

Q: In the **Figure** 5.1, 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.

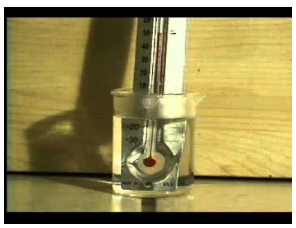
Review

1. Define physical change.
2. What are some examples of physical change?
3. The wood in the **Figure** 5.2 is being cut with a chainsaw. Is this a physical change? Why or why not?

FIGURE 5.2

Explore More

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



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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?

References

1. Scissors: Robert Lopez; Ice cubes: Flickr: jar (); Lighthouse: Flickr: wsilver; Tablet: F Delventhal (Flickr: krossbow). Paper being cut by scissors, ice cube melting, tablet dissolving in water, lighthouse being coated i n ice . Scissors: CC BY-NC 3.0; Ice cubes: CC BY 2.0; Lighthouse: CC BY 2.0; Tablet: CC BY 2.0
2. Alex Murphy (Flickr: APM Alex). Wood being cut by a chainsaw . CC BY 2.0

Concept 6 Mixtures

- Define mixture, and give examples of mixtures.
- Contrast homogeneous and heterogeneous mixtures.
- Identify types of mixtures based on particle size.
- Explain how to separate the components of mixtures.

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** 6.1 is a solid mixture.

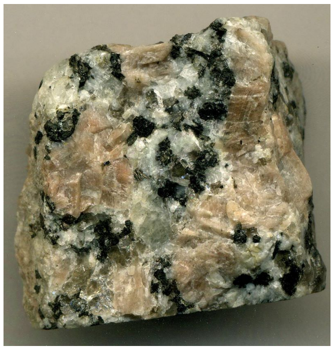

FIGURE 6.1
This rock is a mixture of smaller rocks and minerals.

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** 6.1 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 **Table** 6.1.

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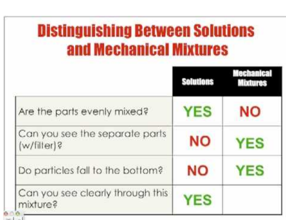

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TABLE 6.1: Solutions, Suspensions, and Colloids

Type of Mixture	Description
Solutions 	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 	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 	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** 6.2 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 6.2

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?

References

1. James St. John (Flickr: jsj1771). A rock is a mixture of smaller rocks and minerals . CC BY 2.0
2. Image copyright Eric Broder Van Dyke, 2013. Picture of the Great Salt Lake in Utah . Used under license from Shutterstock.com

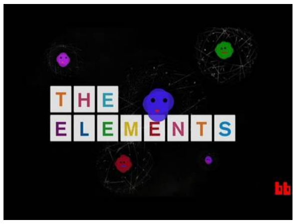
CONCEPT 7 Elements

- Define element.
- Describe how properties of different elements compare.
- Outline the history of elements.
- Relate atoms to elements.

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** 7.1. 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** 7.2 contains neon.

FIGURE 7.1

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

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

FIGURE 7.2
The red lights in this sign contain the element neon.

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** 7.3). 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 7.3
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

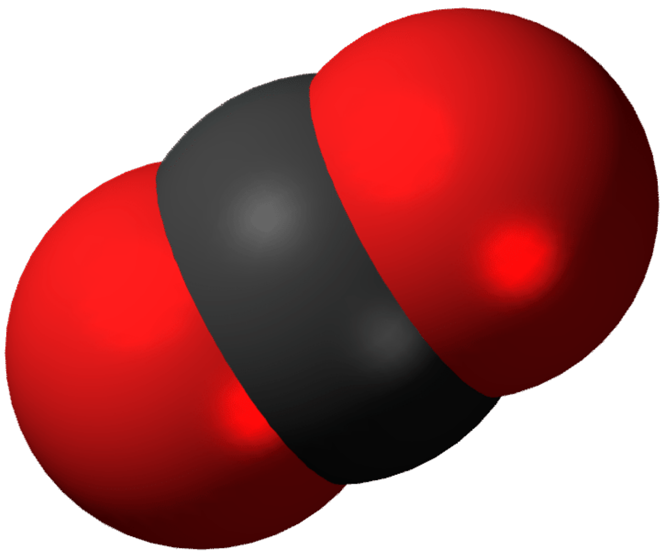
1. What is an element?
2. Why can an element be identified by its properties?
3. Explain why the following statement is either true or false: The idea that all matter consists of the elements was first introduced a few hundred years ago.
4. How are atoms related to elements?

References

1. Calsidyrose. The needle of a compass is made of the element iron . CC BY 2.0
2. Steven Damron. The red lights in a sign contain the element neon . CC BY 2.0
3. Coal: oatsy40; Sugar: Melissa Wiese. Carbon is a major element of coal and sugar . CC BY 2.0

CONCEPT 8 Compounds

- Define compound, and give examples of compounds.
- Contrast the properties of compounds and the properties of the elements that form compounds.
- Describe crystals and molecules.



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.

MEDIA

Click image to the left or use the URL below.

URL: https://www.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** 8.1.

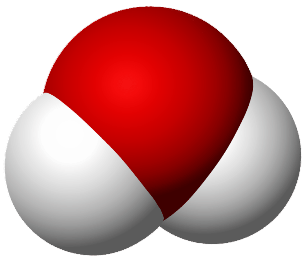


FIGURE 8.1
A model of water.

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** 8.2, 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.

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** 8.3. It is made up of many sodium and chloride ions.

FIGURE 8.2
Sodium and chlorine combine to form sodium chloride, or table salt.

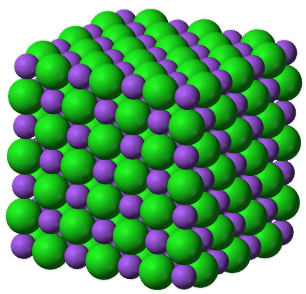


FIGURE 8.3
A sodium chloride crystal consists of many sodium ions (blue) and chloride ions (green) arranged in a rigid framework.

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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.

References

1. User:Dbc334 and User:Jynto/Wikimedia Commons. A model of water . Public Domain
2. Sodium: User:Jurii/Wikimedia Commons; Chlorine: User:Greenhorn1/Wikimedia Commons; Salt: Dubravko Sorić. Sodium and chlorine combine to form sodium chloride, or table salt . Sodium: CC BY 3.0; Chlorine: Public Domain; Salt: CC BY 2.0
3. Ben Mills (Wikimedia Commons: Benjah-bmm27). Sodium and chloride ions make up a sodium chloride crystal . Public Domain

CONCEPT 9 Chemical Bond

- Define chemical bond.
- Explain why chemical bonds form.
- Compare and contrast types of chemical bonds.

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** 9.1, 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.

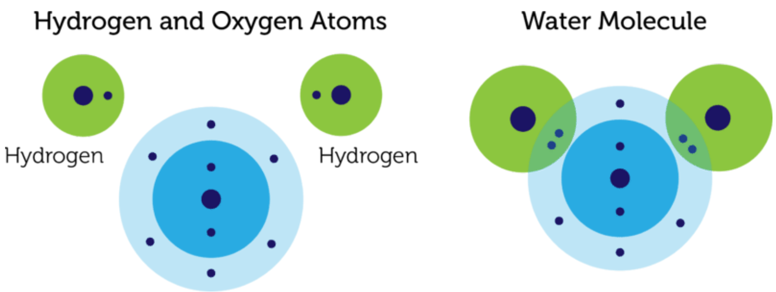
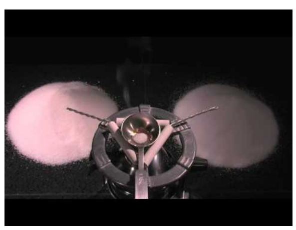


FIGURE 9.1

In the water molecule on the right in the **Figure** 9.1, 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** 9.1 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** 9.2, form metallic bonds.

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.

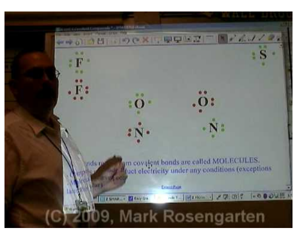
FIGURE 9.2
Metallic bonds explain many of the properties of metals. This coil of wire is made of the metal copper. Like other metals, copper is shiny, can be formed into wires, and conducts electricity.

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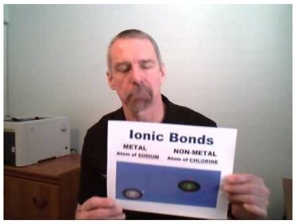
1. Which types of elements can form covalent bonds?
2. How can you tell the number of covalent bonds an element can form?
3. Why does one atom of nitrogen form bonds with three atoms of hydrogen?

Resources



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URL: https://www.ck12.org/flx/render/embeddedobject/177332

References

1. Christopher Auyeung. Bonds between hydrogen and oxygen atoms in water . CC BY-NC 3.0
2. Image copyright SergiyN, 2014. Coil of copper wire, which conducts electricity well due to metallic bonds . Used under license from Shutterstock.com

CONCEPT 10 Chemistry of Compounds

- Identify the type of matter called a compound.
- Explain how the same elements can form different compounds.
- List two types of chemical compounds.

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.

MEDIA

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Water is an example of a common chemical compound. As you can see in the **Figure** 10.1, 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.

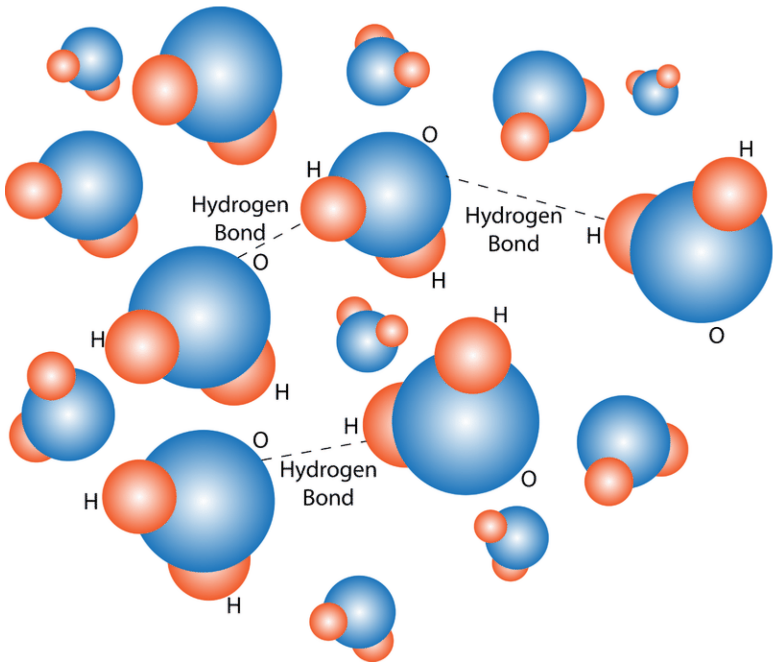


FIGURE 10.1
All water molecules have two hydrogen atoms (gray) and one oxygen atom (blue).

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** 10.2 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!

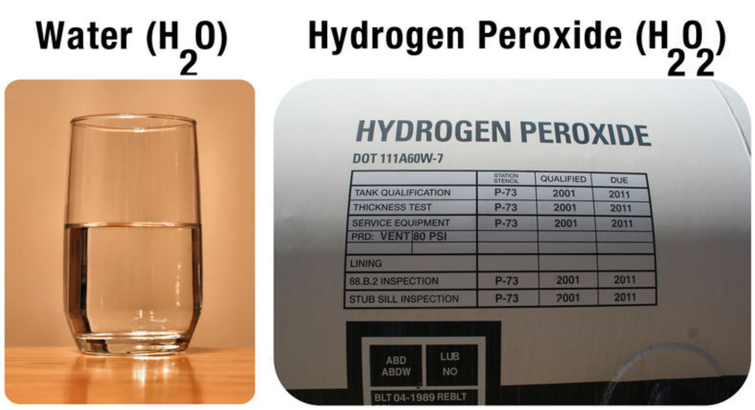


FIGURE 10.2
Water: Water is odorless and colorless. We drink it, bathe in it, and use it to wash our clothes. In fact, we can't live without it. Hydrogen Peroxide: Hydrogen peroxide is also odorless and colorless. It's used as an antiseptic to kill germs on cuts. It's also used as bleach to remove color form hair.

Q: Read the **Figure** 10.3 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?

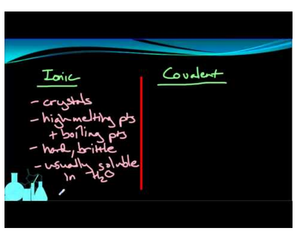
A: You can tell that they are different compounds from their very different properties. Carbon dioxide is a harmless gas that living things add to the atmosphere during respiration. Carbon monoxide is a deadly gas that can quickly kill people if it becomes too concentrated in the air.

FIGURE 10.3

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.

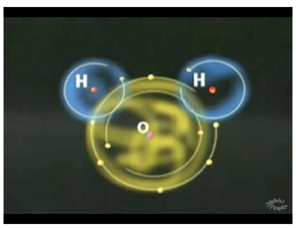
- Types of compounds include covalent and ionic compounds. They differ in the nature of the bonds that hold their atoms or ions together.

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. Name a gas that consists of two atoms of the same element bonded together. Do the molecules of this gas represent a compound? Why or why not?
3. Identify at least one property of water that differs from the properties of the elements that form it.
4. 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?

References

1. Jodi So. W . CC BY-NC 3.0
2. Left: Derek Jensen; Right: Robert Taylor (Flickr:Bobolink). Water and hydrogen peroxide have very different properties . Left: Public Domain; Right: CC BY 2.0
3. Left: Image copyright arek_malang, 2013; Right: User:Sideroxylon/Wikimedia Commons. Carbon dioxide and carbon monoxide have very different properties . Left: Used under license from Shutterstock.com; Right: Public Domain

CONCEPT 11 Chemical Change

- Define chemical change, and give examples of chemical changes.
- List signs that a chemical change has occurred.
- Explain how some chemical changes can be reversed.

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.

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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** 11.1.

FIGURE 11.1

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

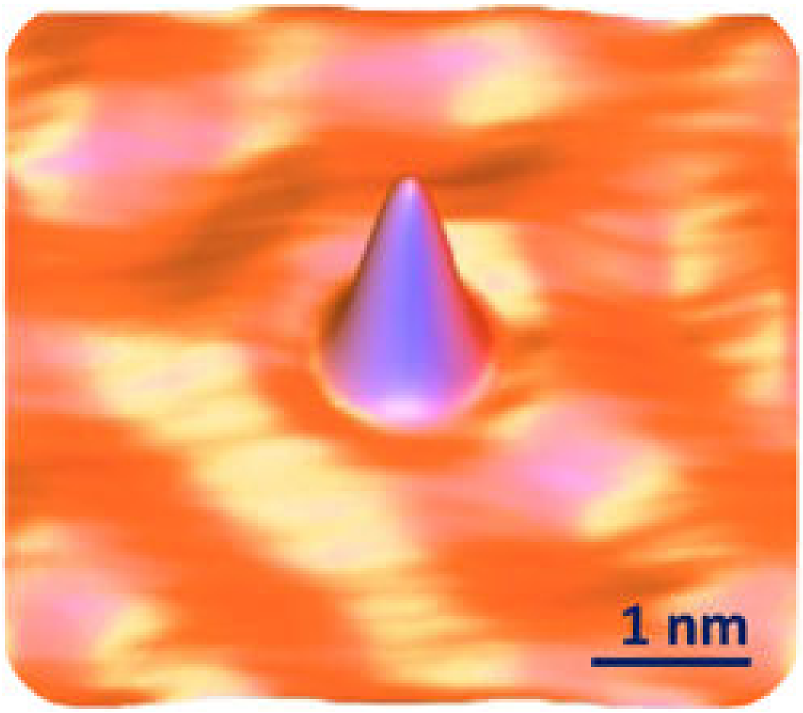
1. What happens in any chemical change?
2. List three signs that a chemical change has occurred.
3. Give an example of a chemical change. Explain why you think it is a chemical change.
4. Why can chemical changes often not be reversed?

References

1. Bubbles: Flickr:jimmiehomeschoolmom; Pipes: Flickr:longhairbroad; Stinky: Image copyright Iakov Filimonov, 2013; Candle: Flickr:ElTico68; Gun: Kristen Wong. Examples of chemical reactions . Bubbles, Pipes, Candle, Gun: CC BY 2.0; Stinky: Used under license from Shutterstock.com

CONCEPT 12 Atoms

- Describe atoms and how they are related to elements.
- Identify the three main subatomic particles that make up atoms.



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 small as atoms. How small are atoms? You will find out in this lesson.

What Are 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 number 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** 12.1 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** 12.1.

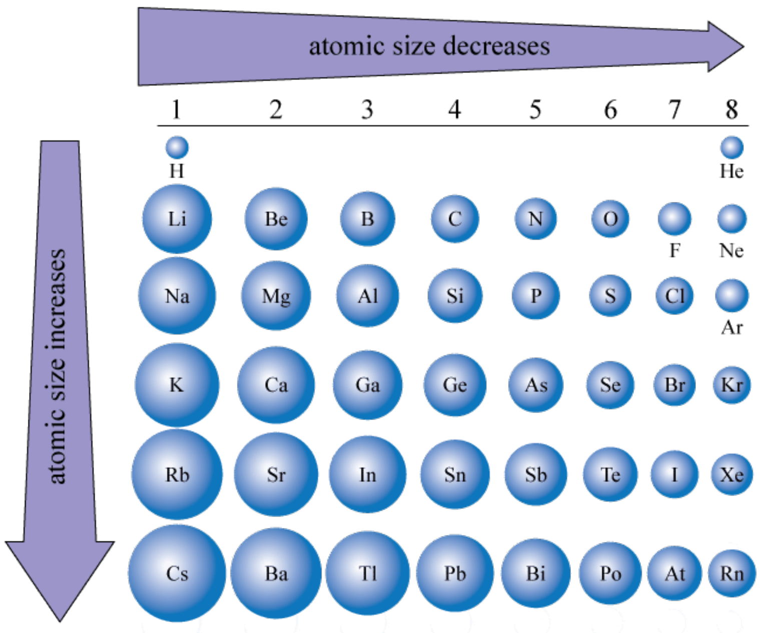


FIGURE 12.1

Q: Which element in the **Figure** 12.1 has the biggest atoms?

A: The element in the figure 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, which have a positive electric charge.
- electrons, which have a negative electric charge.
- neutrons, which are neutral in electric charge.

The model in the **Figure** 12.2 shows how these particles are arranged in an atom. The particular atom represented by the model is helium, 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 12.2 for helium.

A: Does your sketch resemble the model in the **Figure** 12.3? The model has three protons (blue) and four neutrons (gray) in the nucleus, with three electrons (red) moving around the nucleus.

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.

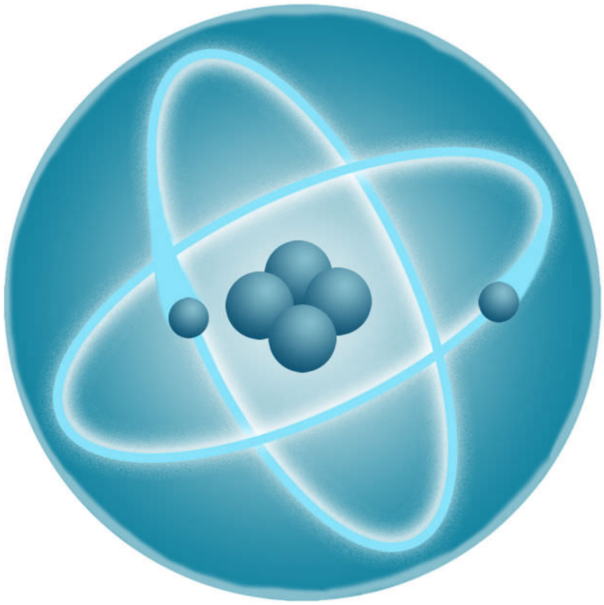


FIGURE 12.2

Model of a helium atom.

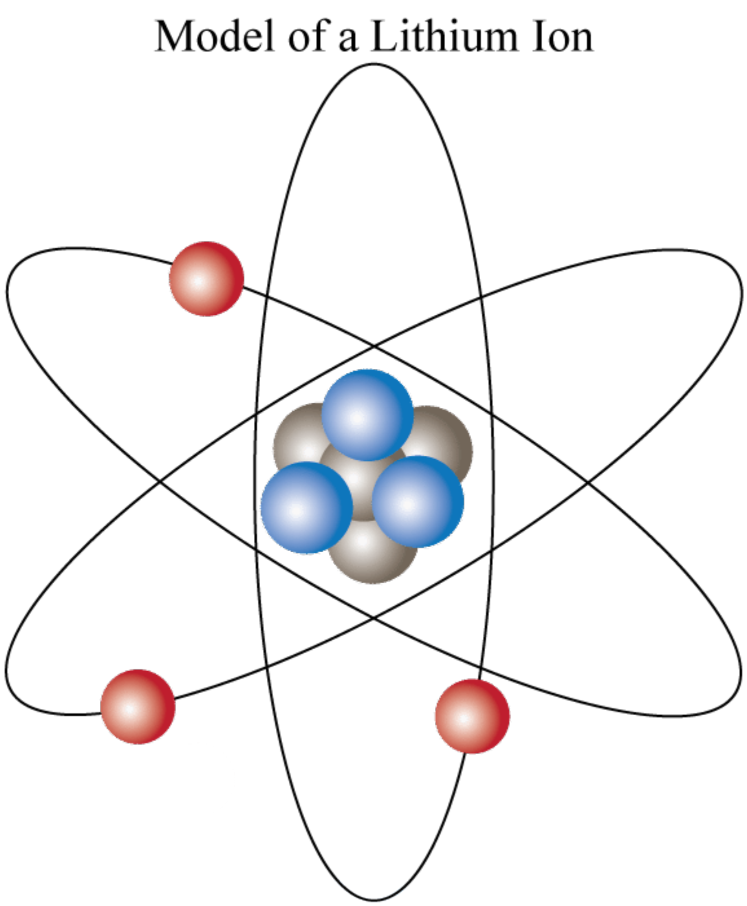


FIGURE 12.3

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 statements is true about the atoms of any element?
    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 neutrons.
3. Explain why atoms are always neutral in charge.

References

1. Zachary Wilson. Atomic size chart . CC BY-NC 3.0
2. Laura Guerin. Model of a helium atom . CC BY-NC 3.0
3. Zachary Wilson. Model of a lithium atom . CC BY-NC 3.0

Concept 13 Democritus' Idea of the Atom

- Review how and when Democritus arrived at his idea of the atom.
- Describe the atom as Democritus understood it.
- State how Democritus explained the diversity of matter.
- Explain why Democritus' idea was ignored until about 1800.

The man shown above has been called the "laughing philosopher" because of his cheerful disposition. He certainly looks cheerful in this picture. Why is a philosopher featured in a science text? He made an amazing contribution to science, although it was ridiculed by others and then ignored for more than 2000 years. His name was Democritus, and he introduced the idea of the atom as the basic building block of all matter. You can learn about Democritus' place in the history of the atom at this URL:

http://www.youtube.com/watch?v=BhWgv0STLZs (9:03)

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/5075

Cutting the Cheese

Democritus lived in Greece from about 460 to 370 B.C.E. Like many other ancient Greek philosophers, he spent a lot of time wondering about the natural world. Democritus wondered, for example, what would happen if you cut a chunk of matter—such as a piece of cheese into smaller and smaller pieces. He thought that a point would be reached at which the cheese could not be cut into still smaller pieces. He called these pieces *atomos*, which means "uncuttable" in Greek. This is where the modern term *atom* comes from. In the video at the following URL, Bill Nye the Science Guy demonstrates how Democritus arrived at his idea of the atom.

http://www.youtube.com/watch?v=cnXV7Ph3WPk (6:37)

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/54885

FIGURE 13.1

How many times could you cut this piece of cheese in half? How small would the smallest pieces be?

Just a Guess

Democritus' idea of the atom has been called "the best guess in antiquity." That's because it was correct in many ways, yet it was based on pure speculation. It really was just a guess. Here's what Democritus thought about the atom:

- All matter consists of atoms, which cannot be further subdivided into smaller particles.
- Atoms are extremely small—too small to see.
- Atoms are solid particles that are indestructible.
- Atoms are separated from one another by emptiness, or "void."

Q: How are Democritus' ideas about atoms similar to modern ideas about atoms?

A: Modern ideas agree that all matter is made up of extremely small building blocks called atoms.

Q: How are Democritus' ideas different from modern ideas?

A: Although atoms are extremely small, it is now possible to see them with very powerful microscopes. Atoms also aren't the solid, uncuttable particles Democritus thought. Instead, they consist of several kinds of smaller, simpler particles as well as a lot of empty space. In addition, atoms aren't really indestructible because they can be changed to other forms of matter or energy.

Keep on Moving

Did you ever notice dust motes moving in still air where a beam of sunlight passes through it? You can see an example in the forest scene in the **Figure** 13.2. This sort of observation gave Democritus the idea that atoms are in constant, random motion. If this were true, Democritus thought, then atoms must always be bumping into each other. When they do, he surmised, they either bounce apart or stick together to form clumps of atoms. Eventually, the clumps could grow big enough to be visible matter.

FIGURE 13.2
Dust motes dance in a beam of sunlight.

Q: Which modern theory of matter is similar to Democritus' ideas about the motion of atoms?

A: The modern kinetic theory of matter is remarkably similar to Democritus' ideas about the motion of atoms. According to this theory, atoms of matter are in constant random motion. This motion is greater in gases than in liquids, and it is greater in liquids than in solids. But even in solids, atoms are constantly vibrating in place.

Why Matter Varies

Democritus thought that different kinds of matter vary because of the size, shape, and arrangement of their atoms. For example, he suggested that sweet substances are made of smooth atoms and bitter substances are made of sharp atoms. He speculated that atoms of liquids are slippery, which allows them to slide over each other and liquids to flow. Atoms of solids, in contrast, stick together, so they cannot move apart. Differences in the weight of matter, he argued, could be explained by the closeness of atoms. Atoms of lighter matter, he thought, were more spread out and separated by more empty space.

Q: Democritus thought that different kinds of atoms make up different types of matter. How is this similar to modern ideas about atoms?

A: The modern view is that atoms of different elements differ in their numbers of protons and electrons and this gives them different physical and chemical properties.

That's Ridiculous!

Democritus was an important philosopher, but he was less influential than another Greek philosopher named Aristotle, who lived about 100 years after Democritus. Aristotle rejected Democritus' idea of the atom. In fact, Aristotle thought the idea was ridiculous. Unfortunately, Aristotle's opinion was accepted for more than 2000 years, and Democritus' idea was more or less forgotten. However, the idea of the atom was revived around 1800 by the English scientist John Dalton. Dalton developed an entire theory about the atom, much of which is still accepted today. He based his theory on experimental evidence, not on lucky guesses.

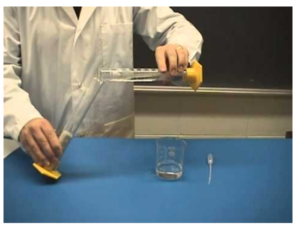
Summary

- Around 400 B.C.E., the Greek philosopher Democritus introduced the idea of the atom as the basic building block matter.
- Democritus thought that atoms are tiny, uncuttable, solid particles that are surrounded by empty space and constantly moving at random.
- Democritus surmised that different kinds of matter consist of different types or arrangements of atoms.

Explore More

Watch the video at the following URL, and then develop a hypothesis to explain the results of the two experiments. Relate your hypothesis to Democritus' ideas about atoms.

http://www.youtube.com/watch?v=g7debF-bSj8 (3:32)



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Review

1. Who was Democritus?
2. How did Democritus reason for the existence of atoms?
3. How did Democritus describe atoms?
4. Discuss how well Democritus' ideas about atoms have withstood the test of time.
5. Iron and lead are both metals, but iron is much harder than lead. How do you think Democritus might have explained this difference?

References

1. Flickr: Dinner Series. Cutting cheese, how Democritus' thought about the atom . CC BY 2.0
2. Michael Hodge. Beam of light shining through dust in trees . CC BY 2.0

CONCEPT 14 Dalton's Atomic Theory

- Explain why Dalton reintroduced the idea of the atom.
- State Dalton's atomic theory.
- Describe Dalton's billiard ball model of the atom.

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 14.1. 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.

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.

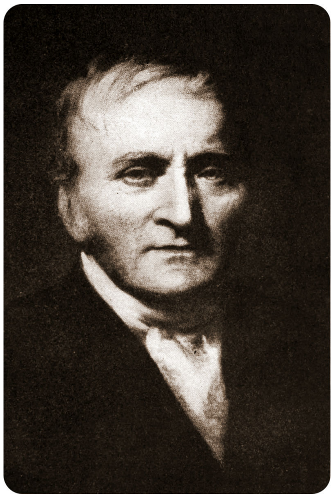

FIGURE 14.1

- 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** 14.2. 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.

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.

FIGURE 14.2

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

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/177313

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Click image to the left or use the URL below.

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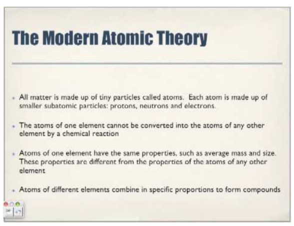

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URL: https://www.ck12.org/flx/render/embeddedobject/177316

References

1. Arthur Shuster Arthur E. Shipley, based on a painting by R.R. Faulkner. Portrait of John Dalton . Public Domain
2. Christopher Auyeung. Dalton's model of atoms . CC BY-NC 3.0

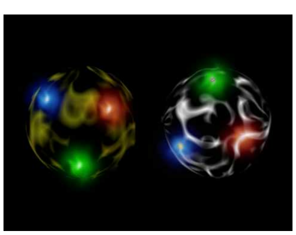
Concept 15 Electrons

- Describe electrons.
- Explain where electrons are found in atoms.
- Describe energy levels in atoms.

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 15.1 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.

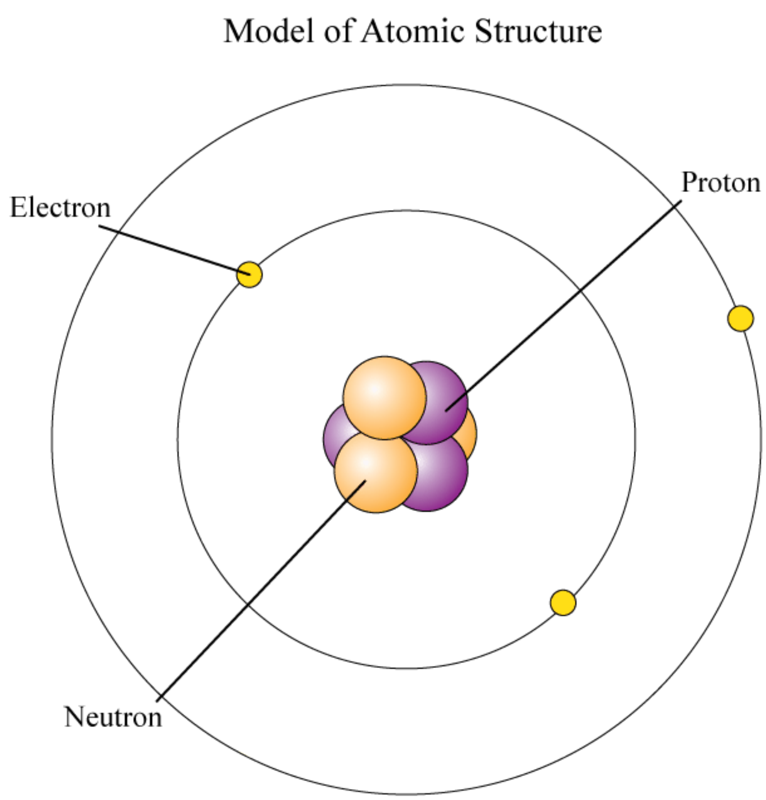
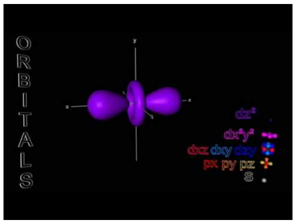


FIGURE 15.1

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** 15.2. Where the dots are denser, the chance of finding an electron is greater. Also pictured in **Figure** 15.2 is a P orbital. P orbitals are shaped like dumbbells, with the nucleus in the pinched part of the dumbbell.



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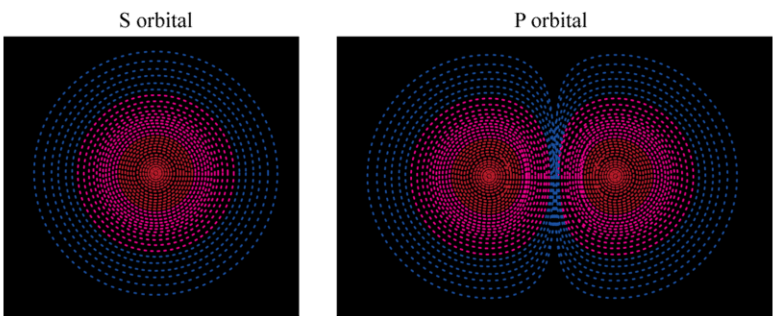


FIGURE 15.2

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** 15.3. 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.

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.

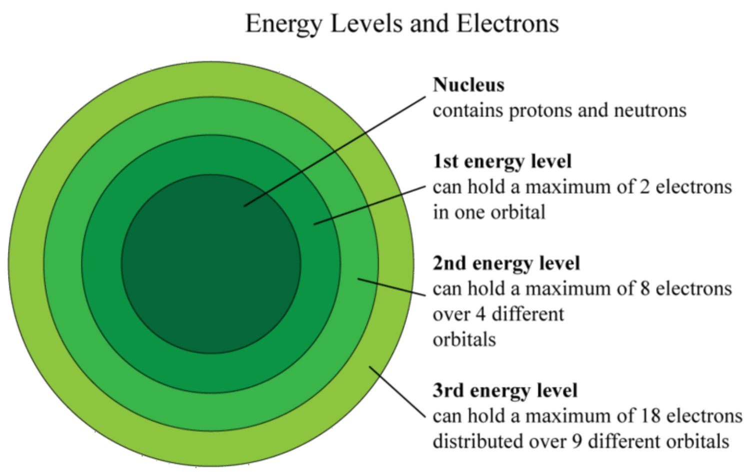


FIGURE 15.3

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.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/176798

1. Who discovered electrons? When were they discovered?

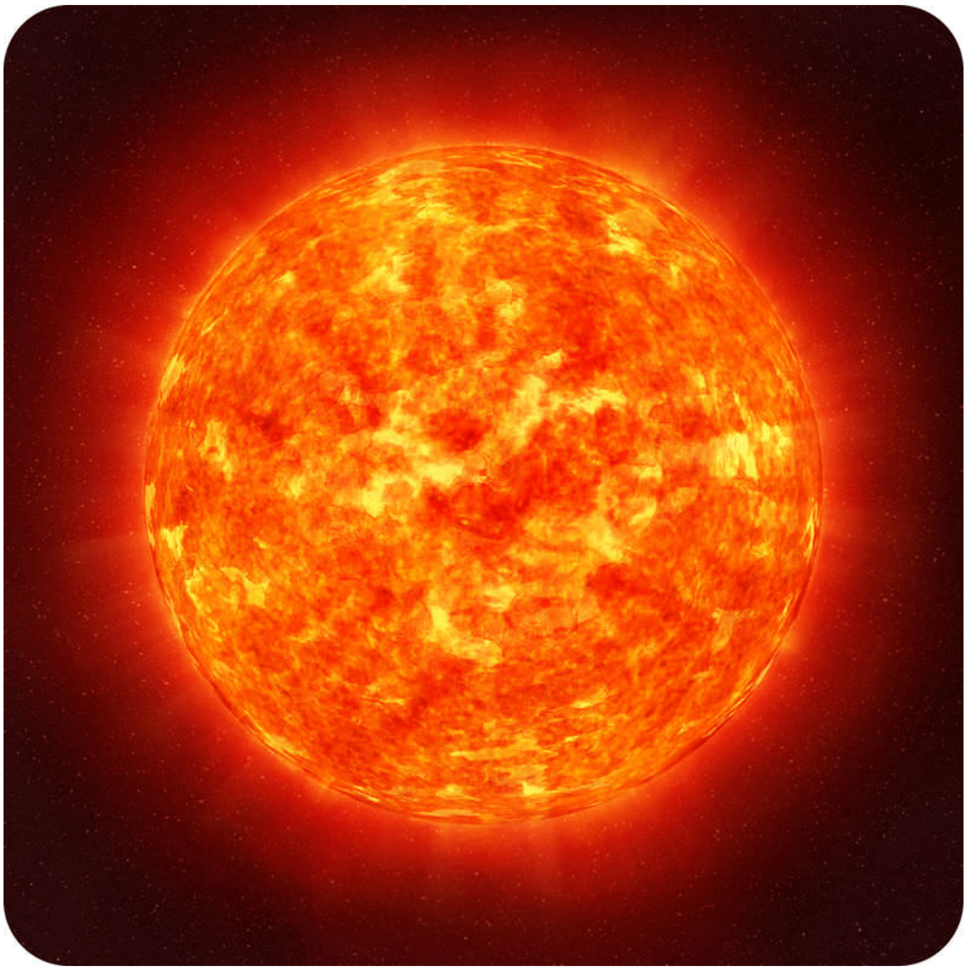
2. Outline how electrons were discovered.
3. What was the significance of the discovery of electrons?
4. Where did Thomson think electrons were located in the atom? How does this differ from the modern view of electrons presented above?

References

1. CK-12 Foundation - CK-12 Foundation. . CC-BY-NC-SA 3.0
2. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0
3. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

CONCEPT 16 Protons

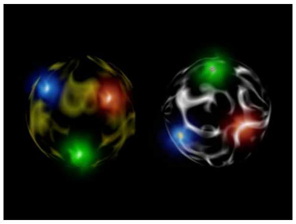
- Describe protons.
- State the relationship between protons and elements.
- Identify particles that make up protons.



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** 16.1, 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.

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?

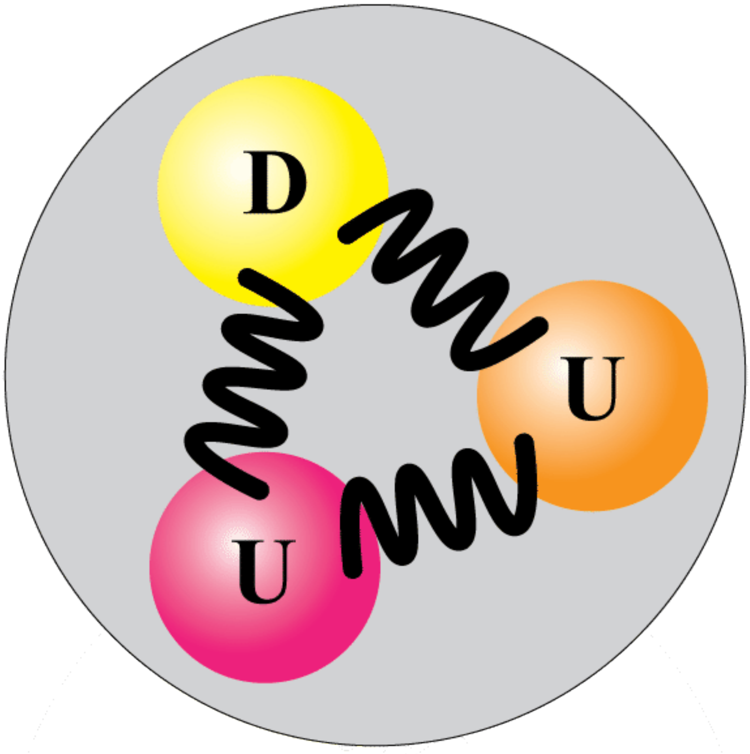


FIGURE 16.1

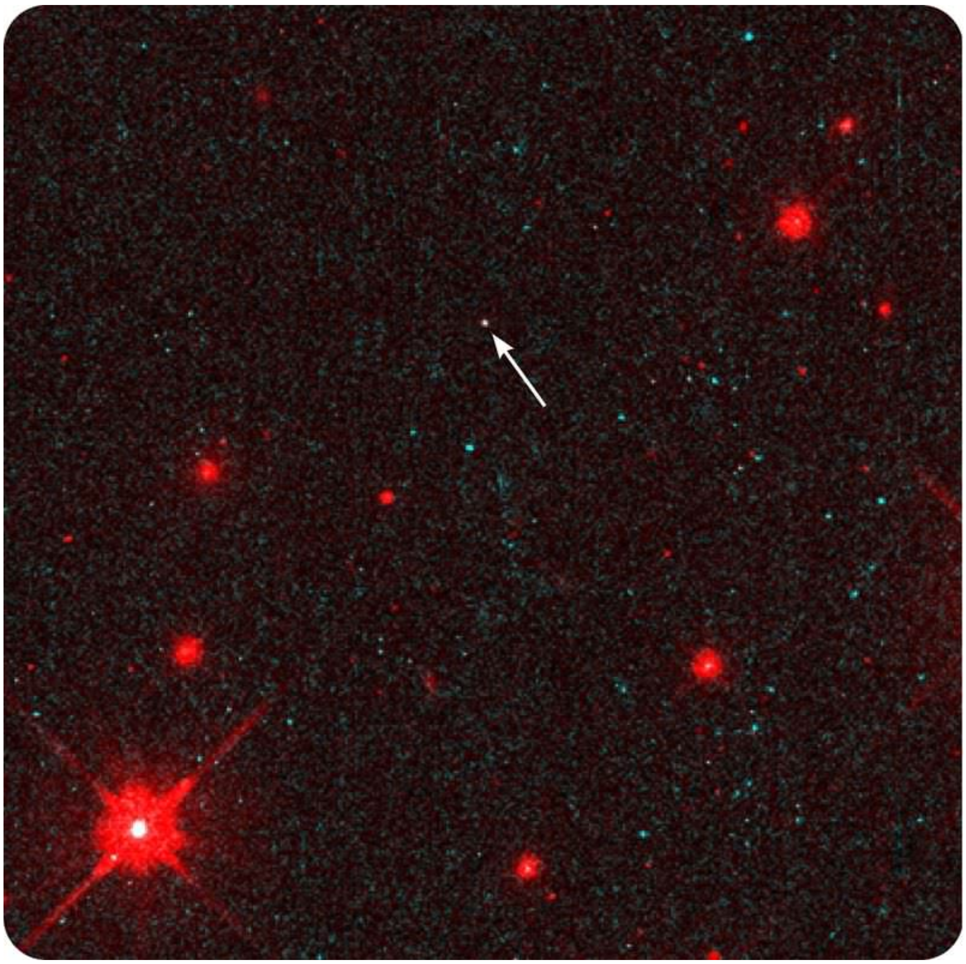
3. Atoms, which are always neutral in electric charge, contain electrons as well as protons and neutrons. An electron has an electrical charge of -1. If an atom has three electrons, infer how many protons it has.
4. Identify the fundamental particles that make up a proton.

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0

CONCEPT 17 Neutrons

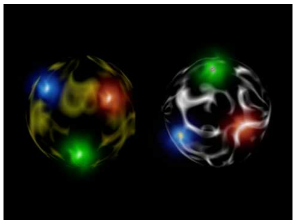
- Describe neutrons.
- Explain how isotopes of an element differ from one another.
- Identify fundamental particles in neutrons.



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** 17.1.



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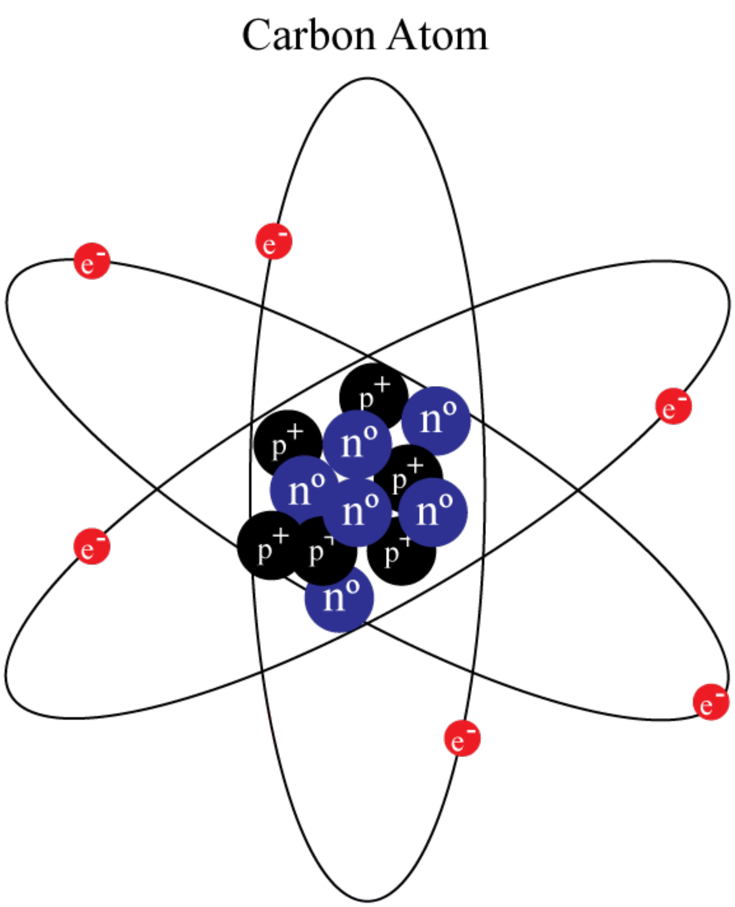

FIGURE 17.1

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** 22.1. The isotope called carbon-14 is used to find the ages of fossils.

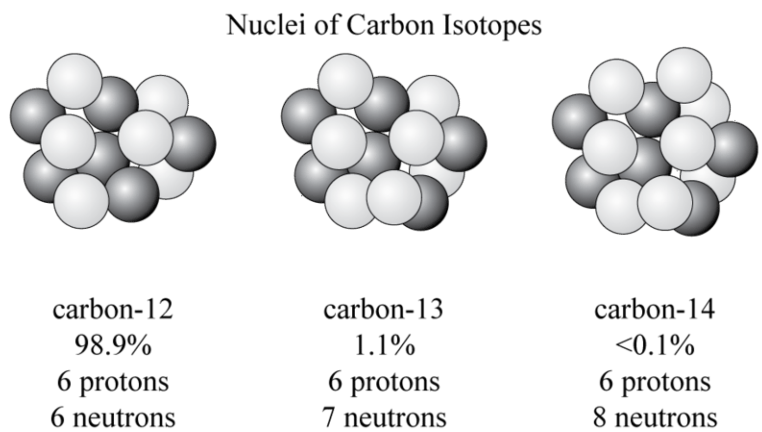

FIGURE 17.2

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 black 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.

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.

References

1. CK-12 Foundation - Zachary Wilson. . CC-BY-NC-SA 3.0
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CONCEPT 18 Thomson's Atomic Model

- Explain how J. J. Thomson discovered the electron.
- Describe Thomson's plum pudding model of the atom.

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 18.1.

Thomson's Experiments

In his research, Thomson passed current through a cathode ray tube, similar to the one seen in the **Figure** 18.2. 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

FIGURE 18.1

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.

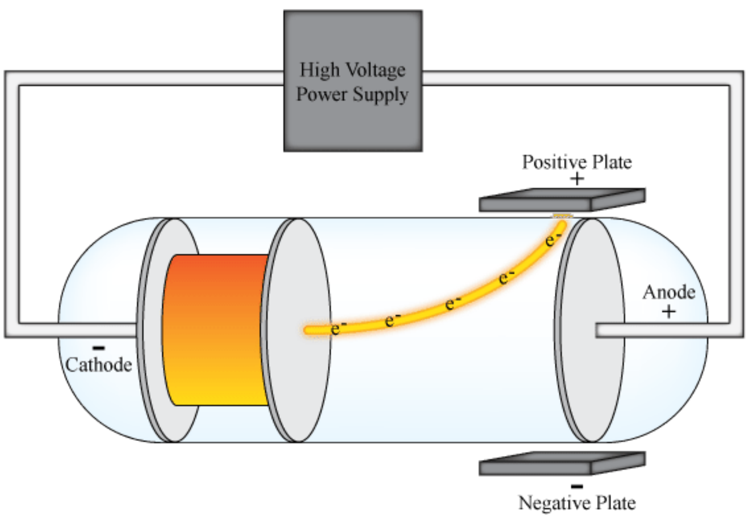


FIGURE 18.2

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** 18.3—mostly positive in charge (the pudding) with negative electrons (the plums) scattered through it.

FIGURE 18.3

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** 18.4. The nucleus was discovered just a few years after Thomson discovered the electron, so the plum pudding model was soon rejected.

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?

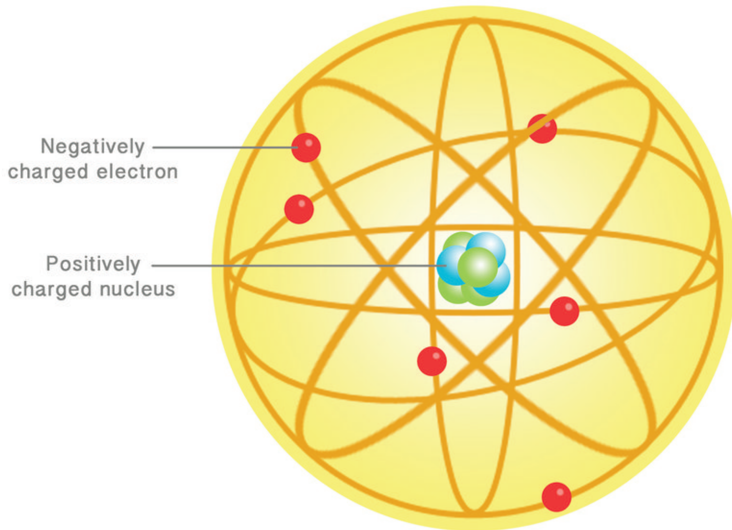
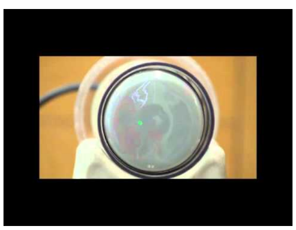


FIGURE 18.4

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?

References

1. . Portrait of J.J. Thomson . Public Domain
2. Zachary Wilson. Cathode ray tube used in Thomson's experiment . CC BY-NC 3.0
3. Plum pudding: Lachlan Hardy; Model: User:Fastfission/Wikimedia Commons. Plum pudding and Thomson 's plum pudding model . Plum pudding: CC BY 2.0; Model: Public Domain
4. Laura Guerin. Model of an atom . CC BY-NC 3.0

CONCEPT 19 Rutherford's Atomic Model

- Explain how Ernest Rutherford discovered the nucleus of the atom.
- Describe Rutherford's planetary model of the atom.

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** 19.1. 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.

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

FIGURE 19.1

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** 19.2.

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.

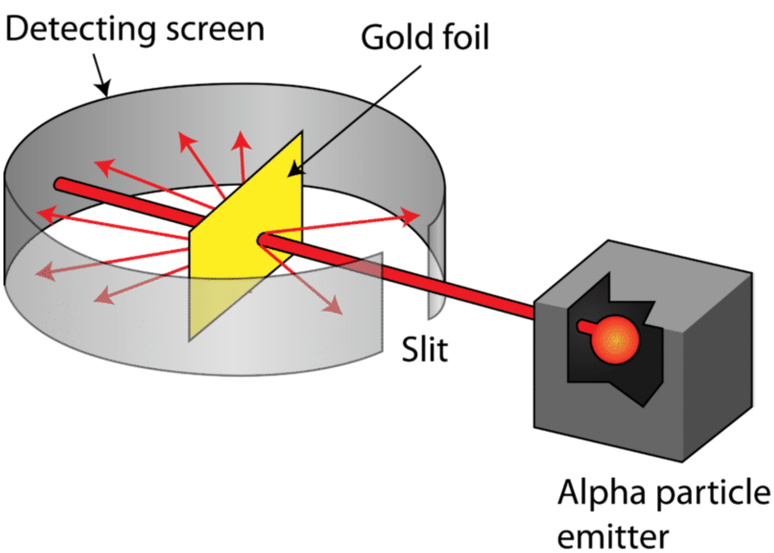


FIGURE 19.2

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** 19.2. 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** 19.3, 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.

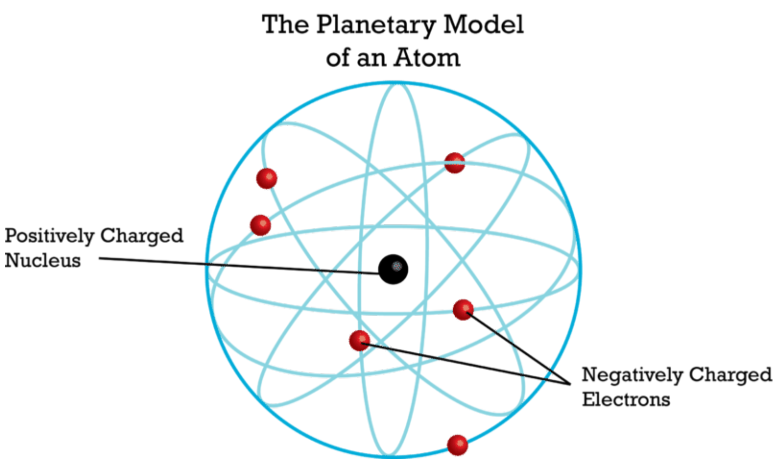


FIGURE 19.3

Summary

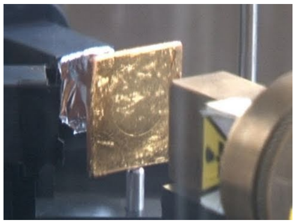
- Ernest Rutherford discovered the nucleus of the atom in 1911. He sent a beam of alpha particles toward gold foil and observed the way the particles were deflected by the gold atoms. From his results, he concluded that all of the positive charge and virtually all of the mass of an atom are concentrated 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?

Resources

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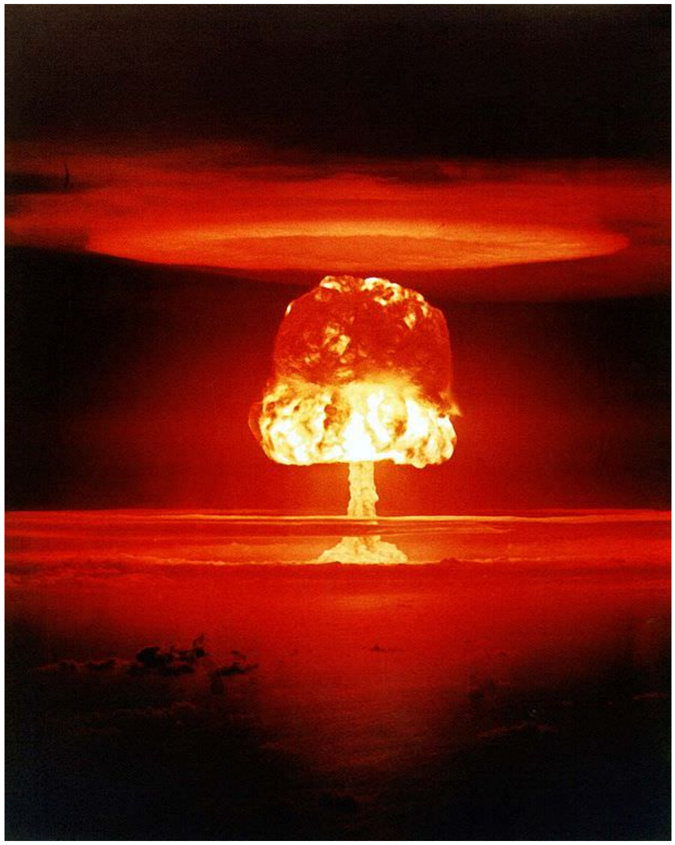
References

1. Bain News Service, courtesy of the US Library of Congress. Portrait of Rutherford . Public Domain
2. Christopher Auyeung. Rutherford's experiment of shooting alpha particles at gold foil . CC BY-NC 3.0
3. Christopher Auyeung. Rutherford's planetary model . CC BY-NC 3.0

Concept 20 Atomic Nucleus

- Identify the nucleus of the atom.
- Describe the size and mass of the nucleus.
- Explain what holds the nucleus together.



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** 20.1 shows these parts of the atom.

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!

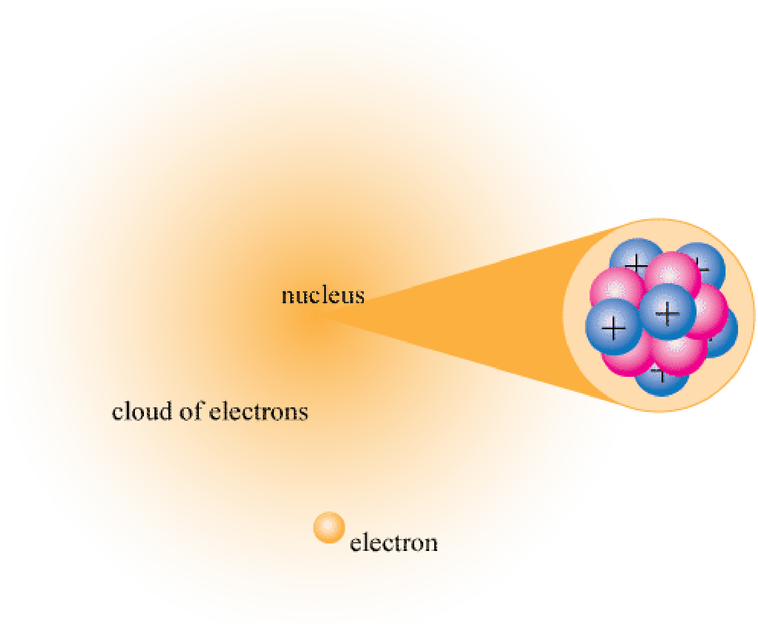
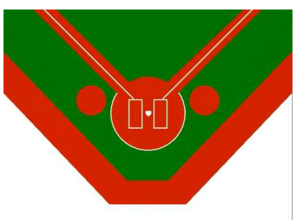


FIGURE 20.1



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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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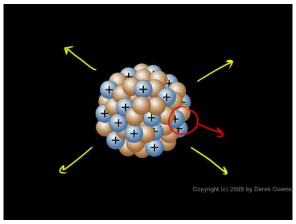
Holding It All Together

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

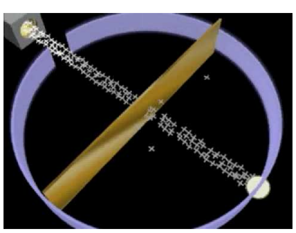
- The nucleus is a small, dense region at the center of the atom. It consists of positive protons and neutral neutrons, so it has an overall positive charge.
- The nucleus is just a tiny part of the atom, but it contains virtually all of the atom's mass.
- The strong nuclear force holds together protons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

References

1. Zachary Wilson. Nucleus of an atom . CC BY-NC 3.0

Concept 21 Atomic Number

- Define atomic number.
- Explain what mass number represents.

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** 21.1.

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*.

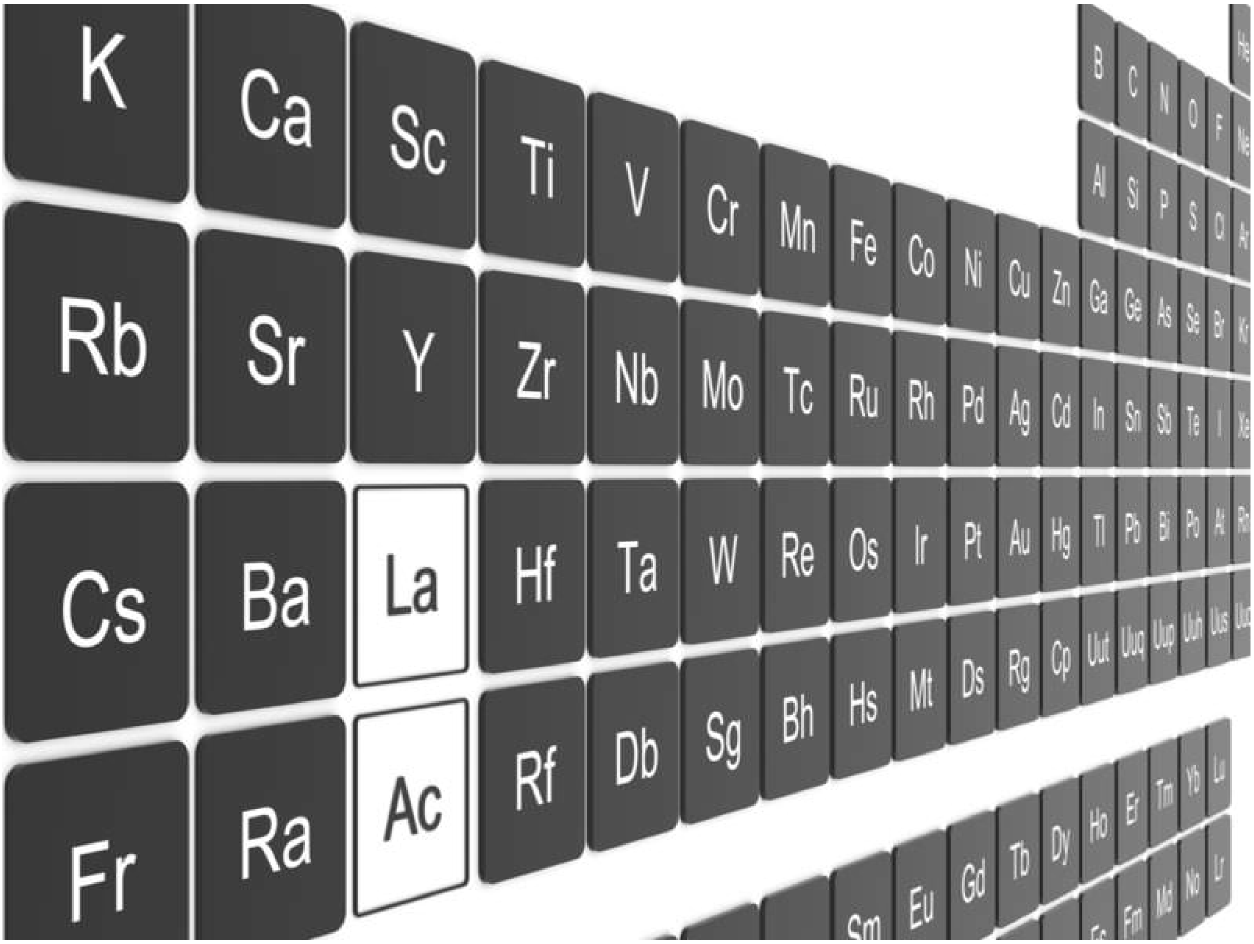


FIGURE 21.1

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** 21.2 for helium.

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.

FIGURE 21.2

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:

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

Summary

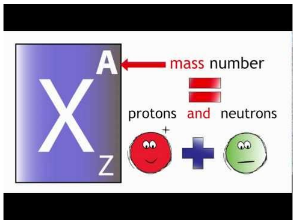
- Elements are pure substances that make up all matter, so each one is given a unique name. The names of elements are also represented by unique one-, two-, or three- letter symbols.
- The number of protons in an atom is called its atomic number. This is also unique for each element.
- An atom's mass 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?
4. 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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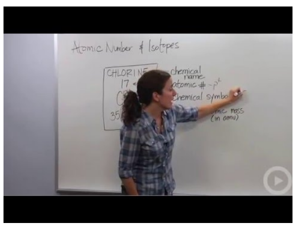

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References

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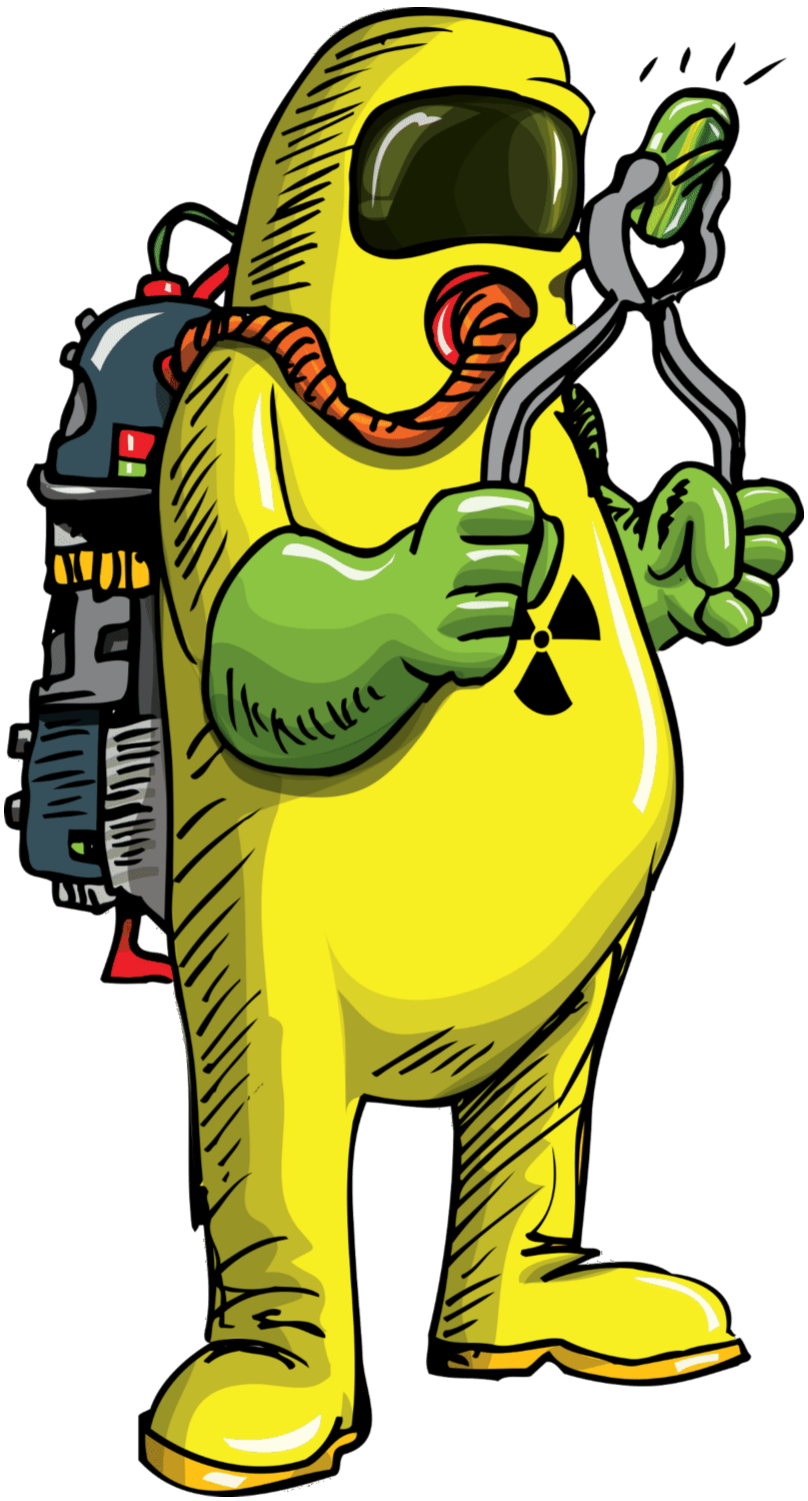
2. CK 12 Foundation. . CC-BY-NC-SA 3.0

Concept 22 Isotopes

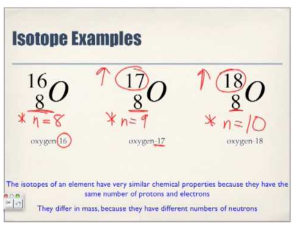
- Define isotope.
- Describe three isotopes of hydrogen.
- State how isotopes are named.
- Explain why many isotopes are radioactive.



Is this creature a space alien? It may look alien, but the sketch is actually just a scientist wearing a special suit to protect himself from harmful radiation. The scientist is working with radioactive chemicals called isotopes. Not all isotopes are radioactive, but many of them are. To understand why, you first need to know what isotopes are.

What Are Isotopes?

All atoms of the same element have the same number of protons, but some may have different numbers of neutrons. For example, all carbon atoms have six protons, and most have six neutrons as well. But some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in their numbers of neutrons are called **isotopes**. Many isotopes occur naturally. Usually one or two isotopes of an element are the most stable and common. Different isotopes of an element generally have the same physical and chemical properties. That's because they have the same numbers of protons and electrons.



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An Example: Hydrogen Isotopes

Hydrogen is an example of an element that has isotopes. Three isotopes of hydrogen are modeled in the **Figure** 22.1. Most hydrogen atoms have just one proton and one electron and lack a neutron. These atoms are just called hydrogen. Some hydrogen atoms have one neutron as well. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope named tritium.

Q: The mass number of an atom is the sum of its protons and neutrons. What is the mass number of each isotope of hydrogen shown above?

A: The mass numbers are: hydrogen = 1, deuterium = 2, and tritium = 3.

Naming Isotopes

For most elements other than hydrogen, isotopes are named for their mass number. For example, carbon atoms with the usual 6 neutrons have a mass number of 12 (6 protons + 6 neutrons = 12), so they are called carbon-12. Carbon atoms with 7 neutrons have an atomic mass of 13 (6 protons + 7 neutrons = 13). These atoms are the isotope called carbon-13.

Q: Some carbon atoms have 8 neutrons. What is the name of this isotope of carbon?

A: Carbon atoms with 8 neutrons have an atomic mass of 14 (6 protons + 8 neutrons = 14), so this isotope of carbon is named carbon-14.

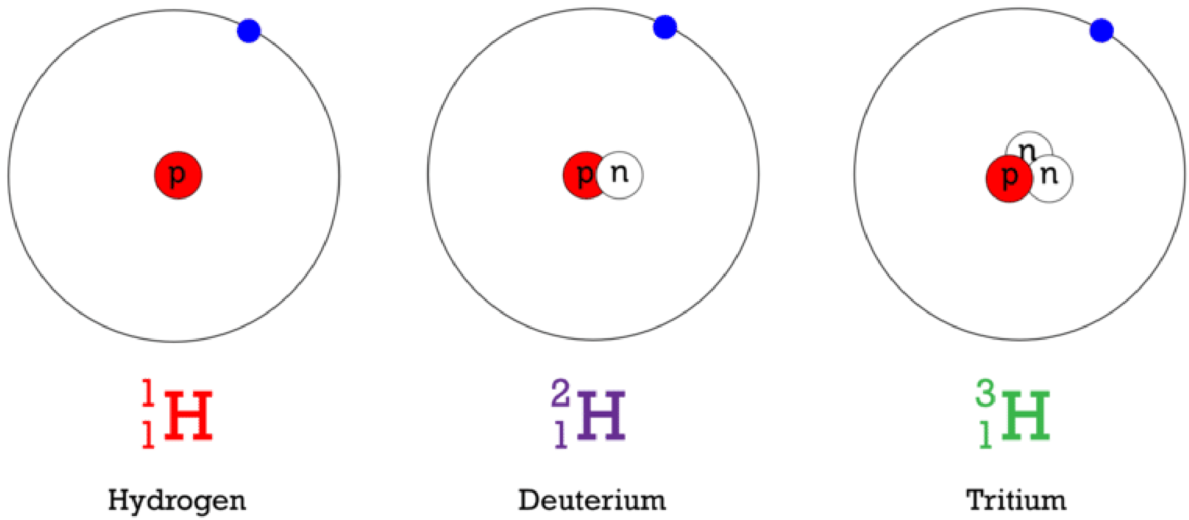

FIGURE 22.1

Stability of Isotopes

Atoms need a certain ratio of neutrons to protons to have a stable nucleus. Having too many or too few neutrons relative to protons results in an unstable, or radioactive, nucleus that will sooner or later break down to a more stable form. This process is called radioactive decay. Many isotopes have radioactive nuclei, and these isotopes are referred to as radioisotopes. When they decay, they release particles that may be harmful. This is why radioactive isotopes are dangerous and why working with them requires special suits for protection. The isotope of carbon known as carbon-14 is an example of a radioisotope. In contrast, the carbon isotopes called carbon-12 and carbon-13 are stable.

Summary

- Atoms of the same element that differ in their numbers of neutrons are called isotopes. Different isotopes of an element generally have the same physical and chemical properties because they have the same numbers of protons and electrons.
- Most hydrogen atoms lack a neutron and are just called hydrogen. Hydrogen atoms with one neutron are the isotope known as deuterium, and those with two neutrons are the isotope named tritium.
- For most elements other than hydrogen, isotopes are named for their mass number, which is the number of protons plus neutrons. For example, carbon with a mass number of 14 is called carbon-14.
- Atoms need a certain ratio of neutrons to protons to have a stable nucleus. If they have too many or too few neutrons relative to protons, they are radioactive and will decay to more stable forms. Isotopes with radioactive nuclei are called radioisotopes.

Review

1. What are isotopes?
2. Why do different isotopes of an element generally have the same physical and chemical properties?

3. Describe the three isotopes of hydrogen.
4. Relate the concepts of isotope and mass number.
5. All oxygen atoms have eight protons, and most have eight neutrons as well. What is the mass number of an oxygen isotope that has nine neutrons? What is the name of this isotope?
6. Why are many isotopes radioactive?

Explore More

Watch the video about isotopes of carbon. Then answer the questions below.

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1. How does carbon-14 form?
2. Carbon-14 slowly decays over time because it is radioactive. Why does the percent of carbon-14 remain the same in living organisms?
3. How can the percent of carbon-14 in a dead organism be used to estimate the amount of time that has passed since the organism died?

References

1. Ck 12 Foundation. . CC-BY-NC-SA 3.0

CONCEPT 23 Bohr's Atomic Model

- Describe how Bohr modified Rutherford's atomic model.
- Explain energy levels in atoms in terms of energy quanta.

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 23.1.

FIGURE 23.1

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** 23.2.

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.

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.

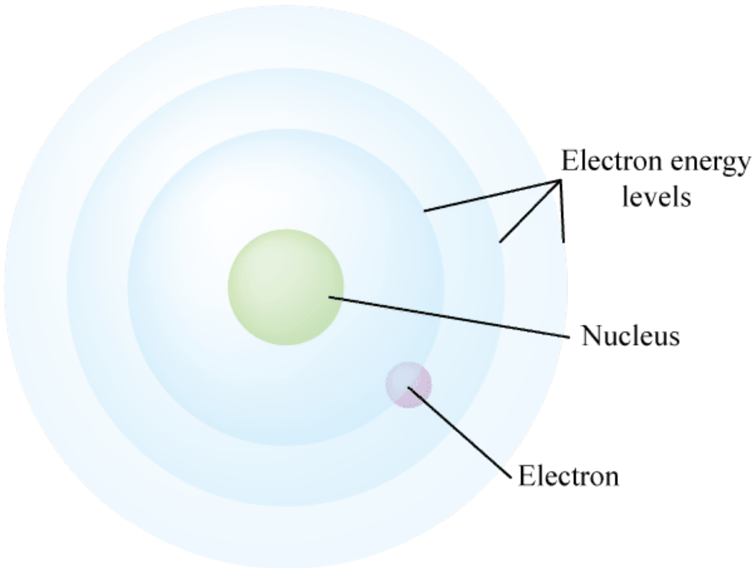


FIGURE 23.2
This is a two-dimensional model of a three-dimensional atom. The concentric circles actually represent concentric spheres.

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.

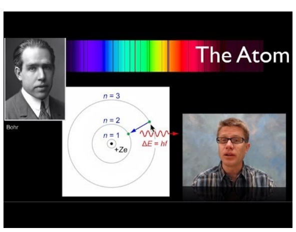
Summary

- 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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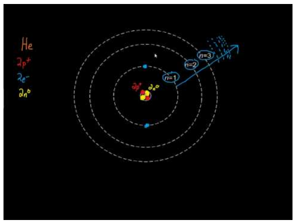

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References

1. AB Lagrelius Westphal. Portrait of Bohr . Public Domain
2. Zachary Wilson. Bohr's model of the atom . CC BY-NC 3.0

CONCEPT 24 Energy Level

- Describe energy levels.
- Relate energy levels to orbitals.
- Explain the significance of electrons in the outermost energy level of an atom.

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** 24.1 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.

Q: In the atomic model **Figure** 24.1, where would you find electrons that have the most energy?

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

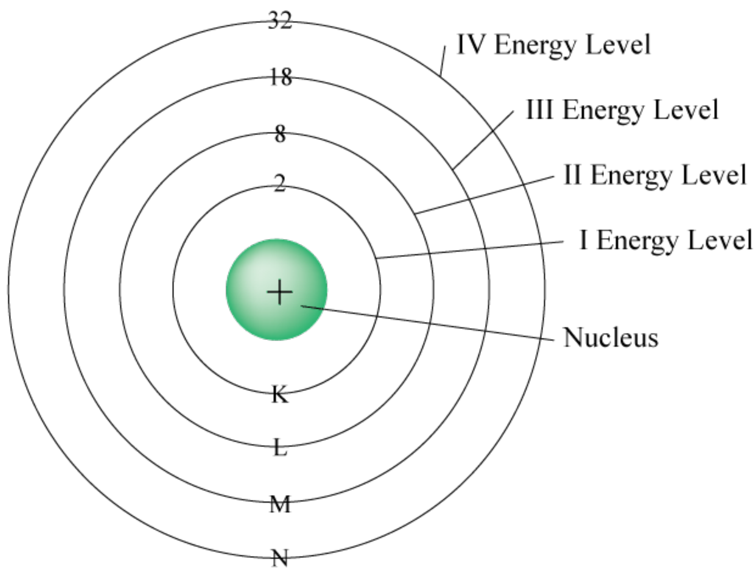

FIGURE 24.1

Energy Levels and Orbitals

The smallest atoms are hydrogen atoms. They have just one electron orbiting the nucleus. 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** 24.1. 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** 24.2, some orbitals are shaped like spheres (S orbitals) and some are shaped like dumbbells (P orbitals). There are other types of orbitals as well.

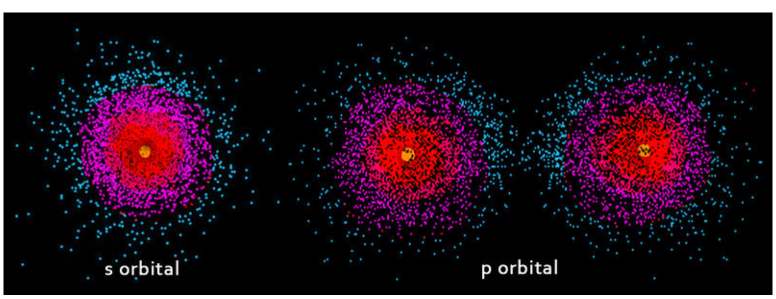

FIGURE 24.2

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** 24.3. 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).

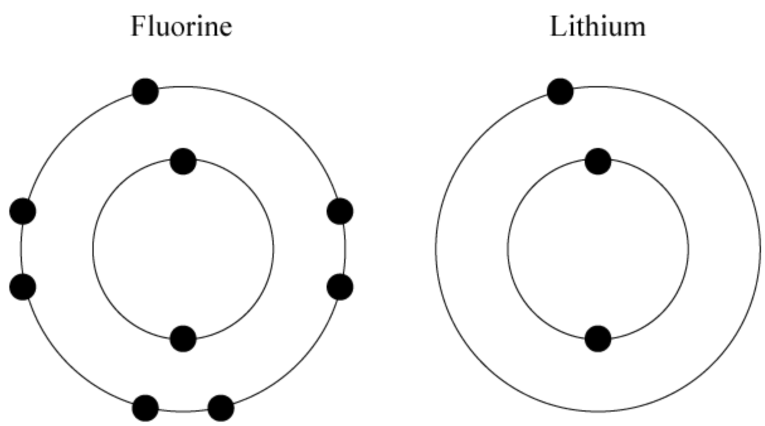

FIGURE 24.3

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** 24.4. When the two elements react, lithium transfers its one "extra" electron to fluorine.

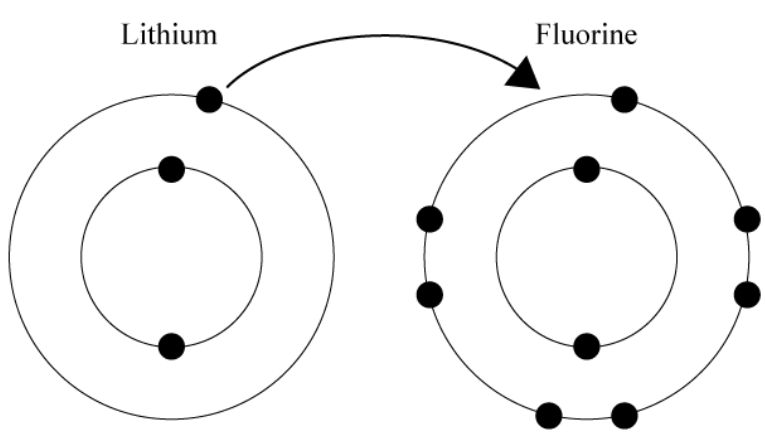

FIGURE 24.4

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.

Explore More

Watch the video about electrons below, and then answer the questions that follow.

Adobe Flash

MEDIA

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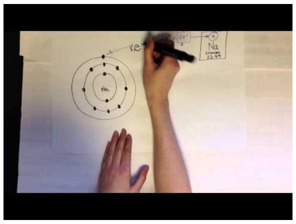
1. How many energy levels exist in atoms?
2. What is the maximum possible number of electrons at the fifth energy level?
3. Assume an energy level can hold a maximum of 98 electrons. Which energy level is it? How many orbitals does this energy level have?

Resources



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References

1. Zachary Wilson. Energy levels in an atom . CC BY-NC 3.0
2. Laura Guerin. Models of S and P orbitals . CC BY-NC 3.0
3. Zachary Wilson. Fluorine and lithium atoms . CC BY-NC 3.0
4. Zachary Wilson. Fluorine and lithium electron transfer reaction . CC BY-NC 3.0

Concept 25 Valence Electrons

- Define valence electron.
- Show how to represent valence electrons with electron dot diagrams.
- Describe variation in valence electrons in the periodic table.
- Relate valence electrons to reactivity and electrical conductivity of elements.

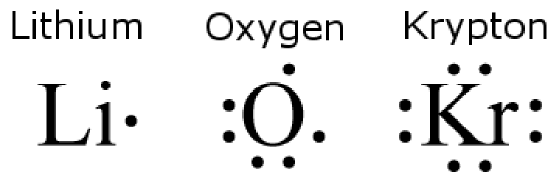
Did you ever play the card game called "Go fish"? Players try to form groups of cards of the same value, such as four sevens, with the cards they are dealt or by getting cards from other players or the deck. This give and take of cards is a simple analogy for the way atoms give and take valence electrons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

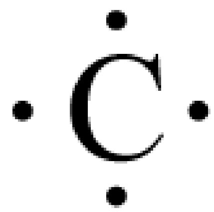
Electron Dot Diagrams

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.



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:



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** 25.1). 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.

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** 25.2. 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.

Q: Based on both periodic tables above (**Figures** 25.1 and 25.2), 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** 25.3 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.

Q: Why does sodium give up an electron?

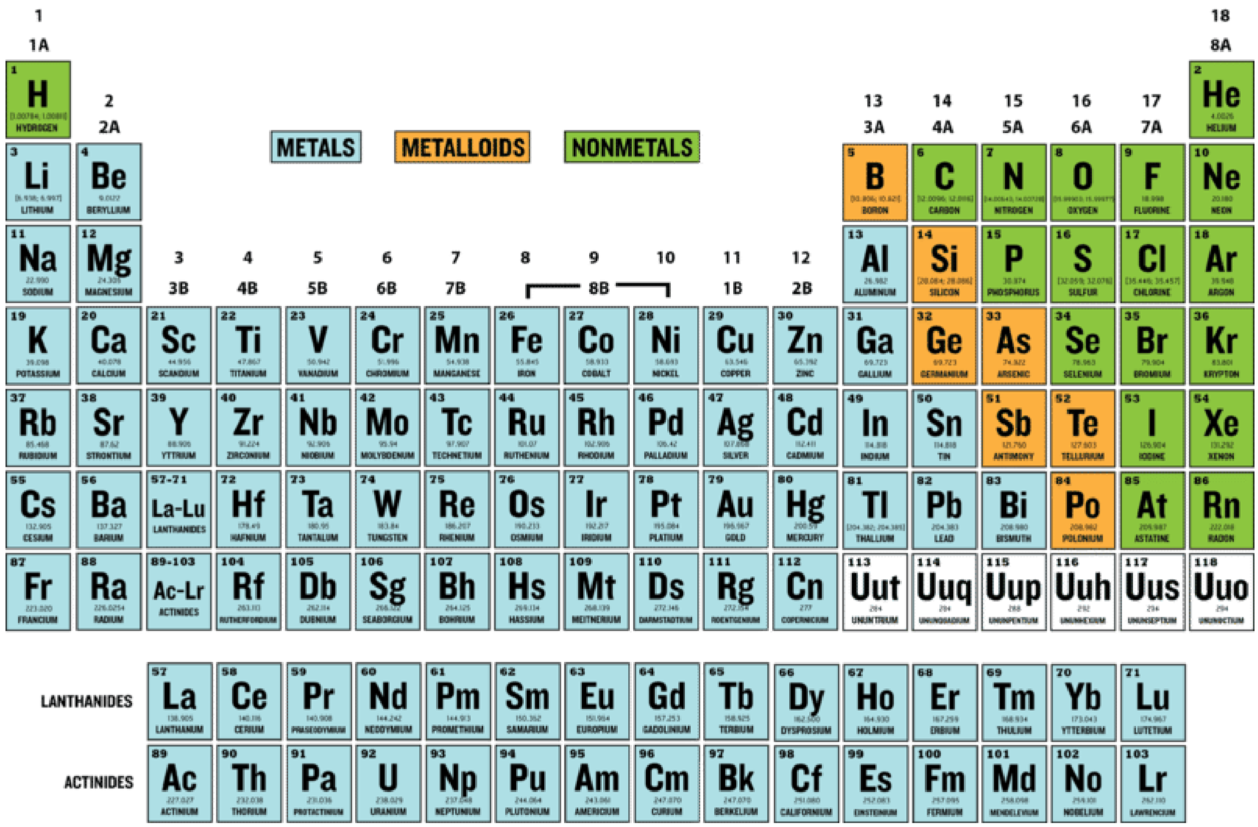


FIGURE 25.1

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 animation at the following URL and in the **Figure** 25.4. Group 2 elements with two valence electrons are almost as reactive as elements in group 1 for the same reason.

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** 25.1). 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.

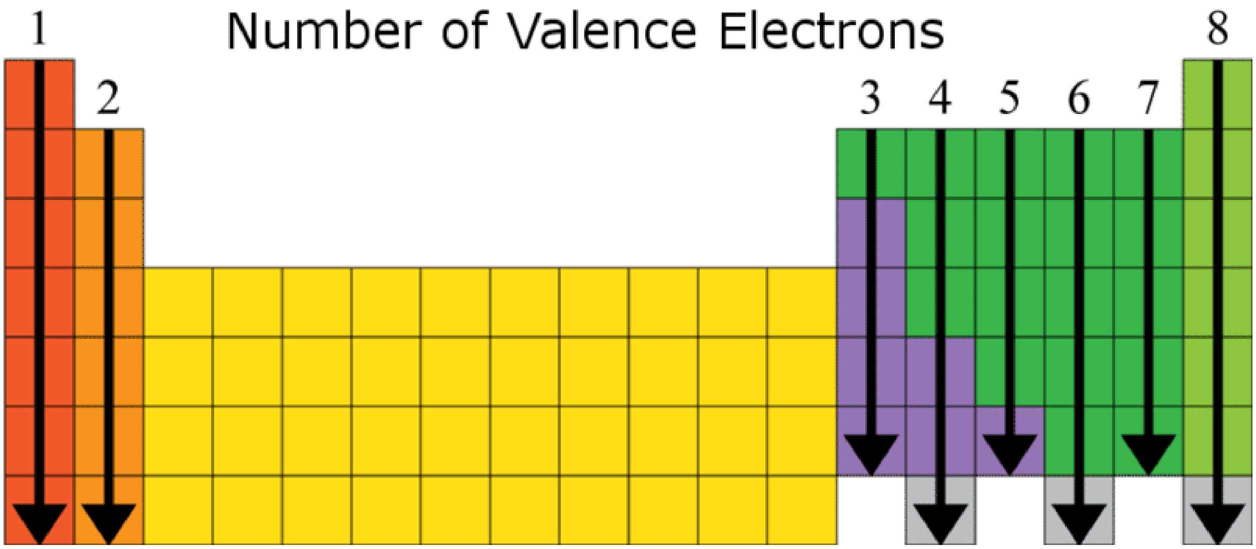


FIGURE 25.2

FIGURE 25.3
Table salt (sodium chloride).

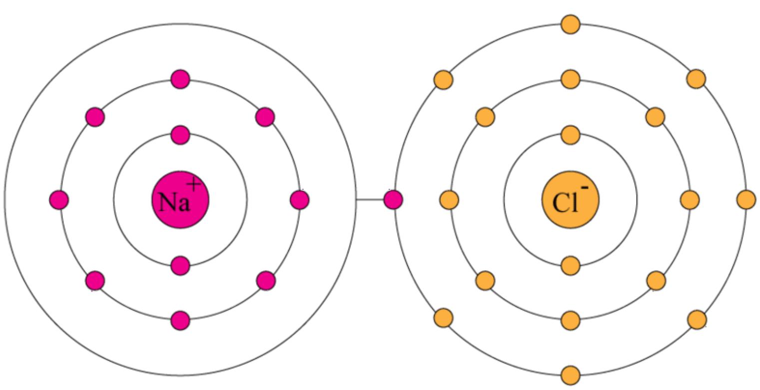


FIGURE 25.4

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** 25.5 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.

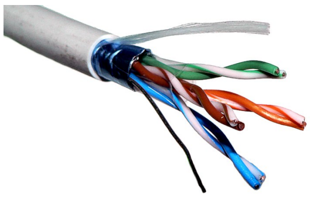


FIGURE 25.5

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

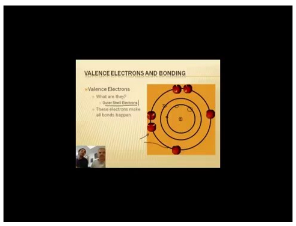
- Valence electrons are the electrons in the outer energy level of an atom that can participate in interactions with other atoms.
- Because valence electrons are so important, atoms may be represented by electron dot diagrams that show only their valence electrons.
- The number of valence electrons in 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?

Explore More

Watch the video and then answer the questions below.



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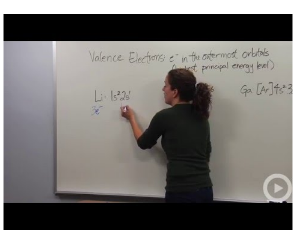
1. What analogy does Mr. Sams use to show how atoms "view" each other?
2. What is the octet rule? What is it based on?
3. What are two ways atoms can achieve an octet of valence electrons?

Resources



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References

1. Christopher Auyeung. The periodic table . CC BY-NC 3.0
2. Steven Lai. Number of electrons in the periodic table . CC BY-NC 3.0
3. Karyn Christner (Flickr: TooFarNorth). Salt contains sodium and chloride ions . CC BY 2.0
4. Steven Lai. Electron diagram of sodium chloride . CC BY-NC 3.0
5. Baran Ivo. Plastic insulates copper wires . Public Domain

CONCEPT 26 Mendeleev's Periodic Table

- State how Mendeleev developed his periodic table of the elements.
- Identify the groups and periods of Mendeleev's table.
- Explain why Mendeleev's table was a good model.

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 26.1. Mendeleev's method of organizing elements was later revised, but it served as a basis for the method that is still used today.

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.

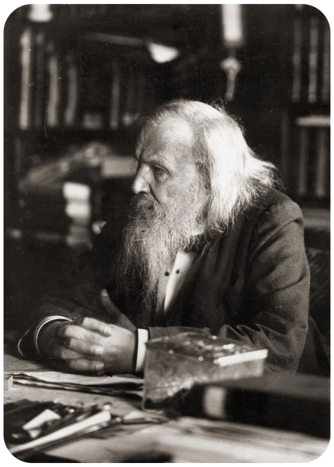

FIGURE 26.1

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** 26.2. 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	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo 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 26.2

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

MEDIA

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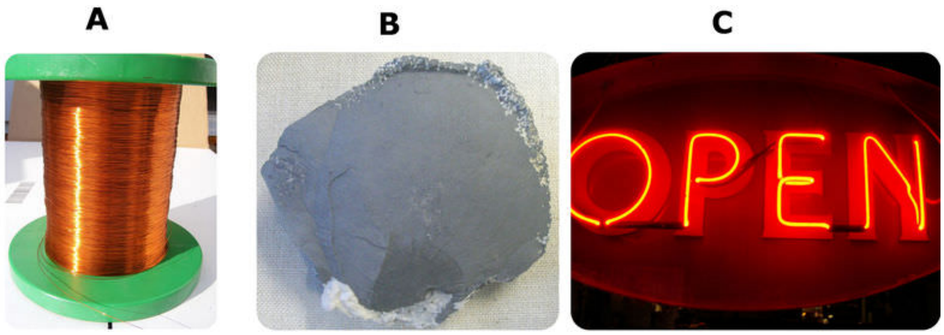
References

1. Uploaded by User:Serge Lachinov/Ru.Wikipedia. Portrait of Mendeleev . Public Domain
2. Dmitri Mendeleev. Mendeleev's first periodic table . Public Domain

CONCEPT 27 Modern Periodic Table

- Describe the modern periodic table of the elements.
- Demonstrate how to read the modern periodic table.
- Compare and contrast periods and groups of the modern periodic table.
- Identify classes of elements in the modern periodic table.



Look at substances A-C in the photos above. They look very different from one another, but they have something important in common. All three are elements, or pure substances. Can you identify which elements they are? For ideas, listen to the amazing elements song below. The singer rapidly names all of the known elements while pictures of the elements flash by. Even if the video doesn't help you name the elements pictured above, it will certainly impress you with the need to organize the large number of elements that have been discovered.

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The First Periodic Table

In the 1860s, a scientist named Dmitri Mendeleev also saw the need to organize the elements. He created a table in which he arranged all of the elements by increasing atomic mass from left to right across each row. When he placed eight elements in each row and then started again in the next row, each column of the table contained elements with similar properties. He called the columns of elements groups. Mendeleev's table is called a **periodic table** and the rows are called periods. That's because the table keeps repeating from row to row, and periodic means "repeating."

The Modern Periodic Table

A periodic table is still used today to organize the elements. You can see a simple version of the modern periodic table in the **Figure** 27.1. The modern table is based on Mendeleev's table, except the modern table arranges the elements by increasing atomic number instead of atomic mass. Atomic number is the number of protons in an atom, and this number is unique for each element. The modern table has more elements than Mendeleev's table because many elements have been discovered since Mendeleev's time.

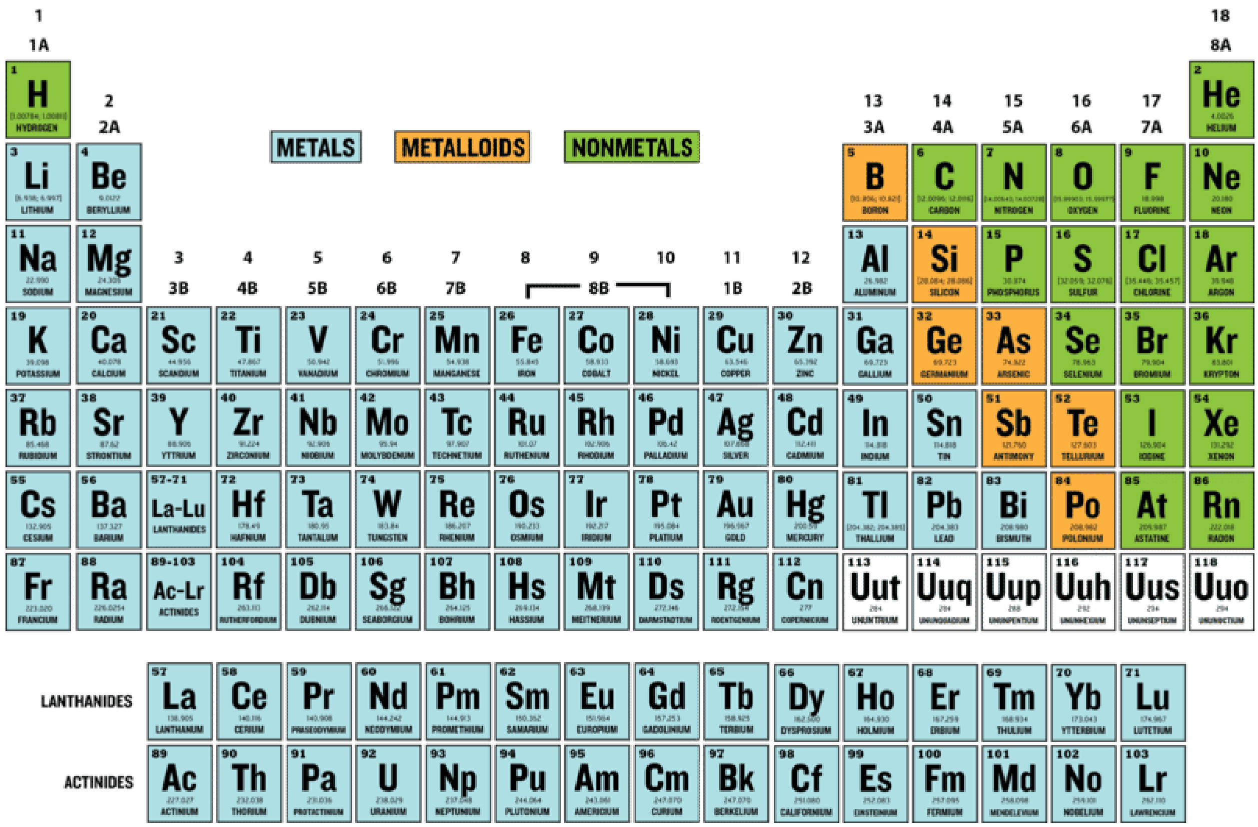


FIGURE 27.1

Reading the Table

In the **Figure** 27.1, each element is represented by its chemical symbol, which consists of one or two letters. The first letter of the symbol is always written in upper case, and the second letter—if there is one—is always written in lower case. For example, the symbol for copper is Cu. It stands for *cuprum*, which is the Latin word for copper. The number above each symbol in the table is its unique atomic number. Notice how the atomic numbers increase from left to right and from top to bottom in the table.

Q: Find the symbol for copper in the **Figure** 27.1. What is its atomic number? What does this number represent?

A: The atomic number of copper is 29. This number represents the number of protons in each atom of copper. (Copper is the element that makes up the coil of wire in photo A of the opening sequence of photos.)

Periods of the Modern Periodic Table

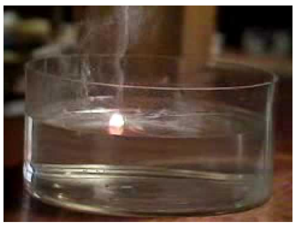
Rows of the modern periodic table are called **periods**, as they are in Mendeleev's table. From left to right across a period, each element has one more proton than the element before it. Some periods in the modern periodic table are longer than others. For example, period 1 contains only two elements: hydrogen (H) and helium (He). In contrast, periods 6 and 7 are so long that many of their elements are placed below the main part of the table. They are the elements starting with lanthanum (La) in period 6 and actinium (Ac) in period 7. Some elements in period 7 have not yet been named. They are represented by temporary three-letter symbols, such as Uub. The number of each period represents the number of energy levels that have electrons in them for atoms of each element in that period.

Q: Find calcium (Ca) in the **Figure** 27.1. How many energy levels have electrons in them for atoms of calcium?

A: Calcium is in period 4, so its atoms have electrons in them for the first four energy levels.

Groups of the Modern Periodic Table

Columns of the modern table are called **groups**, as they are in Mendeleev's table. However, the modern table has many more groups—18 compared with just 8 in Mendeleev's table. Elements in the same group have similar properties. For example, all elements in group 18 are colorless, odorless gases, such as neon (Ne). (Neon is the element inside the light in opening photo C.) In contrast, all elements in group 1 are very reactive solids. They react explosively with water, as you can see in the video and **Figure** 27.2.



MEDIA

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URL: https://www.ck12.org/flx/render/embeddedobject/79974

FIGURE 27.2

The alkali metal sodium (Na) reacting with water.

Classes of Elements

All elements can be classified in one of three classes: metals, metalloids, or nonmetals. Elements in each class share certain basic properties. For example, elements in the metals class can conduct electricity, whereas elements in the nonmetals class generally cannot. Elements in the metalloids class fall in between the metals and nonmetals in their properties. An example of a metalloid is arsenic (As). (Arsenic is the element in opening photo B.) In the periodic table above, elements are color coded to show their class. As you move from left to right across each period of the table, the elements change from metals to metalloids to nonmetals.

Q: To which class of elements does copper (Cu) belong: metal, metalloid, or nonmetal? Identify three other elements in this class.

A: In the **Figure** 27.1, the cell for copper is colored blue. This means that copper belongs to the metals class. Other elements in the metals class include iron (Fe), sodium (Na), and gold (Au). It is apparent from the table that the majority of elements are metals.

Summary

- The modern periodic table is used to organize all the known elements. Elements are arranged in the table by increasing atomic number.
- In the modern periodic table, each element is represented by its chemical symbol. The number above each symbol is its atomic number. Atomic numbers increase from left to right and from top to bottom in the table.
- Rows of the periodic table are called periods. From left to right across a period, each element has one more proton than the element before it.
- Columns of the periodic table are called groups. Elements in the same group have similar properties.
- All elements can be classified in one of three classes: metals, metalloids, or nonmetals. Elements in each class share certain basic properties. From left to right across each period of the periodic table, elements change from metals to metalloids to nonmetals.

Review

1. What is the modern periodic table?
2. Compare and contrast the periods and groups of the modern periodic table.
3. In the modern periodic table in **Figure** 27.1, find the element named lead (Pb). How many protons do atoms of lead have? To which class of elements does lead belong?
4. Which groups of the modern periodic table contain elements that are classified as metalloids?

References

1. Christopher Auyeung. Periodic Table . CC BY-NC 3.0
2. User:Ajhalls/Wikimedia Commons. Sodium reacting with water . Public Domain

CONCEPT 28 Metals

- Identify the metals class of elements.
- Describe properties of metals.
- Explain why metals are good conductors of electricity.

When you think of metals, do you think of solid objects such as iron nails and gold jewelry? If so, it might surprise you to learn that the shiny liquid pouring out of the pipette in the photo above is also a metal. It's called mercury, and it's the only metal that normally exists on Earth as a liquid. Just what are metals, and what are their properties? Read on to find out.

What Are Metals?

Metals are elements that can conduct electricity. They are one of three classes of elements (the other two classes are nonmetals and metalloids). Metals are by far the largest of the three classes. In fact, most elements are metals. All of the elements on the left side and in the middle of the periodic table, except for hydrogen, are metals. There are several different types of metals, including alkali metals in group 1 of the periodic table, alkaline Earth metals in group 2, and transition metals in groups 3-12. The majority of metals are transition metals.

Properties of Metals

Elements in the same class share certain basic similarities. In addition to conducting electricity, many metals have several other shared properties, including those listed below.

- Metals have relatively high melting points. This explains why all metals except for mercury are solids at room temperature.
- Most metals are good conductors of heat. That's why metals such as iron, copper, and aluminum are used for pots and pans.

- Metals are generally shiny. This is because they reflect much of the light that strikes them. The mercury pictured above is very shiny.
- The majority of metals are ductile. This means that they can be pulled into long, thin shapes, like the aluminum electric wires pictured in the **Figure** 28.1.
- Metals tend to be malleable. This means that they can be formed into thin sheets without breaking. An example is aluminum foil, also pictured in the **Figure** 28.1.

FIGURE 28.1

Q: The defining characteristic of metals is their ability to conduct electricity. Why do you think metals have this property?

A: The properties of metals—as well as of elements in the other classes—depend mainly on the number and arrangement of their electrons.

Explaining the Properties of Metals

To understand why metals can conduct electricity, consider the metal lithium as an example. An atom of lithium is modeled below. Look at lithium's electrons. There are two electrons at the first energy level. This energy level can hold only two electrons, so it is full in lithium. The second energy level is another story. It can hold a maximum of eight electrons, but in lithium it has just one. A full outer energy level is the most stable arrangement of electrons. Lithium would need to gain seven electrons to fill its outer energy level and make it stable. It's far easier for lithium to give up its one electron in energy level 2, leaving it with a full outer energy level (now level 1). Electricity is a flow of electrons. Because lithium (like most other metals) easily gives up its "extra" electron, it is a good conductor of electricity. This tendency to give up electrons also explains other properties of metals such as lithium.

Summary

- Metals are elements that can conduct electricity. Most elements are metals.
- All metals except for mercury are solids at room temperature. Many metals are shiny, ductile, and malleable. Most are also good conductors of heat.

- Electricity is a flow of electrons. Atoms of metals tend to give up electrons, explaining why they are good conductors of electricity. The tendency to give up electrons also explains many of the other properties of metals.

Review

1. What are metals?
2. List several properties of metals.
3. Explain why metals can conduct electricity.

Resources

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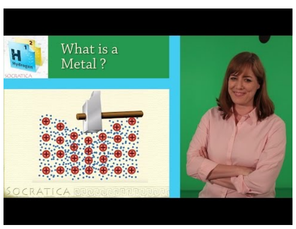

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References

1. Wire: Image copyright Geoff Hardy, 2012; Foil: Image copyright Picsfive, 2012. . Used under licenses from Shutterstock.com

CONCEPT 29 Nonmetals

- Identify the nonmetals class of elements.
- List properties of nonmetals.
- Explain why nonmetals vary in their reactivity and cannot conduct electricity.

The three pure substances pictured above have the distinction of being among the top ten elements that make up the human body. All three of them belong to the class of elements called nonmetals. Most of the elements that comprise the human body—as well as the majority of other living things—are nonmetals. In fact, seven of the top ten elements in your own body belong to this class of elements. What do you know about nonmetals? What are their properties, and how are they different from other elements? In this article, you'll find out.

What Are Nonmetals?

Nonmetals are elements that generally do not conduct electricity. They are one of three classes of elements (the other two classes are metals and metalloids.) Nonmetals are the second largest of the three classes after metals. They are the elements located on the right side of the periodic table.

Q: From left to right across each period (row) of the periodic table, each element has atoms with one more proton and one more electron than the element before it. How might this be related to the properties of nonmetals?

A: Because nonmetals are on the right side of the periodic table, they have more electrons in their outer energy level than elements on the left side or in the middle of the periodic table. The number of electrons in the outer energy level of an atom determines many of its properties.

Properties of Nonmetals

As their name suggests, nonmetals generally have properties that are very different from the properties of metals. Properties of nonmetals include a relatively low boiling point, which explains why many of them are gases at room temperature. However, some nonmetals are solids at room temperature, including the three pictured above, and one nonmetal—bromine—is a liquid at room temperature. Other properties of nonmetals are illustrated and described in the **Figure** 29.1.

Reactivity of Nonmetals

Reactivity is how likely an element is to react chemically with other elements. Some nonmetals are extremely reactive, whereas others are completely nonreactive. What explains this variation in nonmetals? The answer is their number of valence electrons. These are the electrons in the outer energy level of an atom that are involved in

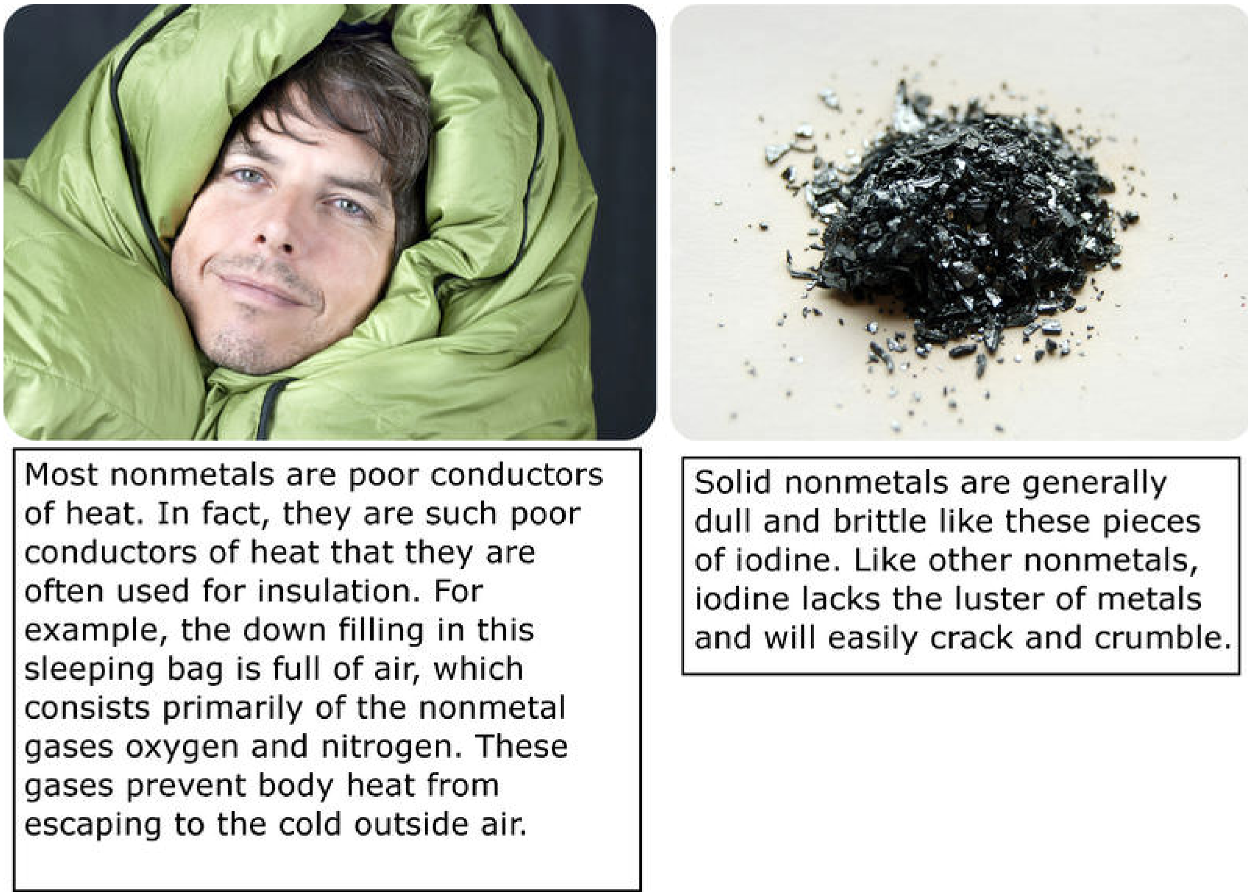

FIGURE 29.1

interactions with other atoms. Let's look at two examples of nonmetals, fluorine and neon. Simple atomic models of these two elements are shown in the **Figure** 29.2.

Q: Which element, fluorine or neon, do you predict is more reactive?

A: Fluorine is more reactive than neon. That's because it has seven of eight possible electrons in its outer energy level, whereas neon already has eight electrons in this energy level.

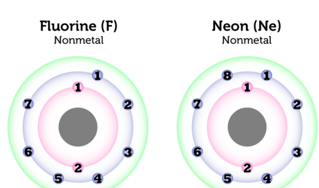

FIGURE 29.2

Although neon has just one more electron than fluorine in its outer energy level, that one electron makes a huge difference. Fluorine needs one more electron to fill its outer energy level in order to have the most stable arrangement of electrons. Therefore, fluorine readily accepts an electron from any element that is equally "eager" to give one up, such as the metal lithium or sodium. As a result, fluorine is highly reactive. In fact, reactions with fluorine are often explosive. Neon, on the other hand, already has a full outer energy level. It is already very stable and never reacts with other elements. It neither accepts nor gives up electrons. Neon doesn't even react with fluorine, which reacts with all other elements except helium.

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Why Most Nonmetals Cannot Conduct Electricity

Like most other nonmetals, fluorine cannot conduct electricity, and its electrons explain this as well. An electric current is a flow of electrons. Elements that readily give up electrons (the metals) can carry electric current because their electrons can flow freely. Elements that gain electrons instead of giving them up cannot carry electric current. They hold onto their electrons so they cannot flow.

Summary

- Nonmetals are elements that generally cannot conduct electricity. They are the second largest class of elements after metals. Examples of nonmetals include hydrogen, carbon, chlorine, and helium.
- Properties of nonmetals include a relatively low boiling point, so many nonmetals are gases. Nonmetals are also poor conductors of heat, and solid nonmetals are dull and brittle.
- Some nonmetals are very reactive, whereas others are not reactive at all. It depends on the number of electrons in their outer energy level.
- Reactive nonmetals tend to gain electrons. This explains why they cannot conduct electricity, which is a flow of electrons.

Review

1. What are nonmetals?
2. List properties of nonmetals.
3. Explain why nonmetals vary in their reactivity.
4. Carbon cannot conduct electricity. Why not?

Explore More

Watch the video about nonmetals below, and then answer the questions that follow.

MEDIA

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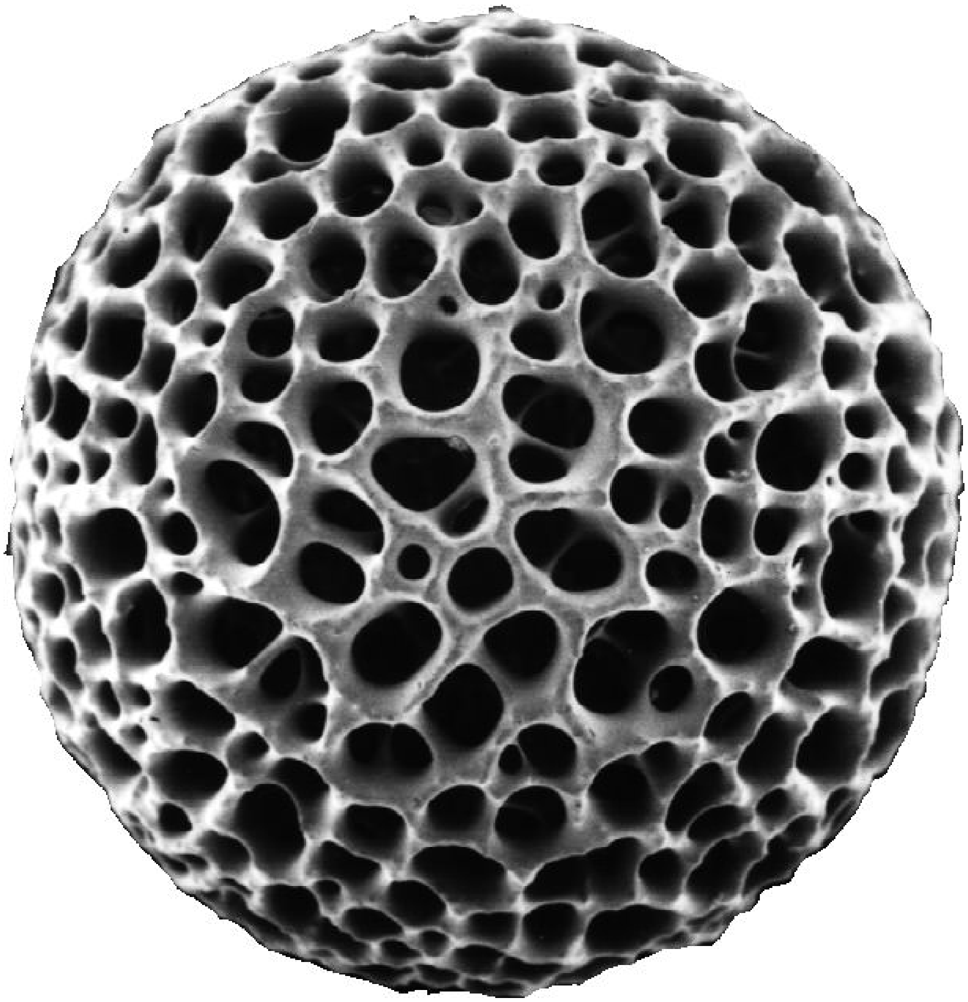
1. The science teacher in the video does an experiment in which he tests the reactivity of four nonmetal gases. How does he test them?
2. What is the outcome of the experiment?
3. Based on this outcome, what conclusion can you draw?
4. Why do the gases differ in reactivity?

References

1. Sleeping Bag: Image copyright David Stuart, 2012; Iodine: Ben Mills. . Sleeping Bag: Used under license from Shutterstock.com; Iodine: Public Domain
2. CK 12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0

CONCEPT 30 Metalloids

- Identify the metalloids class of elements.
- List physical properties of metalloids.
- Explain why some metalloids react like metals and others react like nonmetals.



What is this intricate orb? It is the greatly magnified skeleton of single-celled ocean organisms call radiolarian. The skeleton is made of an element that is extremely common on Earth. In fact, it is the second most abundant element in Earth's crust. It is also one of the most common elements in the entire universe. What is this important element? Its name is silicon, and it belongs to a class of elements called metalloids.

What Are Metalloids?

Metalloids are the smallest class of elements. (The other two classes of elements are metals and nonmetals). There are just six metalloids. In addition to silicon, they include boron, germanium, arsenic, antimony, and tellurium. Metalloids fall between metals and nonmetals in the periodic table. They also fall between metals and nonmetals in terms of their properties.

Q: How does the position of an element in the periodic table influence its properties?

A: Elements are arranged in the periodic table by their atomic number, which is the number of protons in their atoms. Atoms are neutral in electric charge, so they always have the same number of electrons as protons. It is the number of electrons in the outer energy level of atoms that determines most of the properties of elements.

Chemical Properties of Metalloids

How metalloids behave in chemical interactions with other elements depends mainly on the number of electrons in the outer energy level of their atoms. Metalloids have from three to six electrons in their outer energy level. Boron, pictured in the **Figure** 30.1, is the only metalloid with just three electrons in its outer energy level. It tends to act like metals by giving up its electrons in chemical reactions. Metalloids with more than four electrons in their outer energy level (arsenic, antimony, and tellurium) tend to act like nonmetals by gaining electrons in chemical reactions. Those with exactly four electrons in their outer energy level (silicon and germanium) may act like either metals or nonmetals, depending on the other elements in the reaction.

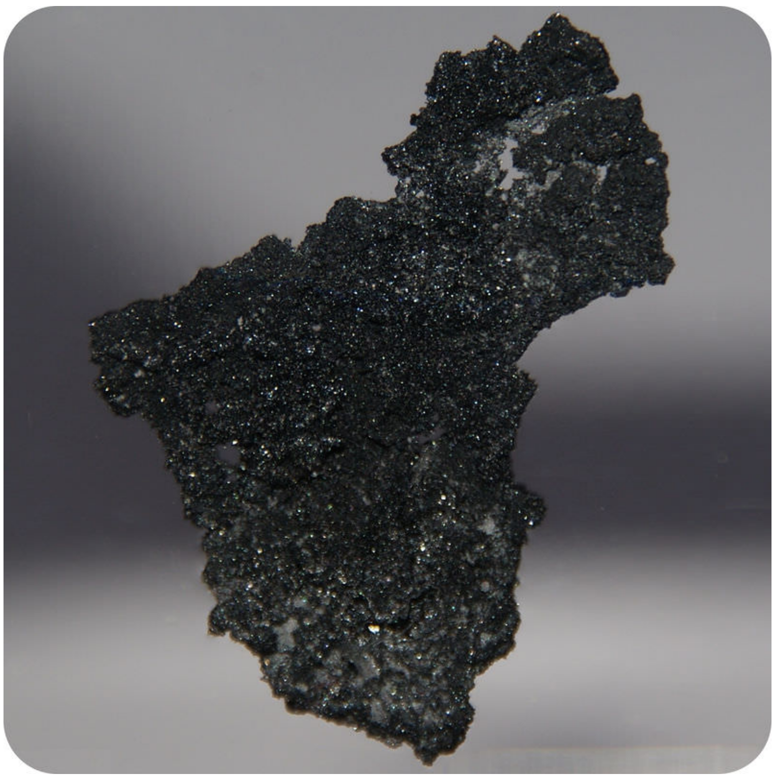


FIGURE 30.1

Physical Properties of Metalloids

Most metalloids have some physical properties of metals and some physical properties of nonmetals. For example, metals are good conductors of both heat and electricity, whereas nonmetals generally cannot conduct heat or electricity. And metalloids? They fall between metals and nonmetals in their ability to conduct heat, and if they can conduct electricity, they usually can do so only at higher temperatures. Metalloids that can conduct electricity at higher temperatures are called semiconductors. Silicon is an example of a semiconductor. It is used to make the tiny electric circuits in computer chips. You can see a sample of silicon and a silicon chip in the **Figure** 30.2.

Metalloids tend to be shiny like metals but brittle like nonmetals. Because they are brittle, they may chip like glass or crumble to a powder if struck. Other physical properties of metalloids are more variable, including their boiling and melting points, although all metalloids exist as solids at room temperature.

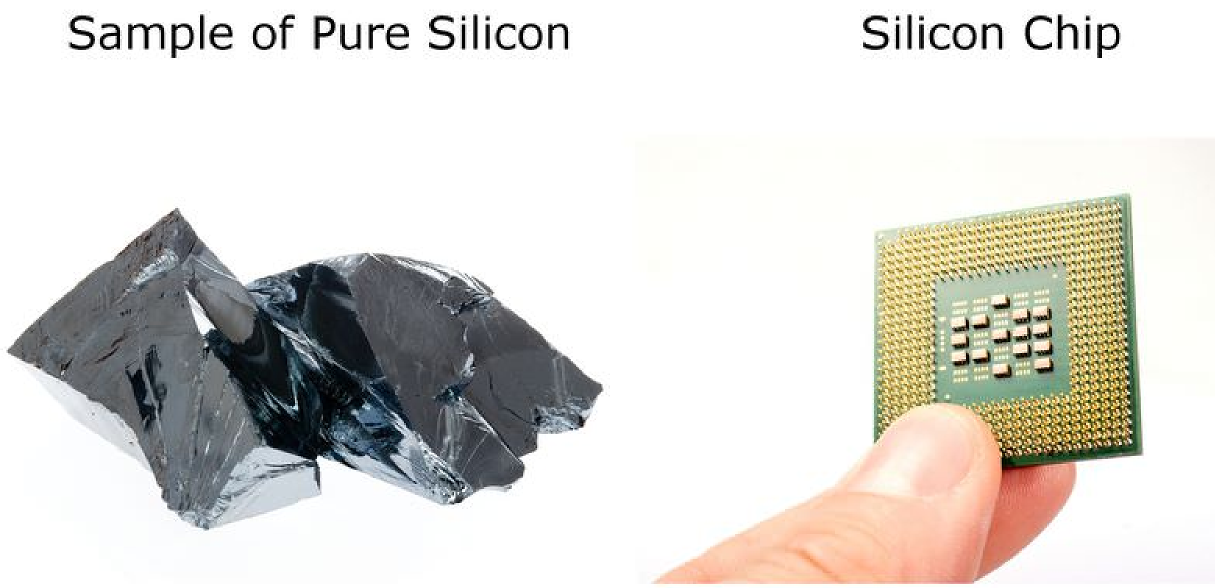
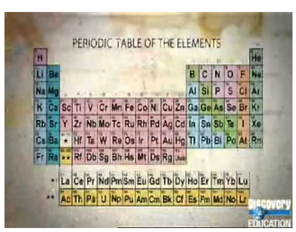


FIGURE 30.2



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Summary

- Metalloids are the smallest class of elements, containing just six elements. They fall between metals and nonmetals in the periodic table.
- How metalloids behave in chemical interactions with other elements depends mainly on the number of electrons in the outer energy level of their atoms. Metalloids may act either like metals or nonmetals in chemical reactions.
- Most metalloids have some physical properties of metals and some physical properties of nonmetals. They fall between metals and nonmetals in their ability to conduct heat and electricity. They are shiny like metals but brittle like nonmetals. All exist as solids at room temperature.

Review

1. What are metalloids? Which elements are placed in this class of elements?
2. Identify physical properties of metalloids that resemble those of metals.
3. Which physical property of metalloids is like that of nonmetals?
4. Explain the variation in how metalloids react with other elements.
5. Do a Web quest to learn more about semiconductors and why they are used in computer chips. Summarize what you learn in a written report or poster.

References

1. Jurii. . CC-BY 3.0
2. Pure silicon: Image copyright Marcel Paschertz, 2012; Chip: Image copyright Yurchyks, 2012. . Used under licenses from Shutterstock.com

CONCEPT 31 Alloys

- Define alloy.
- Describe examples of alloys.

Metals such as iron are useful for many purposes because of their unique properties. For example, they can conduct electricity and bend without breaking. However, pure metals may be less useful than mixtures of metals with other elements. For example, adding a little carbon to iron makes it much stronger. This mixture is called steel. Steel is so strong that it can hold up huge bridges, like the one pictured above. Steel is also used to make skyscrapers, cargo ships, cars, and trains. Steel is an example of an alloy.

What Are Alloys?

An **alloy** is a mixture of a metal with one or more other elements. The other elements may be metals, nonmetals, or both. An alloy is formed by melting a metal and dissolving the other elements in it. The molten solution is then allowed to cool and harden. Alloys generally have more useful properties than pure metals. Several examples of alloys are described and pictured below. If you have braces on your teeth, you might even have this alloy in your mouth!

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Examples of Alloys

Most metal objects are made of alloys rather than pure metals. Objects made of four different alloys are shown in the **Figure** 31.1.

FIGURE 31.1

Brass saxophone: Brass is an alloy of copper and zinc. It is softer than bronze and easier to shape. It's also very shiny. Notice the curved pieces in this shiny brass saxophone. Brass is used for shaping many other curved objects, such as doorknobs and plumbing fixtures. Stainless steel sink: Stainless steel is a type of steel that contains nickel and chromium in addition to carbon and iron. It is shiny, strong, and resistant to rusting. This makes it useful for sinks, eating utensils, and other objects that are exposed to water. "Gold" bracelet: Pure gold is relatively soft, so it is rarely used for jewelry. Most "gold" jewelry is actually made of an alloy of gold, copper and silver. Bronze statue: Bronze was the first alloy ever made. The earliest bronze dates back many thousands of years. Bronze is a mixture of copper and tin. Both copper and tin are relatively soft metals, but mixed together in bronze they are much harder. Bronze has been used for statues, coins, and other objects.

Q: Sterling silver is an alloy that is used to make fine jewelry. What elements do you think sterling silver contains? What properties might sterling silver have that make it more useful than pure silver?

A: Most sterling silver is about 93 percent silver and about 7 percent copper. Sterling silver is harder and stronger than pure silver, while retaining the malleability and luster of pure silver.

Summary

- An alloy is a mixture of a metal with one or more other elements. An alloy generally has properties that make it more useful than the pure metal.
- Examples of alloys include steel, bronze, and brass.

Review

1. What is an alloy? Describe an example.
2. What are some useful ways alloys may differ from pure metals?

References

1. Saxophone: Thor (Flickr:Geishaboy500); Sink: Granite Charlotte Countertops; Bracelet: Maegan Tintari; Status: Elliot Brown. Brass saxophones, stainless steel sinks, gold bracelets, and bronze statues are all made from alloys . CC BY 2.0

CONCEPT 32

Hydrogen and Alkali Metals

- Identify the elements in group 1 of the periodic table.
- Explain why group 1 elements are very reactive.
- List other properties of alkali metals.

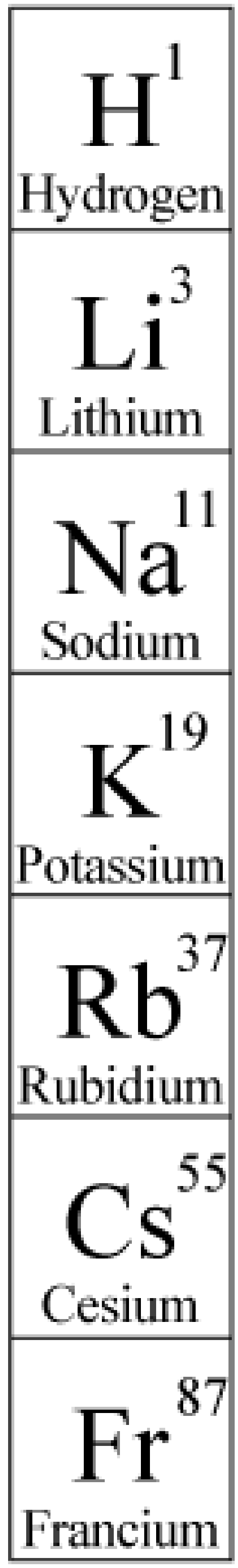
You probably think of water as a substance that can put out fires. But some elements are so reactive that they burn in water. In fact, they virtually explode in water. That's what is happening in the photo above. About 3 pounds of sodium were added to water, and the result was this explosive reaction. Why is sodium such a reactive element? In this lesson you will find out.

The First Group

Sodium (Na) is an element in group 1 of the periodic table of the elements. This group (column) of the table is shown in **Figure** below. It includes the nonmetal hydrogen (H) and six metals that are called **alkali metals**. Elements in the same group of the periodic table have the same number of valence electrons. These are the electrons in their outer energy level that can be involved in chemical reactions. Valence electrons determine many of the properties of an element, so elements in the same group have similar properties. All the elements in group 1 have just one valence electron. This makes them very reactive.

Q: Why does having just one valence electron make group 1 elements very reactive?

A: With just one valence electron, group 1 elements are "eager" to lose that electron. Doing so allows them to achieve a full outer energy level and maximum stability.


H 1
Hydrogen
Li 3
Lithium
Na 11
Sodium
K 19
Potassium
Rb 37
Rubidium
Cs 55
Cesium
Fr 87
Francium

Reactivity of Group 1 Elements

Hydrogen is a very reactive gas, and the alkali metals are even more reactive. In fact, they are the most reactive metals and, along with the elements in group 17, are the most reactive of all elements. The reactivity of alkali metals increases from the top to the bottom of the group, so lithium (Li) is the least reactive alkali metal and francium (Fr) is the most reactive. Because alkali metals are so reactive, they are found in nature only in combination with other elements. They often combine with group 17 elements, which are very "eager" to gain an electron.

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Other Properties of Alkali Metals

Besides being very reactive, alkali metals share a number of other properties.

- Alkali metals are all solids at room temperature.
- Alkali metals are low in density, and some of them float on water.
- Alkali metals are relatively soft. Some are even soft enough to cut with a knife, like the sodium pictured in the **Figure** 32.1.

FIGURE 32.1

A Closer Look

Although all group 1 elements share certain properties, such as being very reactive, they are not alike in every way. Three different group 1 elements are described in more detail below. Notice the ways in which they differ from one another.

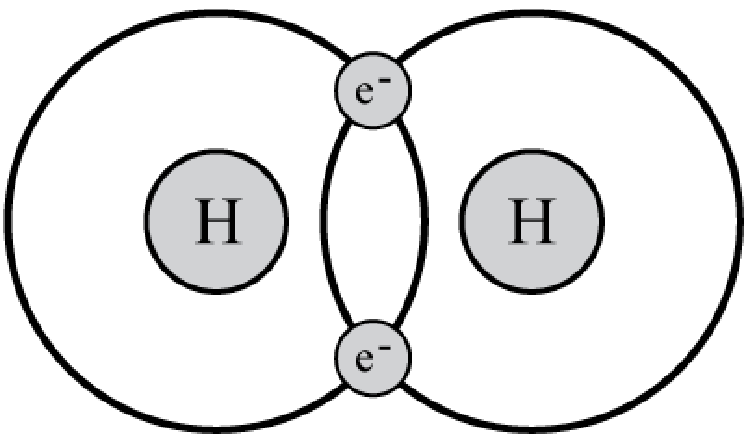


FIGURE 32.2
Hydrogen has the smallest, lightest atoms of all elements. Pure hydrogen is a colorless, odorless, tasteless gas that is nontoxic but highly flammable. Hydrogen gas exists mainly as diatomic ("two-atom") molecules (H_2), as shown in the diagram on the right. Hydrogen is the most abundant element in the universe and the third most abundant element on Earth, occurring mainly in compounds such as water.

Q: Why do you think hydrogen gas usually exists as diatomic molecules?

A: Each hydrogen atom has just one electron. When two hydrogen atoms bond together, they share a pair of electrons. The shared electrons fill their only energy level, giving them the most stable arrangement of electrons.

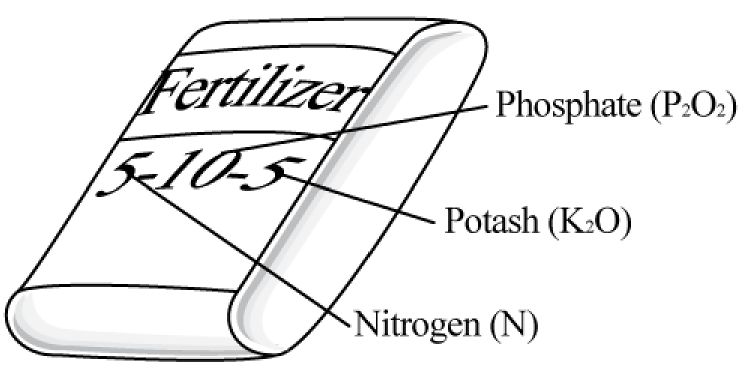


FIGURE 32.3
Potassium is a soft, silvery metal that ignites explosively in water. It easily loses its one valence electron to form positive potassium ions (K^+), which are needed by all living cells. Potassium is so important for plants that it is found in almost all fertilizers, like the one shown here. Potassium is abundant in Earth's crust in minerals such as feldspar.

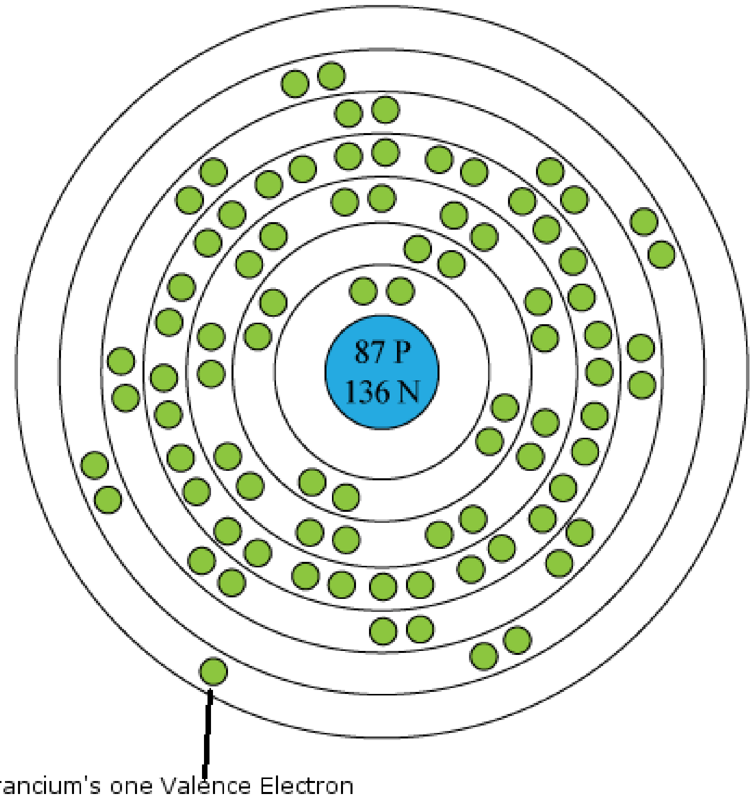


FIGURE 32.4

Francium has one of the largest, heaviest atoms of all elements. Its one valence electron is far removed from the nucleus, as you can see in the atomic model on the right, so it is easily removed from the atom. Francium is radioactive and quickly decays to form other elements such as radium. This is why francium is extremely rare in nature. Less than an ounce of francium is present on Earth at any given time.

Q: Francium decays too quickly to form compounds with other elements. Which elements to you think it would bond with if it could?

A: With one valence electron, francium would bond with a halogen element in group 17, which has seven valence electrons and needs one more to fill its outer energy level. Elements in group 17 include fluorine and chlorine.

Summary

- Group 1 of the periodic table includes hydrogen and the alkali metals.
- Because they have just one valence electron, group 1 elements are very reactive. As a result, they are found in nature only in combination with other elements.
- Alkali metals are all solids at room temperature. They are relatively soft and low in density.
- From the top to the bottom of group 1, the elements have heavier, more reactive atoms.

Review

1. What are alkali metals?
2. Why is hydrogen, a nonmetal, placed in the same group as the alkali metals?
3. Explain why group 1 elements often form compounds with elements in group 17.
4. Compare and contrast hydrogen and francium.

References

1. Courtesy of the US Department of Energy. . Public Domain

CONCEPT 33 Alkaline Earth Metals

- Identify alkaline Earth metals.
- List properties of alkaline Earth metals.
- Explain why alkaline Earth metals are very reactive.

Sparklers like the one this girl is holding make festive additions to many celebrations. You may use them yourself. But watch out if you do because their flames are really hot! The bright white flames are produced when magnesium burns. Magnesium is a light- weight metal that burns at a very high temperature. Other uses of magnesium include flash photography, flares, and fireworks. Magnesium is a metal in group 2 of the periodic table, which you will read about in this concept.

The Second Group

Barium (Ba) is one of six elements in group 2 of the periodic table, which is shown in **Figure** 33.1. Elements in this group are called **alkaline Earth metals**. These metals are silver or gray in color. They are relatively soft and low in density, although not as soft and lightweight as alkali metals.

Reactivity of Alkaline Earth Metals

All alkaline Earth metals have similar properties because they all have two valence electrons. They readily give up their two valence electrons to achieve a full outer energy level, which is the most stable arrangement of electrons. As a result, they are very reactive, although not quite as reactive as the alkali metals in group 1. For example, alkaline Earth metals will react with cold water, but not explosively as alkali metals do. Because of their reactivity, alkaline Earth metals never exist as pure substances in nature. Instead, they are always found combined with other elements.

The reactivity of alkaline Earth metals increases from the top to the bottom of the group. That's because the atoms get bigger from the top to the bottom, so the valence electrons are farther from the nucleus. When valence electrons are farther from the nucleus, they are attracted less strongly by the nucleus and more easily removed from the atom. This makes the atom more reactive.

Q: Alkali metals have just one valence electron. Why are alkaline Earth metals less reactive than alkali metals?

A: It takes more energy to remove two valence electrons from an atom than one valence electron. This makes alkaline Earth metals with their two valence electrons less reactive than alkali metals with their one valence electron.

Examples of Alkaline Earth Metals

For a better understanding of alkaline Earth metals, let's take a closer look at two of them: calcium (Ca) and strontium (Sr). Calcium is a soft, gray, nontoxic alkaline Earth metal. Although pure calcium doesn't exist in nature, calcium compounds are very common in Earth's crust and in sea water. Calcium is also the most abundant metal in the human body, occurring as calcium compounds such as calcium phosphate and calcium carbonate. These calcium compounds are found in bones and make them hard and strong. The skeleton of the average adult contains about a kilogram of calcium. Because calcium—like barium—absorbs x-rays, bones show up white in x-ray images. Calcium is an important component of a healthy human diet. Good food sources of calcium are pictured in **Figure** 33.2.

Q: What health problems might result from a diet low in calcium?

A: Children who don't get enough calcium while their bones are forming may develop a deficiency disease called rickets, in which their bones are softer than normal and become bent and stunted. Adults who don't get enough calcium may develop a condition called osteoporosis, in which the bones lose calcium and become weak and brittle. People with osteoporosis are at high risk of bone fractures.

Strontium is a silver-colored alkaline Earth metal that is even softer than calcium. Strontium compounds are quite common and have a variety of uses—from fireworks to cement to toothpaste. In fireworks, strontium compounds produce deep red explosions. In toothpaste, the compound strontium chloride reduces tooth sensitivity.

Summary

- Elements in group 2 of the periodic table are called alkaline Earth metals. They are silvery or gray in color. They are also relatively soft and low in density.
- Alkaline Earth metals are very reactive because they readily give up their two valence electrons to achieve a full outer energy level, which is the most stable arrangement of electrons. Reactivity increases from the top to the bottom of the group.

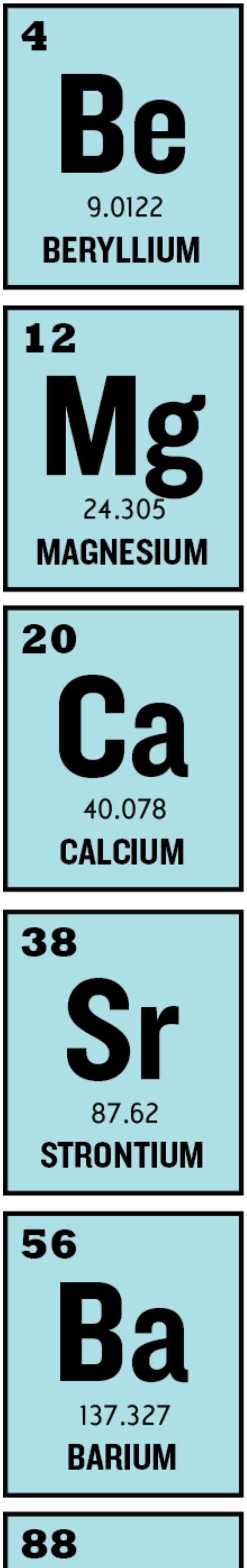

4
Be
9.0122
BERYLLIUM
12
Mg
24.305
MAGNESIUM
20
Ca
40.078
CALCIUM
38
Sr
87.62
STRONTIUM
56
Ba
137.327
BARIUM
88

FIGURE 33.1

FIGURE 33.2

- Examples of alkaline Earth metals include calcium, which is needed for strong bones, and strontium, which is used for making cement and other products.

Review

1. What are alkaline Earth metals? What are their physical properties?
2. Why are alkaline Earth metals very reactive?
3. Compare and contrast the reactivity of beryllium (Be) and barium (Ba).

Explore More

Observe how four different alkaline Earth metals react with water in the video below. Then, answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/54913

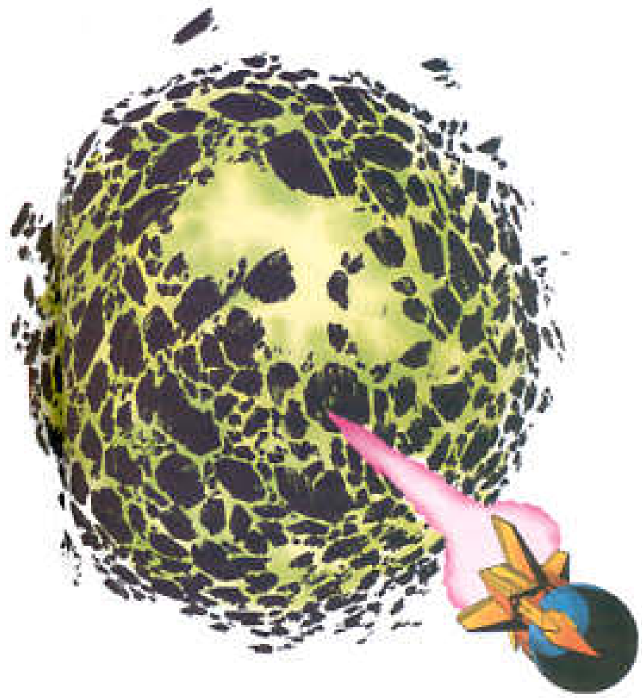
1. Observe the reactions in the video, and then rank the alkaline Earth metals from most to least reactive with water.
2. What explains the differences in reactivity?
3. Predict the reactivity of beryllium with water. Where would it fit in your ranking?
4. What substances are produced in each reaction that you observed in the video?

References

1. CK-12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0
2. Image copyright Robyn Mackenzie, 2012. . Used under license from Shutterstock.com

Concept 34 Noble Gases

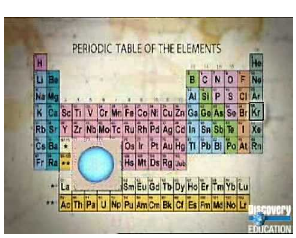
- Identify the noble gases.
- List properties of noble gases.
- Explain the nonreactivity of noble gases and how it is related to the octet rule.



Did you ever see this image before? You may have if you've read Superman comics. The picture shows the planet Krypton, fictional home of Superman, as it is exploding outward into space. Using the name Krypton for an exploding planet is ironic, because krypton the element is one of the least reactive of all the elements. Krypton is nonreactive because it's a noble gas.

What Are Noble Gases?

Noble gases are nonreactive, nonmetallic elements in group 18 of the periodic table. As you can see in the periodic table below, noble gases include helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). All noble gases are colorless and odorless. They also have low boiling points, explaining why they are gases at room temperature. Radon, at the bottom of the group, is radioactive, so it constantly decays to other elements.



MEDIA

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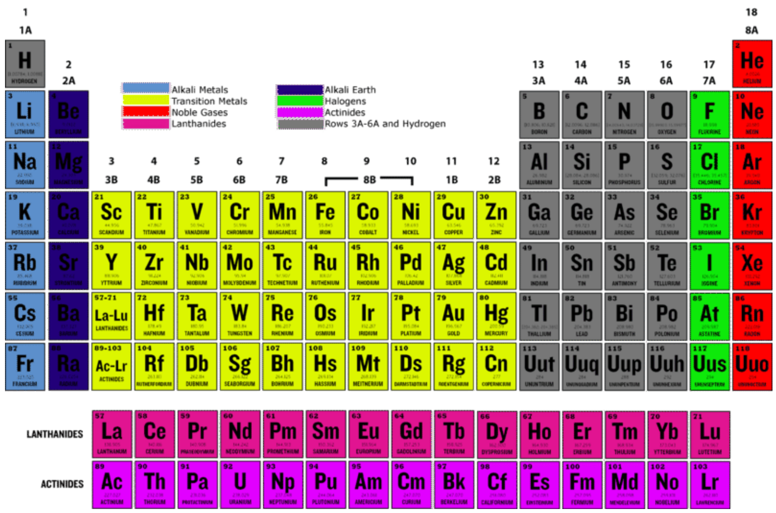


FIGURE 34.1

Q: Based on their position in the periodic table (**Figure** 34.1), how many valence electrons do you think noble gases have?

A: The number of valence electrons starts at one for elements in group 1. It then increases by one from left to right across each period (row) of the periodic table for groups 1-2 and 13-18 (numbered 3-0 in the table above). Therefore, noble gases have eight valence electrons.

Chemical Properties of Noble Gases

Noble gases are the least reactive of all known elements. That's because with eight valence electrons, their outer energy levels are full. The only exception is helium, which has just two electrons. But helium also has a full outer energy level, because its only energy level (energy level 1) can hold a maximum of two electrons. A full outer energy level is the most stable arrangement of electrons. As a result, noble gases cannot become more stable by reacting with other elements and gaining or losing valence electrons. Therefore, noble gases are rarely involved in chemical reactions and almost never form compounds with other elements.

Noble Gases and the Octet Rule

Because the noble gases are the least reactive of all elements, their eight valence electrons are used as the standard for nonreactivity and to explain how other elements interact. This is stated as the octet ("group of eight") rule. According to this rule, atoms react to form compounds that allow them to have a group of eight valence electrons like the noble gases. For example, sodium (with one valence electron) reacts with chlorine (with seven valence electrons) to form the stable compound sodium chloride (table salt). In this reaction, sodium donates an electron and chlorine accepts it, giving each element an octet of valence electrons.

Some Uses of Noble Gases

Did you ever get a birthday balloon like the one pictured 34.2? The balloon is filled with the noble gas helium. The gas is pumped from a tank into a Mylar balloon. Unlike a balloon filled with air, a balloon filled with helium needs to be weighted down so it won't float away.

Q: Why does a helium balloon float away if it's not weighted down?

A: Helium atoms have just two protons, two neutrons, and two electrons, so they have less mass than any other atoms except hydrogen. As a result, helium is lighter than air, explaining why a helium balloon floats up into the air unless weighted down.

FIGURE 34.2

Early incandescent light bulbs, like the one pictured in the **Figure** 34.3, didn't last very long. The filaments quickly burned out. Although air was pumped out of the bulb, it wasn't a complete vacuum. Oxygen in the small amount of air remaining inside the light bulb reacted with the metal filament. This corroded the filament and caused dark deposits on the glass. Filling a light bulb with argon gas prevents these problems. That's why modern light bulbs are filled with argon.

Q: How does argon prevent the problems of early light bulbs?

A: As a noble gas with eight electrons, argon doesn't react with the metal in the filament. This protects the filament and keeps the glass blub free of deposits.

FIGURE 34.3

Noble gases are also used to fill the glass tubes of lighted signs like the one in the **Figure** 34.4. Although noble gases are chemically nonreactive, their electrons can be energized by sending an electric current through them. When this happens, the electrons jump to a higher energy level. When the electrons return to their original energy level, they give off energy as light. Different noble gases give off light of different colors. Neon gives off reddish-orange light, like the word "Open" in the sign below. Krypton gives off violet light and xenon gives off blue light.

Summary

- Noble gases are nonreactive, nonmetallic elements in group 18 of the periodic table.
- Noble gases are the least reactive of all elements. That's because they have eight valence electrons, which fill their outer energy level. This is the most stable arrangement of electrons, so noble gases rarely react with other elements and form compounds.
- The octet rule states that atoms react to form compounds that allow them to have eight valence electrons like the noble gases, which are the least reactive elements.
- Noble gases are used for balloons, light bulbs, and lighted signs.

Review

1. What are noble gases?
2. Explain why noble gases are almost completely nonreactive.

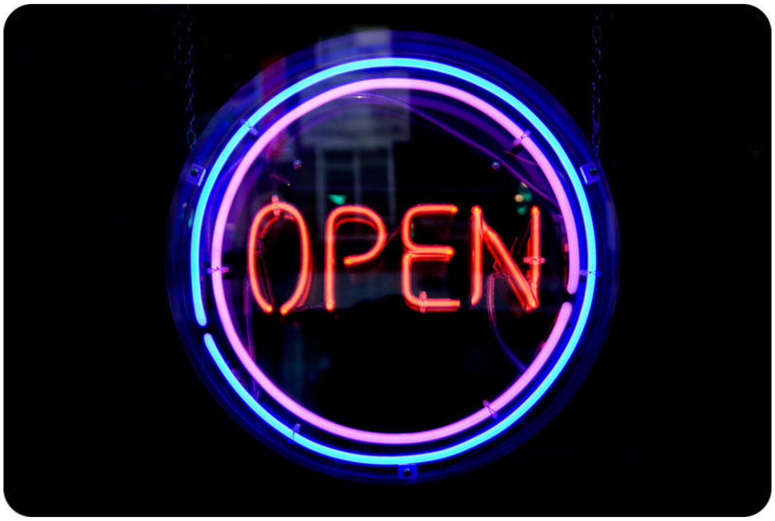
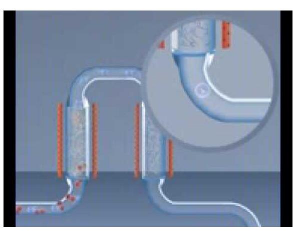


FIGURE 34.4

3. What is the octet rule? How is it related to noble gases?
4. Hydrogen (H) atoms have one electron and exist as diatomic ("two-atom") molecules (H_2). Helium atoms have two electrons and exist only as single helium atoms. Explain why hydrogen and helium differ in this way.

Resources



MEDIA

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References

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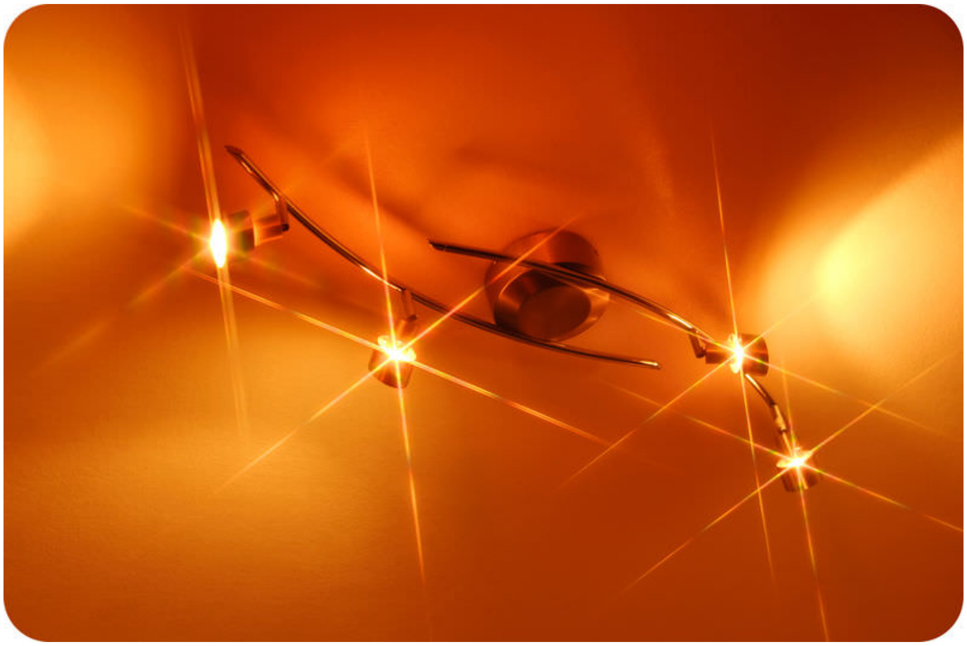
3. Image copyright Charles Taylor, 2012. . Used under license from Shutterstock.com
4. Image copyright photocritical, 2012. . Used under license from Shutterstock.com

CONCEPT 35 Halogens

- Identify halogens.
- Describe physical and chemical properties of halogens.
- List some uses of halogens.



You've probably seen halogen lights like the ones pictured here. You may even have halogen lights in your home. If you do, you may have noticed that they get really hot and give off a lot of light for their size. A halogen light differs from a regular incandescent light bulb in having a small amount of halogen gas inside the bulb. The gas combines chemically with the metal in the filament, and this extends the life of the filament. It allows the lamp to get hotter and give off more light than a regular incandescent light without burning out quickly. What is halogen gas, and which elements are halogens? In this article, you'll find out.

Meet the Halogens

Halogens are highly reactive nonmetallic elements in group 17 of the periodic table. As you can see in the periodic table 35.1, the halogens include the elements fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). All of them are relatively common on Earth except for astatine. Astatine is radioactive and rapidly decays to other, more stable elements. As a result, it is one of the least common elements on Earth.

Q: Based on their position in the periodic table from the **Figure** 35.1, how many valence electrons do you think halogens have?

A: The number of valence electrons starts at one for elements in group 1. It then increases by one from left to right across each period (row) of the periodic table for groups 1-2 and 13-18 (numbered 3-0 in the periodic table above.) Therefore, halogens have seven valence electrons.

Chemical Properties of Halogens

The halogens are among the most reactive of all elements, although reactivity declines from the top to the bottom of the halogen group. Because all halogens have seven valence electrons, they are "eager" to gain one more electron.

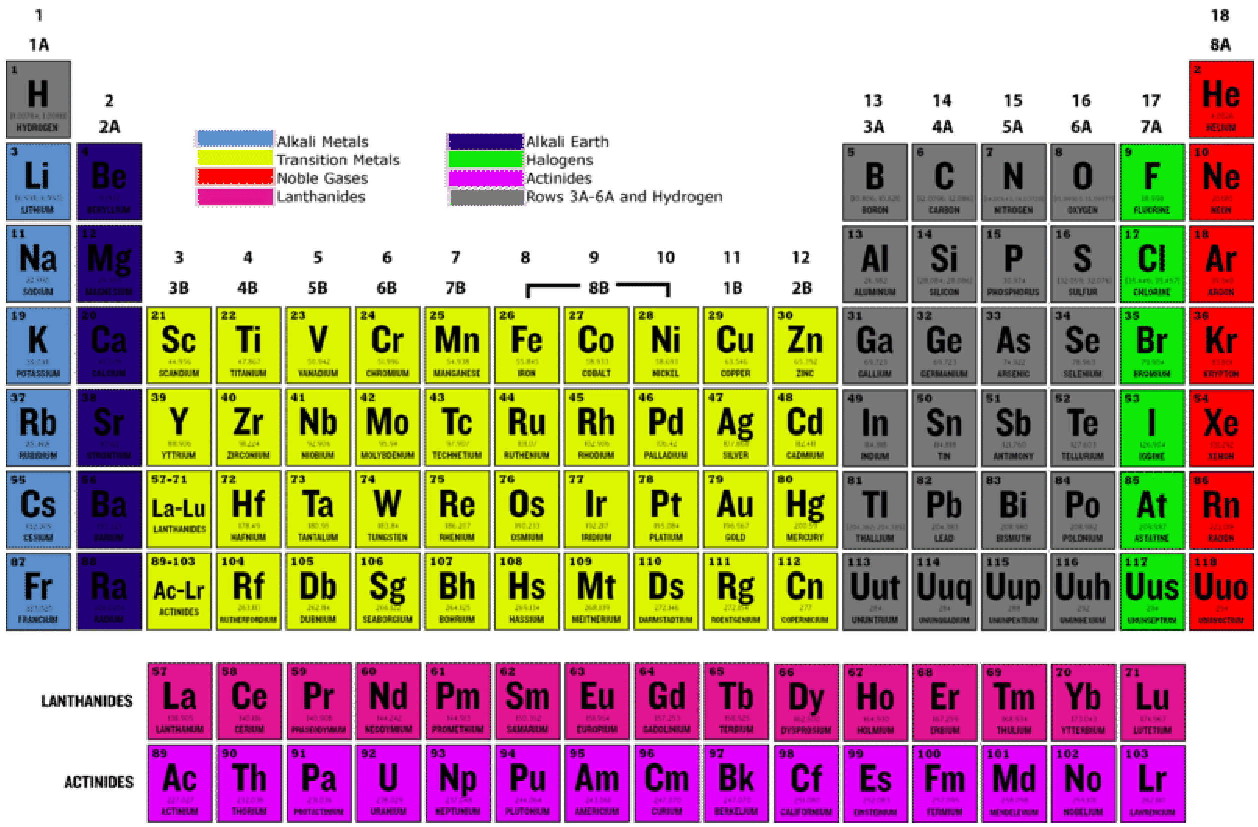


FIGURE 35.1

Doing so gives them a full outer energy level, which is the most stable arrangement of electrons. Halogens often combine with alkali metals in group 1 of the periodic table. Alkali metals have just one valence electron, which they are equally "eager" to donate. Reactions involving halogens, especially halogens near the top of the group, may be explosive. You can see some examples in the video below. (*Warning:* Don't try any of these reactions at home!)

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/54896

Physical Properties of Halogens

The halogen group is quite diverse. It includes elements that occur in three different states of matter at room temperature. Fluorine and chlorine are gases, bromine is a liquid, and iodine and astatine are solids. Halogens also vary in color, as you can see in the **Figure** 35.2. Fluorine and chlorine are green, bromine is red, and iodine and astatine are nearly black. Like other nonmetals, halogens cannot conduct electricity or heat. Compared with most other elements, halogens have relatively low melting and boiling points.

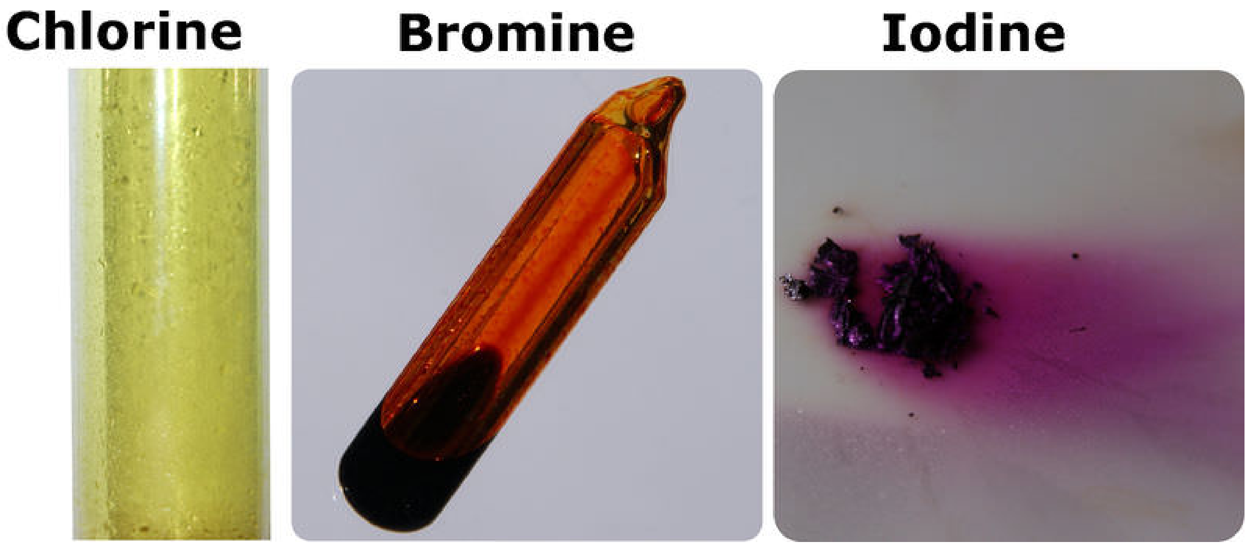


FIGURE 35.2

Uses of Halogens

Most halogens have a variety of important uses. A few are described in the **Figure** 35.3.

Q: Can you relate some of these uses of halogens to the properties of these elements?

A: The ability of halogens to kill germs and bleach clothes relates to their highly reactive nature.

Summary

- Halogens are highly reactive nonmetal elements in group 17 of the periodic table.
- Halogens include solids, liquids, and gases at room temperature, and they vary in color.
- Halogens are among the most reactive of all elements. They have seven valence electrons, so they are very "eager" to gain one electron to have a full outer energy level.
- Halogens have a variety of important uses, such as preventing tooth decay and killing germs.

Review

1. What are halogens?
2. Why are halogens very reactive?

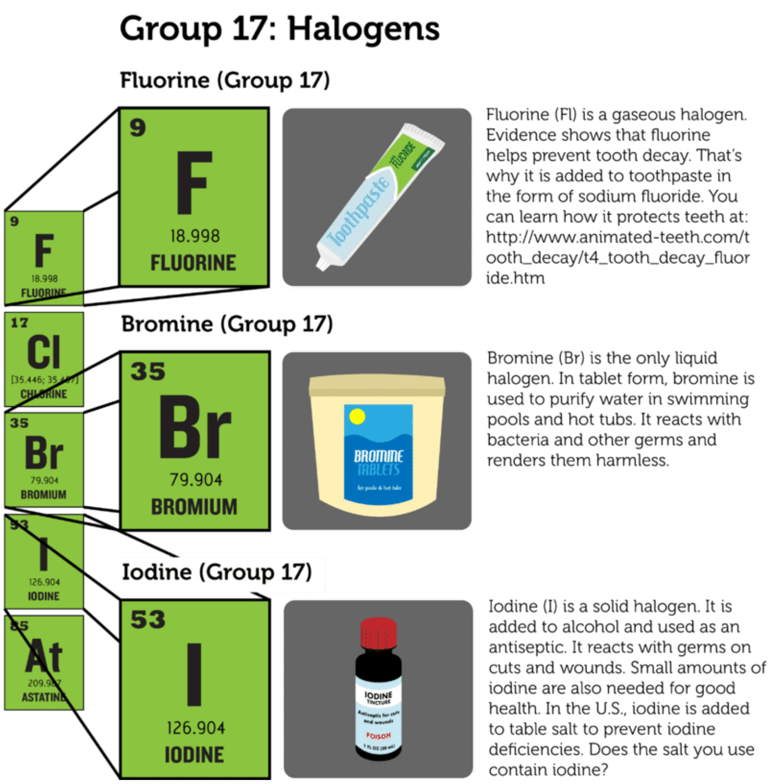


FIGURE 35.3

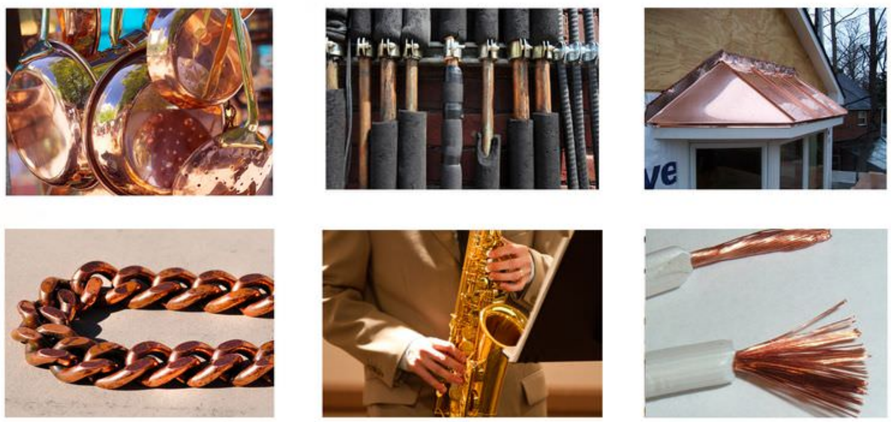
3. Describe the physical properties of halogens.
4. Why is chlorine added to swimming pool water?

References

1. CK-12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0
2. Chlorine: Ben Mills; Bromine: Jurii; Iodine: Jurii. . Chlorine: Public Domain; Bromine: CC-BY 3.0; Iodine: CC-BY 3.0
3. CK-12 Foundation - Christopher Auyeung. . CC-BY-NC-SA 3.0

CONCEPT 36 Transition Metals

- Identify transition metals.
- List properties of transition metals.
- Describe the lanthanides and actinides.



What do all of the objects pictured above have in common? All of them are made completely or primarily of copper. Copper has an amazing variety of uses, including cooking pots, plumbing pipes, roofing tiles, jewelry, musical instruments, and electric wires. Copper is a good choice for these and many other objects because of its properties. It can be formed into wires and flat sheets, it's a great conductor of heat and electricity, it's hard and strong, and it doesn't corrode easily. In all these ways, copper is a typical transition metal.

What Are Transition Metals?

Transition metals are all the elements in groups 3-12 of the periodic table. In the periodic table pictured in **Figure** 36.1, they are the elements shaded yellow, pink, and purple. The transition metals make up about 60 percent of all known elements. In addition to copper (Cu), well known examples of transition metals include iron (Fe), zinc (Zn), silver (Ag), and gold (Au) (Copper (Cu) is pictured in its various applications in the opening image).

Q: Transition metals have been called the most typical of all metals. What do you think this means?

A: Unlike some other metals, transition metals have the properties that define the metals class. They are excellent conductors of electricity, for example, and they also have luster, malleability, and ductility. You can read more about these properties of transition metals below.

Properties of Transition Metals

Transition metals are superior conductors of heat as well as electricity. They are malleable, which means they can be shaped into sheets, and ductile, which means they can be shaped into wires. They have high melting and boiling points, and all are solids at room temperature, except for mercury (Hg), which is a liquid. Transition metals are also high in density and very hard. Most of them are white or silvery in color, and they are generally lustrous, or shiny. The compounds that transition metals form with other elements are often very colorful. You can see several examples in the **Figure** 36.2.

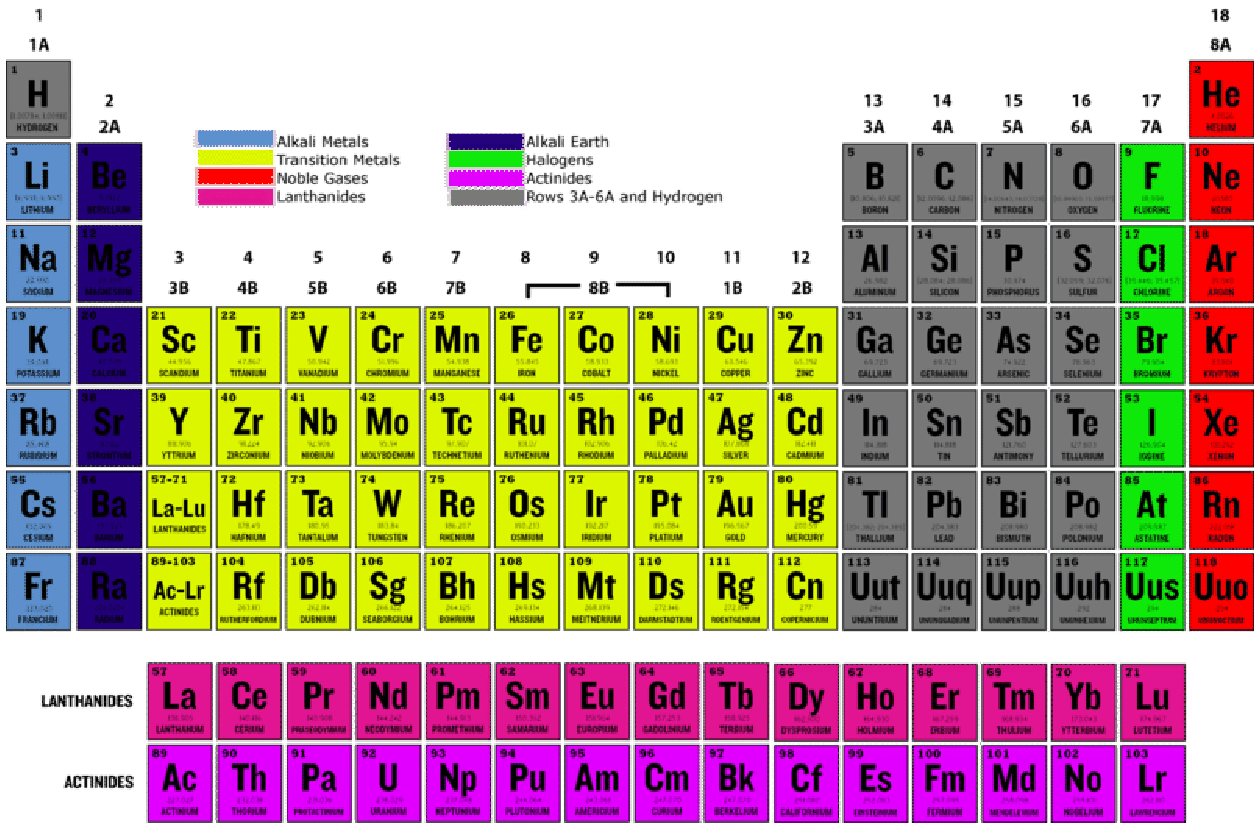


FIGURE 36.1

FIGURE 36.2

Some properties of transition metals set them apart from other metals. Compared with the alkali metals in group 1 and the alkaline Earth metals in group 2, the transition metals are much less reactive. They don't react quickly with water or oxygen, which explains why they resist corrosion.

Other properties of the transition metals are unique. They are the only elements that may use electrons in the next to highest—as well as the highest—energy level as valence electrons. Valence electrons are the electrons that form bonds with other elements in compounds and that generally determine the properties of elements. Transition metals are unusual in having very similar properties even with different numbers of valence electrons. The transition metals also include the only elements that produce a magnetic field. Three of them have this property: iron (Fe), cobalt (Co), and nickel (Ni).

Q: How is the number of valence electrons typically related to the properties of elements?

A: The number of valence electrons usually determines how reactive elements are as well as the ways in which they react with other elements.

Those Elements Down Under

Transition metals include the elements that are most often placed below the periodic table (the pink- and purple-shaded elements in the **Figure** 36.1). Those that follow lanthanum (La) are called lanthanides. They are all relatively reactive for transition metals. Those that follow actinium (Ac) are called actinides. They are all radioactive. This means that they are unstable, so they decay into different, more stable elements. Many of the actinides do not occur in nature but are made in laboratories.

Summary

- Transition metals are all the elements in groups 3-12 of the periodic table. More than half of all elements are transition metals.
- Transition metals are typical metals, with properties such as a superior ability to conduct electricity and heat. They also have the metallic properties of luster, malleability, and ductility. In addition, transition metals have high melting and boiling points and high density.
- The lanthanides and actinides are the transition metals that are usually placed below the main part of the periodic table. Lanthanides are relatively reactive for transition metals, and actinides are radioactive.

Review

1. What are transition metals?
2. Describe properties of transition metals.
3. How do transition metals differ from metals in groups 1 and 2? How are they different from all other elements?
4. Identify the lanthanides and actinides.

References

1. Christopher Auyeung. The periodic table . CC BY-NC 3.0
2. Images by Ben Mills (Wikimedia: Benjah-bmm27). Colorful salts of transition metals . Public Domain

CONCEPT 37 Chemical Formula

- Define chemical formula.
- Explain how to write a chemical formula.
- Identify the ratio of different elements in a compound from its chemical formula.

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

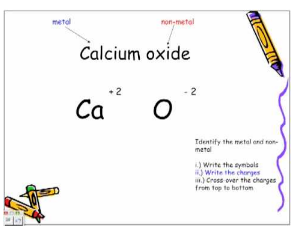
The **Table** 37.1 shows four examples of compounds and their chemical formulas. The first two compounds are ionic compounds, and the second two are covalent compounds. Each formula shows the ratio of ions or atoms that make up the compound.

TABLE 37.1: Compounds and Their Chemical Formulas

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.



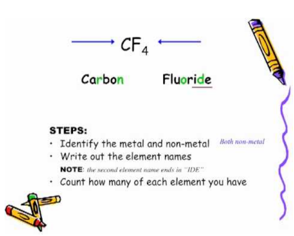
MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/79969

- **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 one sodium ion (Na^+) to two sulfide ions (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.