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Chemistry

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Contents

1	Safety in Science	1
2	Scientific Process	5
3	Types of Matter	8
4	Inside the Atom	17
5	Introduction to Chemical Bonds	25
6	Changes in Matter	30
7	Introduction to Chemical Reactions	36
8	Materials Humans Use	41
9	Solids, Liquids, Gases, and Plasmas	45
10	Chemical Equations	53

CHAPTER

1

Safety in Science

- Identify the meaning of lab safety symbols.
- List rules for staying safe in the lab.
- State what to do in case of accidents in the lab or field.



Research in physical science can be exciting, but it also has potential dangers. For example, the field scientist in this photo is collecting water samples from a polluted lake. There are many microorganisms in the water that could make her sick. The water and shore are also strewn with dangerous objects such as sharp can lids and broken glass bottles that could cause serious injury. Whether in the field or in the lab, knowing how to stay safe in science is important.

Safety Symbols

Lab procedures and equipment may be labeled with safety symbols. These symbols warn of specific hazards, such as flames or broken glass. Learn the symbols so you will recognize the dangers. Then learn how to avoid them. Many common safety symbols are shown in the **Figure 1.1**.

Q: Do you know how you can avoid these hazards?

A: Wearing protective gear is one way to avoid many hazards in science. For example, to avoid being burned by hot objects, use hot mitts to protect your hands. To avoid eye hazards, such as harsh liquids splashed into the eyes, wear safety goggles. You can learn more about these and other lab hazards and how to avoid them at this URL: <http://www.angelfire.com/va3/chemclass/safety.html>.

Safety Rules

Following basic safety rules is another important way to stay safe in science. Safe practices help prevent accidents. Several lab safety rules are listed below. Different rules may apply when you work in the field. But in all cases, you should always follow your teacher's instructions.

Lab Safety Rules

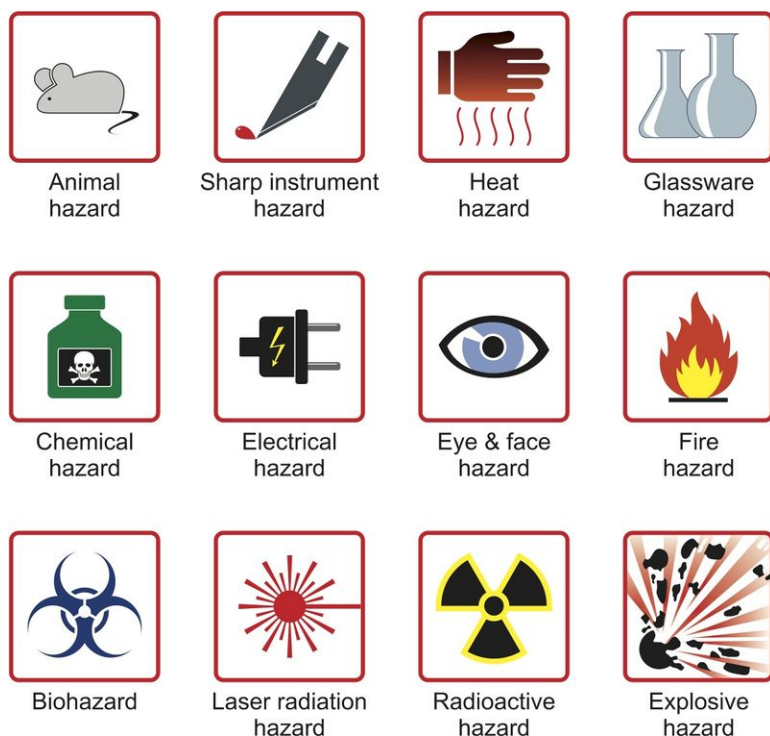


FIGURE 1.1

- Wear long sleeves and shoes that completely cover your feet.
- If your hair is long, tie it back or cover it with a hair net.
- Protect your eyes, skin, and clothing by wearing safety goggles, an apron, and gloves.
- Use hot mitts to handle hot objects.
- Never work in the lab alone.
- Never engage in horseplay in the lab.
- Never eat or drink in the lab.
- Never do experiments without your teacher's approval.
- Always add acid to water, never the other way around, and add the acid slowly to avoid splashing.
- Take care to avoid knocking over Bunsen burners, and keep them away from flammable materials such as paper.
- Use your hand to fan vapors toward your nose rather than smelling substances directly.
- Never point the open end of a test tube toward anyone—including yourself!
- Clean up any spills immediately.
- Dispose of lab wastes according to your teacher's instructions.
- Wash glassware and counters when you finish your work.
- Wash your hands with soap and water before leaving the lab.

In Case of Accident

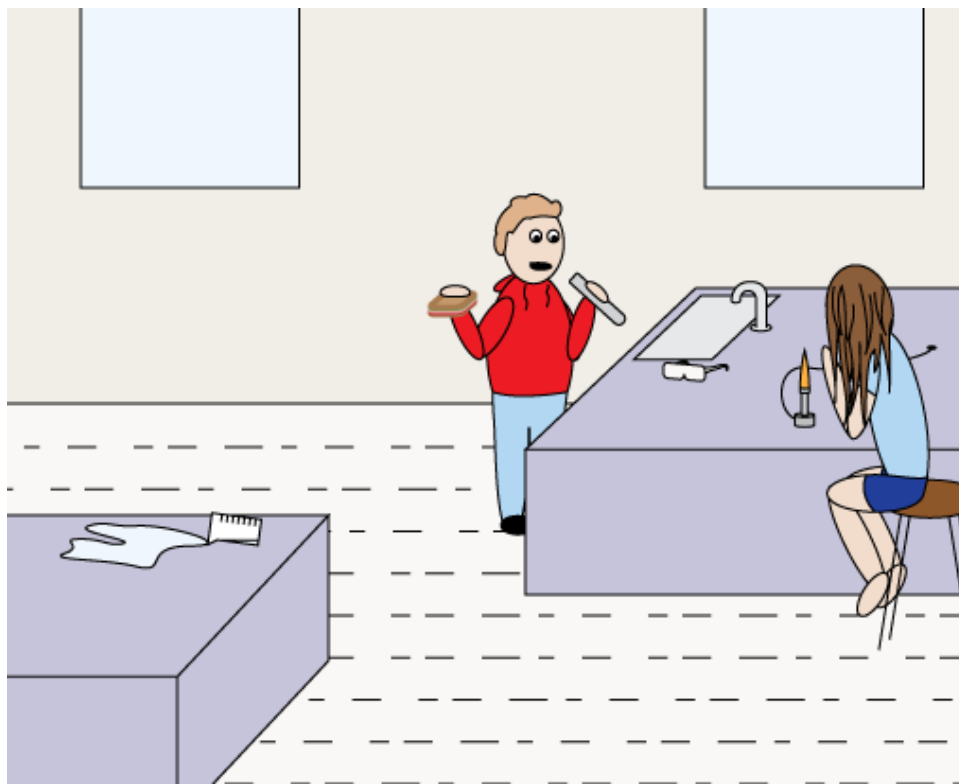
Even when you follow the rules, accidents can happen. Immediately alert your teacher if an accident occurs. Report all accidents, whether or not you think they are serious.

Summary

- Lab safety symbols warn of specific hazards, such as flames or broken glass. Knowing the symbols allows you to recognize and avoid the dangers.
- Following basic safety rules, such as wearing safety gear, helps prevent accidents in the lab and in the field.
- All accidents should be reported immediately.

Practice

Examine this sketch of students working in a lab, and then answer the question below.



1. These students are breaking at least six lab safety rules. What are they doing that is unsafe?

Review

1. What hazard do you think this safety (**Figure 1.2**) symbol represents?
2. Identify three safety rules that help prevent accidents in the lab.
3. Create a safety poster to convey one of the three rules you listed in your answer to 2.

References

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FIGURE 1.2

Safety symbol.

CHAPTER

2

Scientific Process

- State the role of investigations in science.
- Outline the steps of the scientific method.



Do you think that the man in this photo is a real scientist? In science fiction, scientists may be portrayed as wild-eyed and zany, randomly mixing chemicals in a lab. But that portrayal couldn't be farther from the truth. Real scientists are disciplined professionals, and scientific investigations are very organized and methodical.

Investigations in Science

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

Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and questions. However, most scientists follow the general steps outlined in the **Figure 2.1**. This approach is sometimes called the scientific method. Keep in mind that the scientific method is a general approach and not a strict sequence of steps. For example, scientists may follow the steps in a different order. Or they may skip or repeat some of the steps.

Using the Scientific Method: a Simple Example

A simple example will help you understand how the scientific method works. While Cody (**Figure 2.2**) eats a bowl of cereal, he reads the ingredients list on the cereal box. He notices that the cereal contains iron. Cody is studying

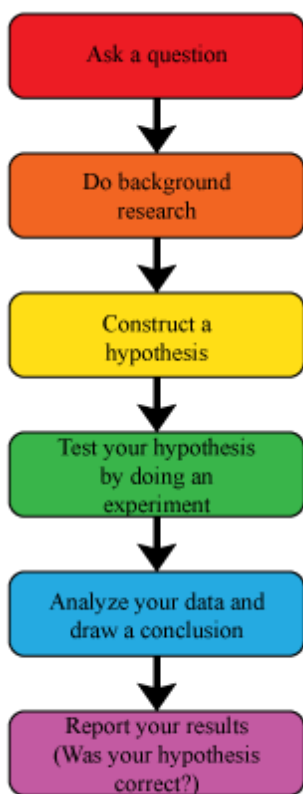


 FIGURE 2.1

magnets in school and knows that magnets attract objects that contain iron. He wonders whether there is enough iron in a flake of the cereal for it to be attracted by a strong magnet. He thinks that the iron content is probably too low for this to happen, even if he uses a strong magnet.



 FIGURE 2.2

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

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

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

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

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

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

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

A: He should report his results to other scientists.

Summary

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

Practice

Read the procedure for the “Money in a Blender” investigation at the following URL. Then answer the questions below. With your teacher's or parent's approval, try the activity yourself.

<http://www.stevespanglerscience.com/experiment/00000126>

1. What research question is addressed by the investigation? What hypothesis does the investigation test?
2. Describe the evidence you would observe if you followed the procedure in the investigation.
3. What would you conclude about the hypothesis from your evidence?

Review

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

References

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CHAPTER 3

Types of Matter

Lesson Objectives

- Describe elements and atoms.
- Describe compounds, molecules, and crystals.
- Define mixture, and identify types of mixtures.

Vocabulary

- atom
- colloid
- compound
- crystal
- element
- mixture
- molecule
- solution
- suspension

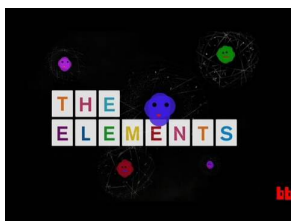
Introduction

The properties of matter, both physical and chemical, depend on the substances that matter is made of. Matter can exist either as a pure substance or as a combination of different substances.

Elements

An **element** is a pure substance. It cannot be separated into any other substances. There are more than 90 different elements that occur in nature. Some are much more common than others. Hydrogen is the most common element in the universe. Oxygen is the most common element in Earth's crust. **Figure 3.1** shows other examples of elements. Still others are described in the video below.

<http://www.youtube.com/watch?v=d0zION8xjbM> (3:47)



MEDIA

Click image to the left for more content.



Helium

Helium is a gas that is lighter than air. That's why it is used in balloons.



Carbon

Carbon has the ability to combine with many other elements as well as with itself. It can form many different substances. It is the most common element in living things.



Neon

Neon is a gas that gives off a reddish orange glow when electricity flows through it. It is used in colored lights and signs.



Iron

Iron is a metal that is very hard and strong. It is the main component of steel.

FIGURE 3.1

Each of the elements described here has different uses because of its properties.

Properties of Elements

Each element has a unique set of properties that make it different from all other elements. As a result, elements can be identified by their properties. For example, the elements iron and nickel are both metals that are good conductors of heat and electricity. However, iron is attracted by a magnet, whereas nickel is not. How could you use this property to separate iron objects from nickel objects?

History of Elements

The idea of elements is not new. It dates back about 2500 years to ancient Greece. The ancient Greek philosopher Aristotle thought that all matter consists of just four elements. He identified the elements as earth, air, water, and fire. He thought that different kinds of matter contain only these four elements but in different combinations.

Aristotle's ideas about elements were accepted for the next 2000 years. Then, scientists started discovering the many unique substances we call elements today. You can read when and how each of the elements was discovered at the link below. Scientists soon realized that there are far more than just four elements. Eventually, they discovered a total of 92 naturally occurring elements. <http://www.nndc.bnl.gov/content/origindc.pdf>

Elements and Atoms

The smallest particle of an element that still has the element's properties is an **atom**. All the atoms of an element are alike, and they are different from the atoms of all other elements. For example, atoms of gold are the same whether they are found in a gold nugget or a gold ring (see **Figure 3.2**). All gold atoms have the same structure and

properties.



FIGURE 3.2

Gold is gold no matter where it is found because all gold atoms are alike.

Compounds

There are millions of different substances in the world. That's because elements can combine in many different ways to form new substances. In fact, most elements are found in compounds. A **compound** is a unique substance that forms when two or more elements combine chemically. An example is water, which forms when hydrogen and oxygen combine chemically. A compound always has the same components in the same proportions. It also has the same composition throughout. You can learn more about compounds and how they form by watching this video: <http://www.youtube.com/watch?v=-HjMoTthEZ0&feature=related> (3:53).



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Properties of Compounds

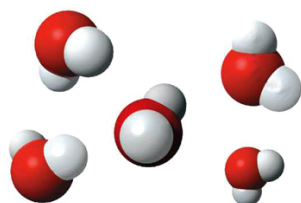
A compound has different properties than the substances it contains. For example, hydrogen and oxygen are gases at room temperature. But when they combine chemically, they form liquid water. Another example is table salt, or sodium chloride. It contains sodium and chlorine. Sodium is a silvery solid that reacts explosively with water, and chlorine is a poisonous gas (see **Figure 3.3**). But together, sodium and chlorine form a harmless, unreactive compound that you can safely sprinkle on food.

Molecules and Crystals

The smallest particle of a compound that still has the compound's properties is a **molecule**. A molecule consists of two or more atoms that are joined together. For example, a molecule of water consists of two hydrogen atoms joined to one oxygen atom (see **Figure 3.4**). You can learn more about molecules at this link: <http://www.nyhallsci.org/marvelousmolecules/marveloussub.html>.

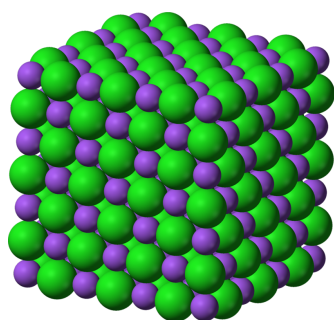
**FIGURE 3.3**

Table salt is much different than its components. What are some of its properties?

**FIGURE 3.4**

Water is a compound that forms molecules. Each water molecule consists of two atoms of hydrogen (white) and one atom of oxygen (red).

Some compounds form crystals instead of molecules. A **crystal** is a rigid, lattice-like framework of many atoms bonded together. Table salt is an example of a compound that forms crystals (see **Figure 3.5**). Its crystals are made up of many sodium and chloride ions. Ions are electrically charged forms of atoms. You can actually watch crystals forming in this video: <http://www.youtube.com/watch?v=Jd9C40Svt5g&feature=related>.

**FIGURE 3.5**

A crystal of table salt has a regular, repeating pattern of ions.

Mixtures

Not all combined substances are compounds. Some are mixtures. A **mixture** is a combination of two or more substances in any proportion. The substances in a mixture may be elements or compounds. The substances don't

combine chemically to form a new substance, as they do in a compound. Instead, they keep their original properties and just intermix. Examples of mixtures include salt and water in the ocean and gases in the atmosphere. Other examples are pictured in **Figure 3.6**.



This lemonade is mixture of water, lemon juice, and sugar.



This rock is a mixture of smaller rocks and minerals.



This salad dressing is a mixture of olive oil, vinegar, herbs, and spices.



This package contains a mixture of seeds of several types of wildflowers.

FIGURE 3.6

All these substances are mixtures. How do they differ from compounds?

Homogeneous and Heterogeneous Mixtures

Some mixtures are homogeneous. This means they have the same composition throughout. An example is salt water in the ocean. Ocean water everywhere is about 3.5 percent salt.

Some mixtures are heterogeneous. This means they vary in their composition. An example is trail mix. No two samples of trail mix, even from the same package, are likely to be exactly the same. One sample might have more raisins, another might have more nuts.

Particle Size in Mixtures

Mixtures have different properties depending on the size of their particles. Three types of mixtures based on particle size are described below. **Figure 3.7** shows examples of each type. You can watch videos about the three types of mixtures at these links:

<http://www.youtube.com/watch?v=q96ljVMHYLo> (4:35)



MEDIA

Click image to the left for more content.

<http://www.youtube.com/watch?v=96OOIL6atXs&feature=related> (6:13)

Distinguishing Between Solutions and Mechanical Mixtures		
	Solutions	Mechanical Mixtures
Are the parts evenly mixed?	YES	NO
Can you see the separate parts (w/filter)?	NO	YES
Do particles fall to the bottom?	NO	YES
Can you see clearly through this mixture?	YES	

MEDIA

Click image to the left for more content.

- A **solution** is a homogeneous mixture with tiny particles. An example is salt water. The particles of a solution are too small to reflect light. As a result, you cannot see them. That's why salt water looks the same as pure water. The particles of solutions are also too small to settle or be filtered out of the mixture.
- A **suspension** is a heterogeneous mixture with large particles. An example is muddy water. The particles of a suspension are big enough to reflect light, so you can see them. They are also big enough to settle or be filtered out. Anything that you have to shake before using, such as salad dressing, is usually a suspension.
- A **colloid** is a homogeneous mixture with medium-sized particles. Examples include homogenized milk and gelatin. The particles of a colloid are large enough to reflect light, so you can see them. But they are too small to settle or filter out of the mixture.



FIGURE 3.7

These three mixtures differ in the size of their particles. Which mixture has the largest particles? Which has the smallest particles?

Separating Mixtures

The components of a mixture keep their own identity when they combine. Therefore, they usually can be easily separated again. Their different physical properties are used to separate them. For example, oil is less dense than water, so a mixture of oil and water can be separated by letting it stand until the oil floats to the top. Other ways of separating mixtures are shown in **Figure 3.8** and in the videos below.

- http://www.youtube.com/watch?v=jWdu_RVy5_A (2:30)

**MEDIA**

Click image to the left for more content.

- <http://www.youtube.com/watch?v=UsouAIL-YZU&NR=1> (2:41)

**MEDIA**

Click image to the left for more content.



The sun heats salt water in this lake. This causes some of the water to evaporate, leaving the salt behind.



A coffee filter lets water but not coffee grounds pass through into the pot below.



A magnet can be used to separate iron filings from sand. Can you explain why?

FIGURE 3.8

Separating the components of a mixture depends on their physical properties. Which physical property is used in each example shown here?

Lesson Summary

- Elements are pure substances with unique properties. There are more than 100 different elements (92 of which occur naturally). The smallest particles of elements are atoms.
- Compounds are unique substances that form when two or more elements combine chemically. The smallest particles of compounds are molecules. Some compounds form crystals instead.

Lesson Review Questions

Recall

1. What is an element? Give three examples.
2. Describe compounds.
3. Identify molecules and crystals.
4. What are mixtures?

Apply Concepts

5. How could you use water and a coffee filter to separate a mixture of salt and sand?
6. Homogenized milk is a colloid. It has been treated to prevent its different components from separating when it stands. When non-homogenized milk stands, the cream rises to the top because it is less dense than the rest of the milk. Which type of mixture is non-homogenized milk? Explain your answer.

Think Critically

7. Create a table comparing and contrasting compounds and mixtures. Include an example of each.
8. How are atoms related to molecules?

Points to Consider

The properties of matter are not fixed. In fact, matter is always changing.

- What are some ways you have seen matter change?
- What do you think caused the changes?

References

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CHAPTER

4

Inside the Atom

Lesson Objectives

- Compare and contrast protons, neutrons, and electrons.
- Describe the forces that hold the particles of atoms together.
- Define atomic number and mass number.
- Describe ions and isotopes
- Identify the particles called quarks.

Vocabulary

- atomic mass unit (amu)
- atomic number
- electron
- ion
- isotope
- mass number
- neutron
- nucleus
- proton
- quark

Introduction

Atoms are the smallest particles of an element that still have the element's properties. They are the building blocks of all matter. Individual atoms are extremely small. In fact, they are so small that trillions of them would fit inside the period at the end of this sentence. Yet atoms, in turn, consist of even smaller particles.

Parts of the Atom

Figure 4.1 represents a simple model of an atom. You will learn about more complex models in later lessons, but this model is a good place to start. You can see similar, animated models of atoms at this URL: <http://web.jjay.cuny.edu/acarpi/NSC/3-atoms.htm>.

The Nucleus

At the center of an atom is the **nucleus** (plural, nuclei). The nucleus contains most of the atom's mass. However, in size, it's just a tiny part of the atom. The model in **Figure 4.1** is not to scale. If an atom were the size of a football stadium, the nucleus would be only about the size of a pea.

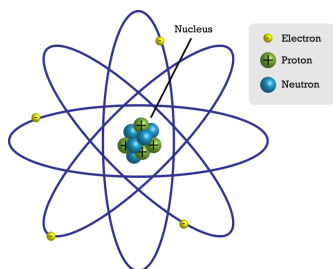


FIGURE 4.1

This simple atomic model shows the particles inside the atom.

The nucleus, in turn, consists of two types of particles, called protons and neutrons. These particles are tightly packed inside the nucleus. Constantly moving about the nucleus are other particles called electrons. You can see a video about all three types of atomic particles at this URL: <http://www.youtube.com/watch?v=IP57gEWcisY> (1:57).

Protons

A **proton** is a particle in the nucleus of an atom that has a positive electric charge. All protons are identical. It is the number of protons that gives atoms of different elements their unique properties. Atoms of each type of element have a characteristic number of protons. For example, each atom of carbon has six protons, as you can see in **Figure 4.2**. No two elements have atoms with the same number of protons.

Neutrons

A **neutron** is a particle in the nucleus of an atom that has no electric charge. Atoms of an element often have the same number of neutrons as protons. For example, most carbon atoms have six neutrons as well as six protons. This is also shown in **Figure 4.2**.

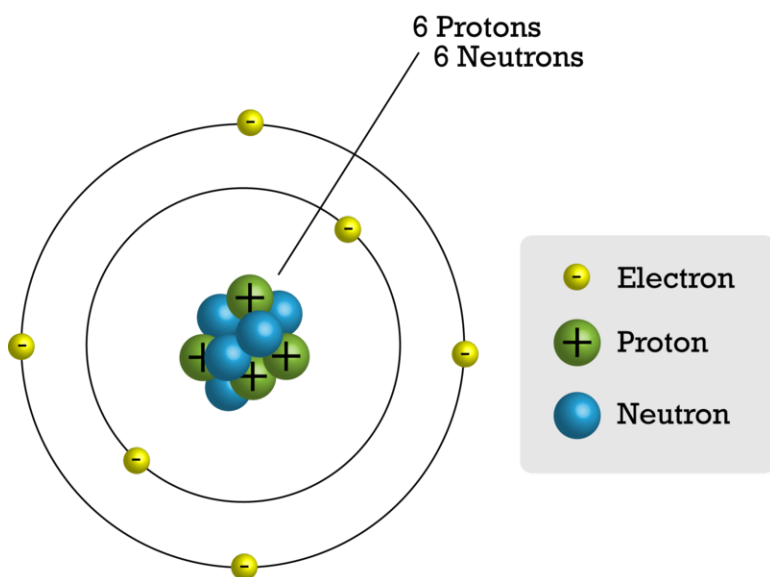


FIGURE 4.2

This model shows the particles that make up a carbon atom.

Electrons

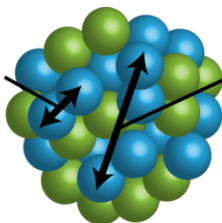
An **electron** is a particle outside the nucleus of an atom that has a negative electric charge. The charge of an electron is opposite but equal to the charge of a proton. Atoms have the same number of electrons as protons. As a result, the negative and positive charges "cancel out." This makes atoms electrically neutral. For example, a carbon atom has six electrons that "cancel out" its six protons.

Atomic Forces

When it comes to atomic particles, opposites attract. Negative electrons are attracted to positive protons. This force of attraction keeps the electrons moving about the nucleus. An analogy is the way planets orbit the sun.

What about particles with the same charge, such as protons in the nucleus? They push apart, or repel, each other. So why doesn't the nucleus fly apart? The reason is a force of attraction between protons and neutrons called the strong force. The name of the strong force suits it. It is stronger than the electric force pushing protons apart. However, the strong force affects only nearby particles (see **Figure 4.3**). It is not effective if the nucleus gets too big. This puts an upper limit on the number of protons an atom can have and remain stable. You can learn more about atomic forces in the colorful tutorial at this URL: http://www.ric.edu/faculty/ptiskus/Atomic_Force/.

The strong force affects particles that are near each other.



The strong force doesn't extend to particles that are distant.

FIGURE 4.3

The strong force is effective only between particles that are very close together in the nucleus.

Atomic Number and Mass Number

Electrons have almost no mass. Instead, almost all the mass of an atom is in its protons and neutrons in the nucleus. The nucleus is very small, but it is densely packed with matter. The SI unit for the mass of an atom is the **atomic mass unit (amu)**. One atomic mass unit equals the mass of a proton, which is about 1.7×10^{-24} g. Each neutron also has a mass of 1 amu. Therefore, the sum of the protons and neutrons in an atom is about equal to the atom's total mass in atomic mass units.

Two numbers are commonly used to distinguish atoms: atomic number and mass number. **Figure 4.4** shows how these numbers are usually written.



FIGURE 4.4

The symbol He stands for the element helium. Can you infer how many electrons a helium atom has?

- The **atomic number** is the number of protons in an atom. This number is unique for atoms of each kind of element. For example, the atomic number of all helium atoms is 2.
- The **mass number** is the number of protons plus the number of neutrons in an atom. For example, most atoms of helium have 2 neutrons, so their mass number is $2 + 2 = 4$. This mass number means that an atom of helium has a mass of about 4 amu.

Problem Solving

Problem: An atom has an atomic number of 12 and a mass number of 24. How many protons and neutrons does the atom have?

Solution: The number of protons is the same as the atomic number, or 12. The number of neutrons is equal to the mass number minus the atomic number, or $24 - 12 = 12$.

You Try It!

Problem: An atom has an atomic number of 8 and a mass number of 16. How many neutrons does it have? What is the atom's mass in atomic mass units?

Ions and Isotopes

The number of protons per atom is always the same for a given element. However, the number of neutrons may vary, and the number of electrons can change.

Ions

Sometimes atoms lose or gain electrons. Then they become **ions**. Ions have a positive or negative charge. That's because they do not have the same number of electrons as protons. If atoms lose electrons, they become positive ions, or cations. If atoms gain electrons, they become negative ions, or anions.

Consider the example of fluorine in **Figure 4.5**. A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride ion with a negative charge of minus one.

Fluorine Atom (F) \longrightarrow Fluoride Ion (F⁻)

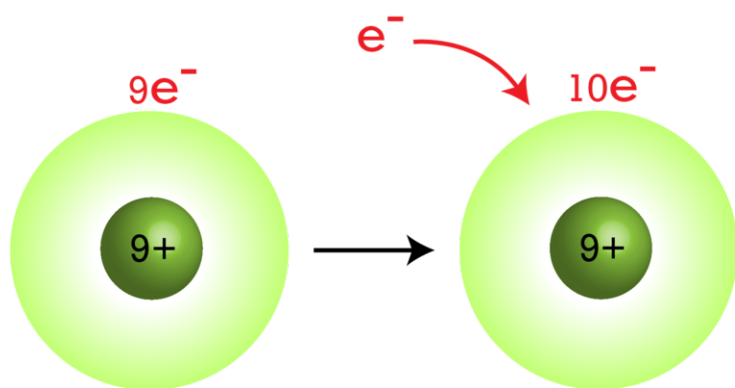
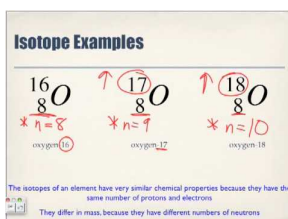


FIGURE 4.5

When a fluorine atom gains an electron, it becomes a negative fluoride ion.

Isotopes of Atoms

Some atoms of the same element may have different numbers of neutrons. For example, some carbon atoms have seven or eight neutrons instead of the usual six. Atoms of the same element that differ in number 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 chemical properties. That's because they have the same numbers of protons and electrons. For a video explanation of isotopes, go to this URL: <http://www.youtube.com/watch?v=6w7raarHNA8> (5:23).



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An Example: Hydrogen Isotopes

Hydrogen is a good example of isotopes because it has the simplest atoms. Three isotopes of hydrogen are modeled in **Figure 4.6**. Most hydrogen atoms have just one proton and one electron and lack a neutron. They are just called hydrogen. Some hydrogen atoms have one neutron. These atoms are the isotope named deuterium. Other hydrogen atoms have two neutrons. These atoms are the isotope named tritium.

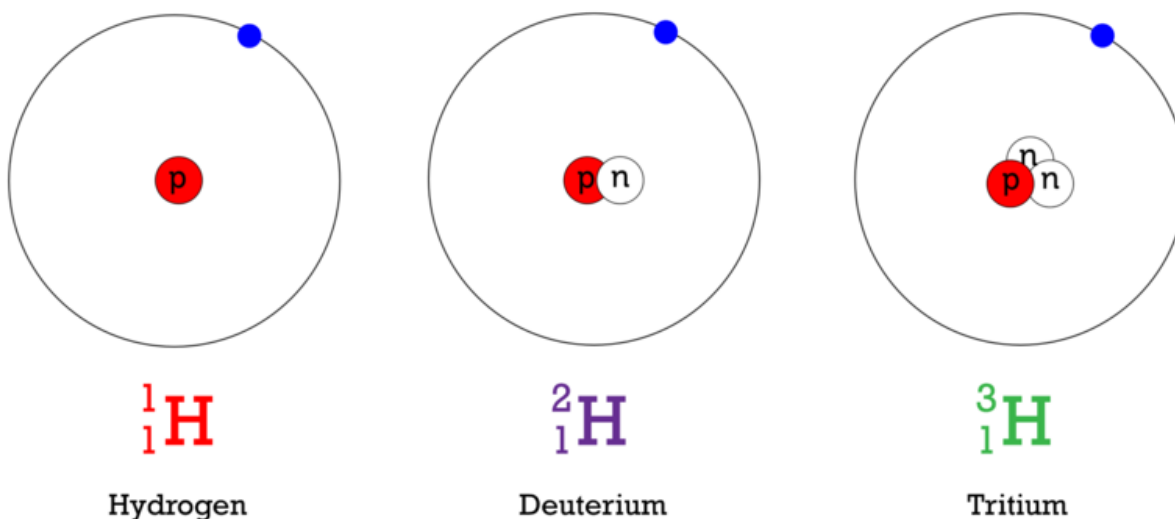


FIGURE 4.6

All isotopes of a given element have the same number of protons (P), but they differ in the number of neutrons (N). What is the mass number of each isotope shown here?

Naming Isotopes

For most other elements, 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. Some carbon atoms have 8 neutrons. What is the name of this isotope of carbon? You can learn more about this isotope at the URL below. It is used by scientists to estimate the ages of rocks and fossils.

<http://www.khanacademy.org/video/carbon-14-dating-1?playlist=Chemistry>

Back to Quarks

Remember the quarks from the first page of this chapter? **Quarks** are even tinier particles of matter that make up protons and neutrons. There are three quarks in each proton and three quarks in each neutron. The charges of quarks are balanced exactly right to give a positive charge to a proton and a neutral charge to a neutron. It might seem strange that quarks are never found alone but only as components of other particles. This is because the quarks are held together by very strange particles called gluons.

Gluons

Gluons make quarks attract each other more strongly the farther apart the quarks get. To understand how gluons work, imagine holding a rubber band between your fingers. If you try to move your hands apart, they will be pulled back together by the rubber band. The farther apart you move your hands, the stronger the force of the rubber band pulling your hands together. Gluons work the same way on quarks inside protons and neutrons (and other, really rare particles too).

If you were to move your hands apart with enough force, the rubber band holding them together would break. The same is true of quarks. If they are given enough energy, they pull apart with enough force to "break" the binding from the gluons. However, all the energy that is put into a particle to make this possible is then used to create a new set of quarks and gluons. And so a new proton or neutron appears.

Finding Quarks

The existence of quarks was first proposed in the 1960s. Since then, scientists have done experiments to show that quarks really do exist. In fact, they have identified six different types of quarks. However, much remains to be learned about these tiny, fundamental particles of matter. They are very difficult and expensive to study. If you want to learn more about them, including how they are studied, the URL below is a good place to start.

<http://www.particleadventure.org/index.html>

Lesson Summary

- The nucleus is at the center of the atom. It contains positive protons and neutral neutrons. Negative electrons constantly move about the nucleus.

- Atomic number is the number of protons in an atom. It is unique for the atoms of each element. Mass number is the number of protons plus neutrons in an atom. It is about equal to the mass of the atom in atomic mass units (amu).
- Negative electrons are attracted to positive protons, and this electric force keeps electrons moving about the nucleus. The force of attraction between protons and neutrons, called the strong force, holds the nucleus together.
- If atoms lose or gain electrons, they become positive or negative ions. Atoms of the same element that have different numbers of neutrons are called isotopes.
- Quarks are even tinier particles of matter that make up protons and neutrons. Scientists have identified six different types of quarks.

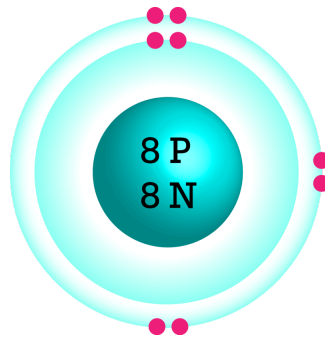
Lesson Review Questions

Recall

1. Describe the nucleus of an atom.
2. Outline the forces that hold particles together in an atom.
3. What does the atomic number of an atom represent?
4. Define isotope. Give an example.
5. What are quarks?

Apply Concepts

6. If an atom gains electrons, it becomes an ion. Is the ion positively or negatively charged? Explain your answer.
7. What is the atomic mass (in atomic mass units) of the atom represented by the model below?



Think Critically

8. Make a table comparing and contrasting protons, neutrons, and electrons. Include their location, mass, and electric charge.
9. Explain why atoms are neutral in electric charge.

Points to Consider

In this lesson, you saw several simple models of atoms. Models are useful for representing things that are very small. Scientists have used models to represent atoms for more than 200 years. In the next lesson, "History of the Atom,"

you'll read about some of the earlier models.

- How might scientists have modeled atoms before the particles inside atoms were discovered?
- How do you think earlier models might have differed from the models in this lesson?

References

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CHAPTER

5

Introduction to Chemical Bonds

Lesson Objectives

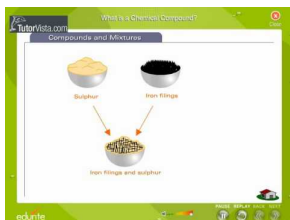
- Define chemical bond.
- List general properties of compounds.

Lesson Vocabulary

- chemical bond
- chemical formula

Introduction

There is an amazing diversity of matter in the universe, but there are only about 100 elements. How can this relatively small number of pure substances make up all kinds of matter? Elements can combine in many different ways. When they do, they form new substances called compounds. For a video introduction to compounds, go this URL: <http://www.youtube.com/watch?v=-HjMoTthEZ0&feature=related> (3:53).

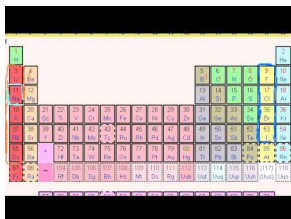


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Chemical Bonding

Elements form compounds when they combine chemically. Their atoms join together to form molecules, crystals, or other structures. The atoms are held together by chemical bonds. A **chemical bond** is a force of attraction between atoms or ions. It occurs when atoms share or transfer valence electrons. Valence electrons are the electrons in the outer energy level of an atom. You can learn more about chemical bonds in this video: <http://www.youtube.com/watch?v=CGA8sRwqIFg&NR=1> (13:21).



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Look at the example of water in **Figure 5.1**. A water molecule consists of two atoms of hydrogen and one atom of oxygen. Each hydrogen atom has just one electron. The oxygen atom has six valence electrons. In a water molecule, two hydrogen atoms share their two electrons with the six valence electrons of one oxygen atom. By sharing electrons, each atom has electrons available to fill its sole or outer energy level. This gives it a more stable arrangement of electrons that takes less energy to maintain.

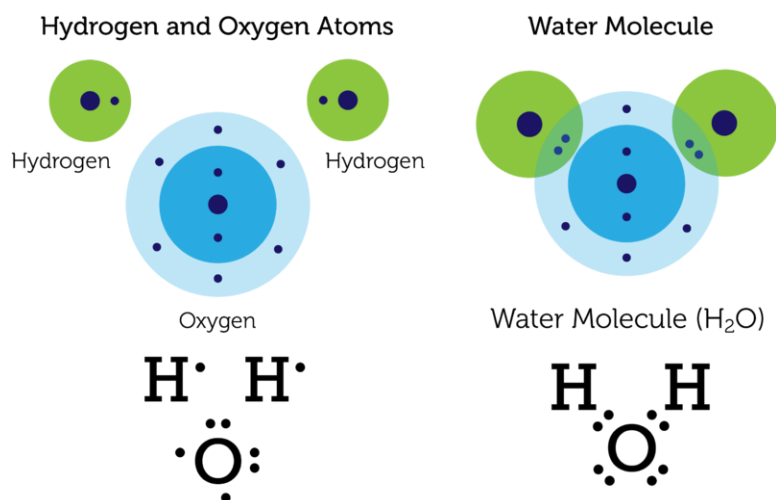


FIGURE 5.1

These diagrams show the valence electrons of hydrogen and water atoms and a water molecule. The diagrams represent electrons with dots, so they are called electron dot diagrams.

Chemical Compounds

Water (H₂O) is an example of a chemical compound. Water molecules always consist of two atoms of hydrogen and one atom of oxygen. Like water, all other chemical 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.

Chemical Formulas

Elements are represented by chemical symbols. Examples are H for hydrogen and O for oxygen. Compounds are represented by **chemical formulas**. You've already seen the chemical formula for water. It's H₂O. The subscript 2 after the H shows that there are two atoms of hydrogen in a molecule of water. The O for oxygen has no subscript. When there is just one atom of an element in a molecule, no subscript is used. **Table 5.1** shows some other examples of compounds and their chemical formulas.

TABLE 5.1: short caption

Name of Compound	Electron Dot Diagram	Numbers of Atoms	Chemical Formula
Hydrogen chloride	$\text{H}:\ddot{\text{Cl}}:$	H = 1 Cl = 1	HCl
Methane	$\begin{array}{c} \text{H} \\ \vdots \\ \text{H}:\text{C}:\text{H} \\ \vdots \\ \text{H} \end{array}$	C = 1 H = 4	CH ₄
Hydrogen peroxide	$\text{H}:\ddot{\text{O}}:\ddot{\text{O}}:\text{H}$	H = 2 O = 2	H ₂ O ₂
Carbon dioxide	$\ddot{\text{O}}::\text{C}::\ddot{\text{O}}$	C = 1 O = 2	CO ₂

Problem Solving

Problem: A molecule of ammonia consists of one atom of nitrogen (N) and three atoms of hydrogen (H). What is its chemical formula?

Solution: The chemical formula is NH₃.

You Try It!

Problem: A molecule of nitrogen dioxide consists of one atom of nitrogen (N) and two atoms of oxygen (O). What is its chemical formula?

Same Elements, Different Compounds

The same elements may combine in different ratios. If they do, they form different compounds. **Figure 5.2** shows some examples. Both water (H₂O) and hydrogen peroxide (H₂O₂) consist of hydrogen and oxygen. However, 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! Both carbon dioxide (CO₂) and carbon monoxide (CO) consist of carbon and oxygen, but in different ratios. How do their properties differ?

Types of Compounds

There are different types of compounds. They differ in the nature of the bonds that hold their atoms together. The type of bonds in a compound determines many of its properties. Three types of bonds are ionic, covalent, and metallic bonds. You will read about these three types in later lessons. You can also learn more about them by watching this video: <http://www.youtube.com/watch?v=hEFeLYWTKX0> (7:18).



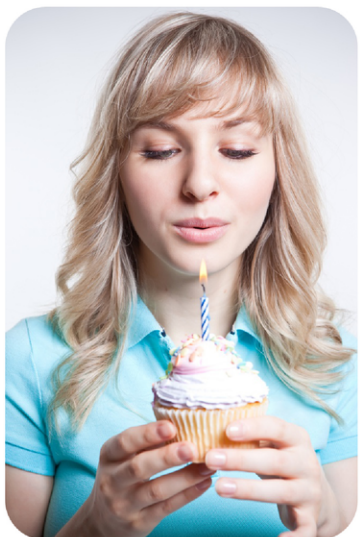
Water (H₂O)

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 (H₂O₂)

Hydrogen peroxide is also odorless and colorless. It's used as an antiseptic. It kills germs on cuts. It's also used as bleach. It removes color from hair.



Carbon Dioxide (CO₂)

Every time you exhale, you release carbon dioxide. It's an odorless, colorless gas. Carbon dioxide contributes to global climate change, but it isn't directly harmful to human health.

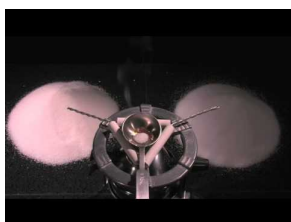


Carbon Monoxide (CO)

Carbon monoxide is produced when matter burns. It's an odorless, colorless gas that is very harmful to human health. In fact, it can kill people in minutes. You can't see or smell carbon monoxide. A carbon monoxide detector sounds an alarm if the level of the gas gets too high.

FIGURE 5.2

Different compounds may contain the same elements in different ratios. How does this affect their properties?



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Lesson Summary

- A chemical bond is a force of attraction between atoms. It occurs when atoms share or transfer electrons.
- A chemical compound is a new substance that forms when atoms of different elements form chemical bonds. A compound always consists of a fixed ratio of elements.

Lesson Review Questions

Recall

1. What is a chemical bond?
2. Define chemical compound.

Apply Concepts

3. Which atoms and how many of each make up a molecule of sulfur dioxide? Write the chemical formula for this compound.

Think Critically

4. Why does a molecule of water have a more stable arrangement of electrons than do individual hydrogen and oxygen atoms?
5. Explain how the ratio of elements in a compound is related to the compound's properties.

Points to Consider

In this lesson, you learned about chemical bonds in a water molecule. The bonds form between atoms of hydrogen and oxygen when they share electrons. This type of bond is an example of a covalent bond.

- What might be other ways that atoms can bond together?
- How might ions form bonds?

References

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CHAPTER 6

Changes in Matter

Lesson Objectives

- Define and give examples of physical changes in matter.
- Define and give examples of chemical changes in matter.
- State the law of conservation of mass.

Vocabulary

- chemical change
- law of conservation of mass
- physical change

Introduction

You hit a baseball out of the park and head for first base. You're excited. The score is tied, and now your team has a chance of getting a winning home run. Then you hear a crash. Oh no! The baseball hit a window in a neighboring house. The glass has a big hole in it, surrounded by a web of cracks (see **Figure 6.1**). The glass has changed. It's been broken into jagged pieces. But the glass is still glass. Breaking the window is an example of a physical change in matter.



FIGURE 6.1

When glass breaks, its physical properties change. Instead of one solid sheet of glass, it now has holes and cracks.

Physical Changes in Matter

A **physical change** in matter is a change in one or more of matter's physical properties. Glass breaking is just one example of a physical change. Some other examples are shown in **Figure 6.2** and in the video below. In each example, matter may look different after the change occurs, but it's still the same substance with the same chemical properties. For example, smaller pieces of wood have the ability to burn just as larger logs do.

<http://www.youtube.com/watch?v=Cne9ncSaN5c&feature=related> (1:53)

**FIGURE 6.2**

In each of these changes, only the physical properties of matter change. The chemical properties remain the same.

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Because the type of matter remains the same with physical changes, the changes are often easy to undo. For example, braided hair can be unbraided again. Melted chocolate can be put in a fridge to re-harden. Dissolving salt in water is also a physical change. How do you think you could undo it?

Chemical Changes in Matter

Did you ever make a "volcano," like the one in **Figure 6.3**, using baking soda and vinegar? What happens when the two substances combine? They produce an eruption of foamy bubbles. This happens because of a chemical change. A **chemical change** occurs when matter changes chemically into an entirely different substance with different chemical properties. When vinegar and baking soda combine, they form carbon dioxide, a gas that causes the bubbles. It's the same gas that gives soft drinks their fizz.

Not all chemical changes are as dramatic as this "volcano." Some are slower and less obvious. **Figure 6.4** and the video below show other examples of chemical changes.

<http://www.youtube.com/watch?v=BqeWpywDuiY> (2:54)

**FIGURE 6.3**

This girl is pouring vinegar on baking soda. This causes a bubbling "volcano."

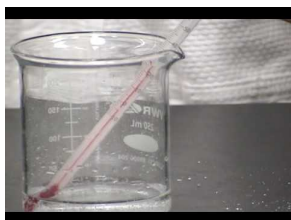
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Signs of Chemical Change

How can you tell whether a chemical change has occurred? Often, there are clues. Several are demonstrated in **Figures 6.3** and **6.4** and in the video below.

<http://www.youtube.com/watch?v=gs0j1EZJ1Uc> (9:57)

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To decide whether a chemical change has occurred, look for these signs:

- Gas bubbles are released. (Example: Baking soda and vinegar mix and produce bubbles.)
- Something changes color. (Example: Leaves turn from green to other colors.)
- An odor is produced. (Example: Logs burn and smell smoky.)
- A solid comes out of a solution. (Example: Eggs cook and a white solid comes out of the clear liquid part of the egg.)

**FIGURE 6.4**

These chemical changes all result in the formation of new substances with different chemical properties. Do you think any of these changes could be undone?

Reversing Chemical Changes

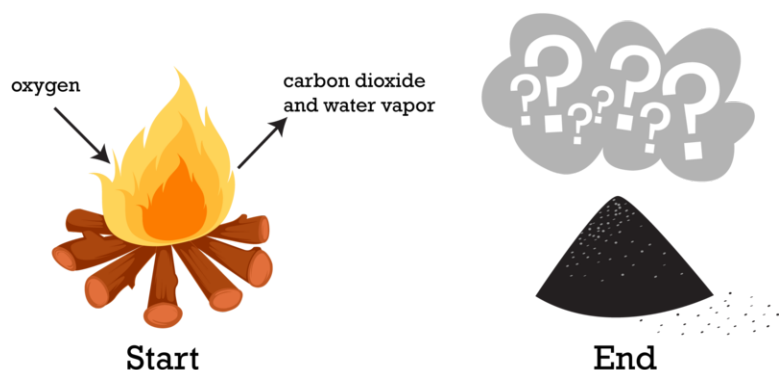
Because chemical changes produce new substances, they often cannot be undone. For example, you can't change a fried egg back to a raw egg. Some chemical changes can be reversed, but only by other chemical changes. For example, to undo the tarnish on copper pennies, you can place them in vinegar. The acid in the vinegar reacts with the tarnish. This is a chemical change that makes the pennies bright and shiny again. You can try this yourself at home to see how well it works.

Conservation of Mass

If you build a campfire, like the one in **Figure 6.5**, you start with a large stack of sticks and logs. As the fire burns, the stack slowly shrinks. By the end of the evening, all that's left is a small pile of ashes. What happened to the matter that you started with? Was it destroyed by the flames? It may seem that way, but in fact, the same amount of matter still exists. The wood changed not only to ashes but also to carbon dioxide, water vapor, and other gases. The gases floated off into the air, leaving behind just the ashes.

Assume you had measured the mass of the wood before you burned it. Assume you had also trapped the gases released by the burning wood and measured their mass and the mass of the ashes. What would you find? The ashes and gases combined have the same mass as the wood you started with.

This example illustrates the **law of conservation of mass**. The law states that matter cannot be created or destroyed. Even when matter goes through physical or chemical changes, the total mass of matter always remains the same. (In

**FIGURE 6.5**

Burning is a chemical process. Is mass destroyed when wood burns?

the chapter *Nuclear Chemistry*, you will learn about nuclear reactions, in which mass is converted into energy. But other than that, the law of conservation of mass holds.) For a fun challenge, try to apply the law of conservation of mass to a scene from a Harry Potter film at this link: <http://www.youtube.com/watch?v=3TsTOnNmkf8>.

Lesson Summary

- Physical changes are changes in the physical properties of matter but not in the makeup of matter. An example of a physical change is glass breaking.
- Chemical changes are changes in the makeup and chemical properties of matter. An example of a chemical change is wood burning.
- Matter cannot be created or destroyed even when it changes. This is the law of conservation of mass.

Lesson Review Questions

Recall

1. What is a physical change in matter?
2. What happens during a chemical change in matter?
3. State the law of conservation of mass.

Apply Concepts

4. When a plant grows, its mass increases over time. Does this mean that new matter is created? Why or why not?
5. Butter melts when you heat it in a pan on the stove. Is this a chemical change or a physical change? How can you tell?

Think Critically

6. Compare and contrast physical and chemical changes in matter. Give an example of each type of change.

Points to Consider

Some physical changes in matter are changes of state.

- What are the states of matter?
- What might cause matter to change state?

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CHAPTER

7

Introduction to Chemical Reactions

Lesson Objectives

- Describe how chemical reactions occur.
- List signs that a chemical reaction has occurred.

Lesson Vocabulary

- chemical reaction
- equilibrium
- product
- reactant

Introduction

No doubt you've seen changes like those pictured in **Figure 7.1**. What do all these changes have in common? They are all chemical changes in matter. In a chemical change, matter changes into a different substance with different properties. Chemical changes occur because of chemical reactions. You can see more examples of chemical changes at this URL: <http://www.youtube.com/watch?v=66kuhJkQCVM> (2:05).

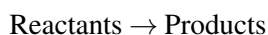


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What Is a Chemical Reaction?

A **chemical reaction** is a process in which some substances change into different substances. Substances that start a chemical reaction are called **reactants**. Substances that are produced in the reaction are called **products**. Reactants and products can be elements or compounds. A chemical reaction can be represented by this general equation:



Metal rusting



Candle burning



Bananas turning brown



Fire extinguisher foaming

**FIGURE 7.1**

Each of these pictures shows a chemical change taking place.

The arrow (\rightarrow) shows the direction in which the reaction occurs. The reaction may occur quickly or slowly. For example, foam shoots out of a fire extinguisher as soon as the lever is pressed. But it might take years for metal to rust.

Breaking and Reforming Chemical Bonds

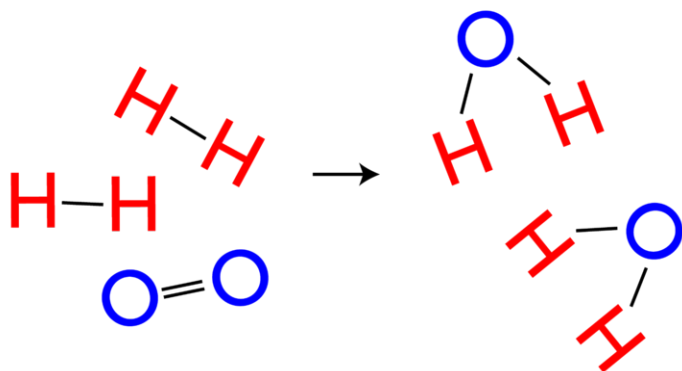
In chemical reactions, bonds break in the reactants and new bonds form in the products. The reactants and products contain the same atoms, but they are rearranged during the reaction. As a result, the atoms are in different combinations in the products than they were in the reactants.

Look at the example in **Figure 7.2**. It shows how water forms. Bonds break in molecules of hydrogen and oxygen. Then new bonds form in molecules of water. In both reactants and products, there are four hydrogen atoms and two oxygen atoms. But the atoms are combined differently in water. You can see another example at this URL: http://www.avogadro.co.uk/h_and_o/bondenthalpy/bondenthalpy.htm.

Reaction Direction and Equilibrium

The arrow in **Figure 7.2** shows that the reaction goes from left to right, from hydrogen and oxygen to water. The reaction can also go in the reverse direction. If an electric current passes through water, water molecules break down into molecules of hydrogen and oxygen. This reaction would be represented by a right-to-left arrow (\leftarrow) in **Figure 7.2**.

Many other reactions can also go in both forward and reverse directions. Often, a point is reached at which the forward and reverse reactions occur at the same rate. When this happens, there is no overall change in the amount of reactants and products. This point is called **equilibrium**, which refers to a balance between any opposing changes. You can see an animation of a chemical reaction reaching equilibrium at this URL: <http://www.tutorvista.com/content/chemistry/chemistry-ii/chemical-equilibrium/chemical-equilibrium-animation.php>.


FIGURE 7.2

A chemical reaction changes hydrogen and oxygen to water.

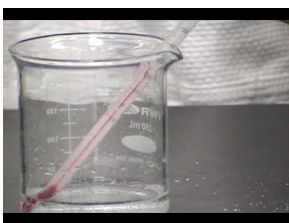
Evidence of Chemical Reactions

Not all changes in matter involve chemical reactions. For example, there are no chemical reactions involved in changes of state. When liquid water freezes or evaporates, it is still water. No bonds are broken and no new products are formed.

How can you tell whether a change in matter involves a chemical reaction? Often, there is evidence. Four common signs that a chemical reaction has occurred are:

- Change in color: the products are a different color than the reactants.
- Change in temperature: heat is released or absorbed during the reaction.
- Production of a gas: gas bubbles are released during the reaction.
- Production of a solid: a solid settles out of a liquid solution. The solid is called a precipitate.

You can see examples of each type of evidence in **Figure 7.3** and at this URL: <http://www.youtube.com/watch?v=s0j1EZJ1Uc> (9:57).



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Lesson Summary

- A chemical reaction is a process in which some substances change into different substances. In a chemical reaction, bonds break in reactants and new bonds form in products.
- Evidence that a chemical reaction has occurred include a change in color, a change in temperature, the production of a gas, or the formation of a precipitate.



Change in color
Bleaching hair changes its color.



Change in temperature
Burning wood produces heat.



Production of a gas
Dissolving an antacid tablet in water produces gas bubbles.



Production of a solid
Adding acid to milk produces solid curds of cottage cheese.

FIGURE 7.3

Can you think of other examples of changes like these? If so, they probably indicate that a chemical reaction has occurred.

Lesson Review Questions

Recall

1. Define chemical reaction.
2. What are the reactants and products in a chemical reaction?
3. Describe what happens to the atoms involved in a chemical reaction.
4. List four common signs that a chemical reaction has occurred.

Apply Concepts

5. Tina made a "volcano" by pouring vinegar over a "mountain" of baking soda. The wet baking soda bubbled and foamed. Did a chemical reaction occur? How do you know?

Think Critically

6. Explain the meaning of the term "equilibrium" as it applies to a chemical reaction. How can you tell when a chemical reaction has reached equilibrium?

Points to Consider

In **Figure 7.2**, you saw how hydrogen and oxygen combine chemically to form water.

- How could you use chemical symbols and formulas to represent this reaction?
- How many molecules of hydrogen and oxygen are involved in this reaction? How many molecules of water are produced? How could you include these numbers in your representation of the reaction?

References

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CHAPTER 8

Materials Humans Use

- Identify resources commonly used by humans.



What resources are in those electronics?

When you pick up your personal electronics device or your mobile phone do you ever think about what's in it? A tremendous variety of elements are needed to make a single electronic device. Some are rare, some are common. All must somehow come from Earth or its environment.

Natural Resources

A **natural resource** is anything in nature that humans need. Metals and fossil fuels are natural resources. But so are water, sunlight, soil, and wind. Even living things are natural resources.

Using Natural Resources

We need natural resources for just about everything we do. We need them for food and clothing, for building materials, and energy. We even need them to have fun. Listed below are examples of how we use natural resources (**Table 8.1**). Can you think of other ways we use natural resources?

TABLE 8.1: short caption

Use
Vehicles



Resources
Rubber for tires from rubber trees
Steel frames and other metal parts from minerals such as iron

Example
iron ore



Electronics



Plastic cases from petroleum products
Glass screens from minerals such as lead

lead ore



Homes



Nails from minerals such as iron
Timber from trees

spruce timber



Jewelry



Gemstones such as diamonds
Minerals such as silver

silver ore



Food



Sunlight, water, and soil
Minerals such as phosphorus

corn seeds in soil



Clothing



Wool from sheep
Cotton from cotton plants

cotton plants



TABLE 8.1: (continued)**Use**

Recreation

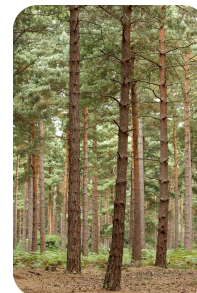
**Resources**

Water for boating and swimming

Forests for hiking and camping

Example

pine forest



Some natural resources are renewable. Others are non renewable. It depends on what they are and how we use them.

Vocabulary

- **natural resource:** Useful material that is found in nature.

Summary

- Many objects, such as a car, contain many types of resources.
- Resources may be renewable or nonrenewable, and an object may contain some of each.
- Rare earth elements and other unusual materials are used in some electronic devices.

Practice

Use the resource below to answer the questions that follow.

- <http://www.bbc.co.uk/news/world-asia-pacific-13777439>

1. What products require rare earth elements?
2. What is neodymium used for?
3. What is lanthanum used for?
4. What is praseodymium used for?
5. What is cerium used to produce?
6. What is gadolinium used in?
7. What country controls 97% of the rare earth elements?
8. What is the largest rare earth mine in the world?
9. Why are rare earth elements difficult to extract?
10. What type of mines are used to extract rare earth elements?
11. How many tons of rare earth elements did China export in 2010?
12. Why is China now limiting their exports?

Review

1. What are natural resources?

2. Is clean air a natural resource? Why or why not?
3. What natural resources are important to you?

CHAPTER 9 Solids, Liquids, Gases, and Plasmas

Lesson Objectives

- Describe matter in the solid state.
- State properties of liquid matter
- Identify properties of gases.
- Describe plasma.
- Explain the relationship between energy and states of matter.

Vocabulary

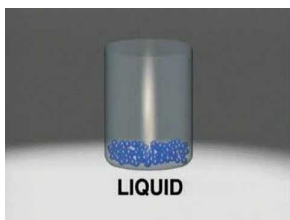
- energy
- gas
- kinetic energy
- kinetic theory of matter
- liquid
- plasma
- solid
- states of matter

Introduction

States of matter are the different forms in which matter can exist. Look at **Figure 9.1**. It represents water in three states: solid (iceberg), liquid (ocean water), and gas (water vapor in the air). In all three states, water is still water. It has the same chemical makeup and the same chemical properties. That's because the state of matter is a physical property.

How do solids, liquids, and gases differ? Their properties are compared in **Figure 9.2** and described below. You can also watch videos about the three states at these URLs:

<http://www.youtube.com/watch?v=s-KvoVzukHo&feature=related> (0:52)



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<http://www.youtube.com/watch?v=NO9OGeHgtBY&feature=related> (1:42)



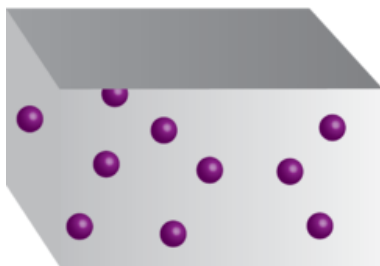
FIGURE 9.1

This photo represents solid, liquid, and gaseous water. Where is the gaseous water in the picture?



MEDIA

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Gas

Shape of container
Volume of container



Liquid

Shape of container
Free surface
Fixed volume



Solid

Holds shape
Fixed volume

FIGURE 9.2

These three states of matter are common on Earth. What are some substances that usually exist in each of these states?

Solids

Ice is an example of solid matter. A **solid** is matter that has a fixed volume and a fixed shape. **Figure 9.3** shows examples of matter that are usually solids under Earth conditions. In the figure, salt and cellulose are examples of crystalline solids. The particles of crystalline solids are arranged in a regular repeating pattern. The steaks and candle wax are examples of amorphous ("shapeless") solids. Their particles have no definite pattern.



FIGURE 9.3

The volume and shape of a solid can be changed, but only with outside help. How could you change the volume and shape of each of the solids in the figure without changing the solid in any other way?

Liquids

Ocean water is an example of a liquid. A **liquid** is matter that has a fixed volume but not a fixed shape. Instead, a liquid takes the shape of its container. If the volume of a liquid is less than the volume of its container, the top surface will be exposed to the air, like the oil in the bottles in **Figure 9.4**.



FIGURE 9.4

Each bottle contains the same volume of oil. How would you describe the shape of the oil in each bottle?

Two interesting properties of liquids are surface tension and viscosity.

- Surface tension is a force that pulls particles at the exposed surface of a liquid toward other liquid particles. Surface tension explains why water forms droplets, like those in **Figure 9.5**.
- Viscosity is a liquid's resistance to flowing. Thicker liquids are more viscous than thinner liquids. For example, the honey in **Figure 9.5** is more viscous than the vinegar.

Rain forms large drops on the hood of a car because of surface tension.



Honey (left) has greater viscosity than vinegar (right).



FIGURE 9.5

These images illustrate surface tension and viscosity of liquids.

You can learn more about surface tension and viscosity at these URLs:

- <http://io9.com/5668221/an-experiment-with-soap-water-pepper-and-surface-tension>
- <http://chemed.chem.wisc.edu/chempaths/GenChem-Textbook/Viscosity-840.html>
- <http://www.youtube.com/watch?v=u5AxIJSiEEs> (1:40)



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Click image to the left for more content.

Gases

Water vapor is an example of a gas. A **gas** is matter that has neither a fixed volume nor a fixed shape. Instead, a gas takes both the volume and the shape of its container. It spreads out to take up all available space. You can see an example in **Figure 9.6**.

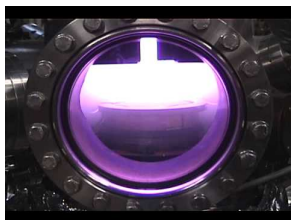
**FIGURE 9.6**

When you add air to a bicycle tire, you add it only through one tiny opening. But the air immediately spreads out to fill the whole tire.

Plasmas

You're probably less familiar with plasmas than with solids, liquids, and gases. Yet, most of the universe consists of plasma. **Plasma** is a state of matter that resembles a gas but has certain properties that a gas does not have. Like a gas, plasma lacks a fixed volume and shape. Unlike a gas, plasma can conduct electricity and respond to magnetism. That's because plasma contains charged particles called ions. This gives plasma other interesting properties. For example, it glows with light.

Where can you find plasmas? Two examples are shown in **Figure 9.7**. The sun and other stars consist of plasma. Plasmas are also found naturally in lightning and the polar auroras (northern and southern lights). Artificial plasmas are found in fluorescent lights, plasma TV screens, and plasma balls like the one that opened this chapter. You can learn more about plasmas at this URL: http://www.youtube.com/watch?v=VkeSI_B5Ljc (2:58).

**MEDIA**

Click image to the left for more content.



Northern Lights



Plasma TV

FIGURE 9.7

Both the northern lights (aurora borealis) and a plasma TV contain matter in the plasma state. What other plasmas are shown in the northern lights picture?

Energy and Matter

Why do different states of matter have different properties? It's because of differences in energy at the level of atoms and molecules, the tiny particles that make up matter.

Energy

Energy is defined as the ability to cause changes in matter. You can change energy from one form to another when you lift your arm or take a step. In each case, energy is used to move matter — you. The energy of moving matter is called **kinetic energy**.

Kinetic Theory of Matter

The particles that make up matter are also constantly moving. They have kinetic energy. The theory that all matter consists of constantly moving particles is called the **kinetic theory of matter**. You can learn more about it at the URL below.

http://www.youtube.com/watch?v=Agk7_D4-deY (10:55)

Energy and States of Matter

Particles of matter of the same substance, such as the same element, are attracted to one another. The force of attraction tends to pull the particles closer together. The particles need a lot of kinetic energy to overcome the force of attraction and move apart. It's like a tug of war between opposing forces. The kinetic energy of individual particles is on one side, and the force of attraction between different particles is on the other side. The outcome of the "war" depends on the state of matter. This is illustrated in **Figure 9.8** and in the animation at this URL: <http://www.tutorvista.com/content/physics/physics-i/heat/kinetic-molecular-theory.php>.

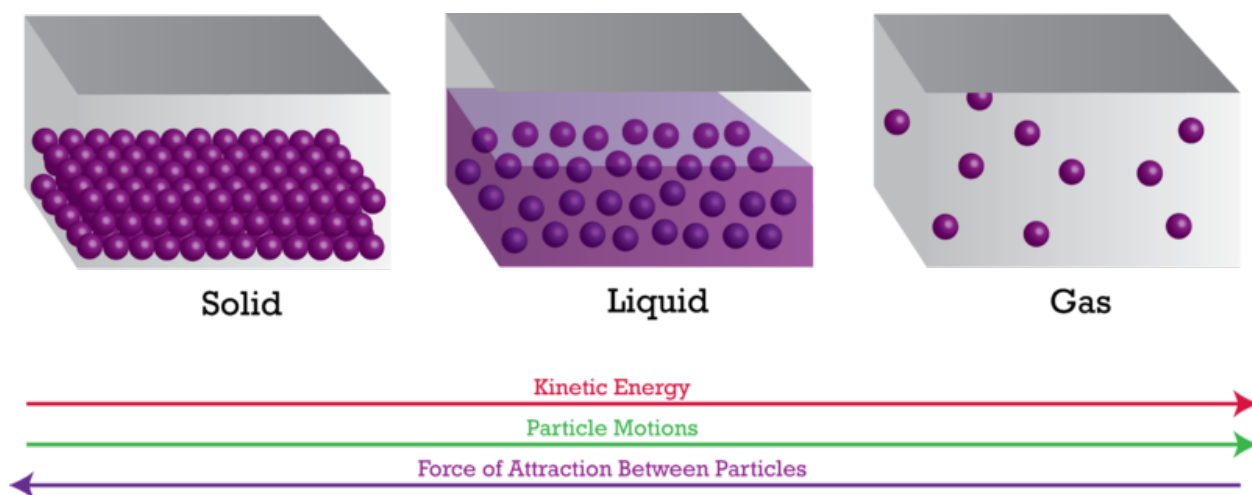


FIGURE 9.8

Kinetic energy is needed to overcome the force of attraction between particles of the same substance.

- In solids, particles don't have enough kinetic energy to overcome the force of attraction between them. The particles are packed closely together and cannot move around. All they can do is vibrate. This explains why solids have a fixed volume and shape.
- In liquids, particles have enough kinetic energy to partly overcome the force of attraction between them. They can slide past one another but not pull completely apart. This explains why liquids can change shape but have a fixed volume.
- In gases, particles have a lot of kinetic energy. They can completely overcome the force of attraction between them and move apart. This explains why gases have neither a fixed volume nor a fixed shape.

Lesson Summary

- A solid is matter that has a fixed volume and a fixed shape.
- A liquid is matter that has a fixed volume but not a fixed shape.
- A gas is matter that has neither a fixed volume nor a fixed shape.
- Like a gas, plasma lacks a fixed volume and shape. Unlike a gas, it can conduct electricity and respond to magnetism.
- The state of matter depends on the kinetic energy of the particles of matter.

Lesson Review Questions

Recall

1. What are states of matter?
2. What are the properties of solids?
3. State the properties of liquids.
4. Describe properties of gases.
5. How do plasmas compare with gases?

Apply Concepts

6. Apply the concept of surface tension to explain why the surface of water in the glass shown in the **Figure 9.9** is curved upward. Why doesn't the water overflow the glass?

Think Critically

7. Explain the relationship between energy and states of matter.

Points to Consider

You read in this lesson that gases expand to fill their container.

- What if gas were forced into a smaller container? Would it shrink to fit?
- What other properties of the gas might change if its particles were crowded closer together?

**FIGURE 9.9**

The surface of water in the glass is curved upward. How does surface tension explain this phenomenon?

References

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CHAPTER

10

Chemical Equations

Lesson Objectives

- Describe how to write chemical equations.
- Demonstrate how to balance chemical equations.
- Relate the law of conservation of mass to balancing chemical equations.

Lesson Vocabulary

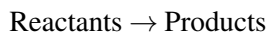
- chemical equation

Introduction

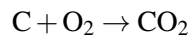
Chemists use a standard method to represent chemical reactions. It includes chemical symbols and formulas to stand for reactants and products. The symbols and formulas are used to write chemical equations.

Writing Chemical Equations

A **chemical equation** is a symbolic representation of a chemical reaction. It is a shorthand way of showing how atoms are rearranged in the reaction. The general form of a chemical equation was introduced in this chapter's lesson "Introduction to Chemical Reactions." It is:



Consider the simple example in **Figure 10.1**. When carbon (C) reacts with oxygen (O₂), it produces carbon dioxide (CO₂). The chemical equation for this reaction is:



The reactants are one atom of carbon and one molecule of oxygen. When there is more than one reactant, they are separated by plus signs (+). The product is one molecule of carbon dioxide. If more than one product were produced, plus signs would be used between them as well.

Reaction: Carbon reacts with oxygen to produce carbon dioxide

Equation: $C + O_2 \rightarrow CO_2$

Arrangement
of atoms:

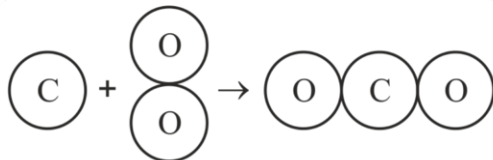


FIGURE 10.1

This figure shows a common chemical reaction. The drawing below the equation shows how the atoms are rearranged in the reaction. What chemical bonds are broken and what new chemical bonds are formed in this reaction?

Balancing Chemical Equations

Some chemical equations are more challenging to write. Consider the reaction in which hydrogen (H_2) and oxygen (O_2) combine to form water (H_2O). Hydrogen and oxygen are the reactants, and water is the product. To write a chemical equation for this reaction, you would start by writing symbols for the reactants and products:

Equation 1: $H_2 + O_2 \rightarrow H_2O$

Like equations in math, equations in chemistry must balance. There must be the same number of each type of atom in the products as there is in the reactants. In equation 1, count the number of hydrogen and oxygen atoms on each side of the arrow. There are two hydrogen atoms in both reactants and products. There are two oxygen atoms in the reactants but only one in the product. Therefore, equation 1 is not balanced.

Using Coefficients

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

Coefficients can be used to balance equation 1 (above) as follows:

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

Equation 2 shows that two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. The two molecules of hydrogen each contain two hydrogen atoms. There are now four hydrogen atoms in both reactants and products. Is equation 2 balanced? Count the oxygen atoms to find out.

Steps in Balancing a Chemical Equation

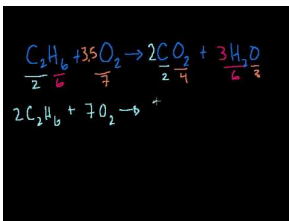
Balancing a chemical equation involves a certain amount of trial and error. In general, however, you should follow these steps:

1. Count the number of each type of atom in reactants and products. Does the same number of each atom appear on both sides of the arrow? If not, the equation is not balanced, and you need to go to step 2.
2. Add coefficients to increase the number of atoms or molecules of reactants or products. Use the smallest coefficients possible.
3. Repeat steps 1 and 2 until the equation is balanced.

Helpful Hint

When you balance chemical equations, never change the subscripts in chemical formulas. Changing subscripts changes the substances involved in the reaction. Change only the coefficients.

Work through the **Problem Solving** examples below. Then do the **You Try It!** problems to check your understanding. If you need more help, go to this URL: <http://www.youtube.com/watch?v=RnGu3xO2h74> (14:28).



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Click image to the left for more content.

Problem Solving

Problem: Balance this chemical equation: $\text{N}_2 + \text{H}_2 \rightarrow \text{NH}_3$

Hints for balancing

1. Two N are needed in the products to match the two N (N_2) in the reactants. Add the coefficient 2 in front of NH_3 . Now N is balanced.
2. Six H are now needed in the reactants to match the six H in the products. Add the coefficient 3 in front of H_2 . Now H is balanced.

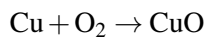
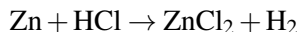
Solution: $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$

Problem: Balance this chemical equation: $\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

Solution: $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$

You Try It!

Problem: Balance these chemical equations:



Conserving Mass

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

How do scientists know that mass is always conserved in chemical reactions? Careful experiments in the 1700s by a French chemist named Antoine Lavoisier led to this conclusion. For this and other contributions, Lavoisier has been called the father of modern chemistry.

Lavoisier carefully measured the mass of reactants and products in many different chemical reactions. He carried out the reactions inside a sealed jar, like the one in **Figure 10.2**. As a result, any gases involved in the reactions were captured and could be measured. In every case, the total mass of the jar and its contents was the same after the reaction as it was before the reaction took place. This showed that matter was neither created nor destroyed in the reactions. Another outcome of Lavoisier's research was his discovery of oxygen. You can learn more about Lavoisier and his important research at: <http://www.youtube.com/watch?v=x9iZq3ZxbO8>

**FIGURE 10.2**

Lavoisier carried out several experiments inside a sealed glass jar. Why was sealing the jar important for his results?

Lesson Summary

- A chemical equation is a symbolic representation of a chemical reaction. It shows how atoms are rearranged in the reaction.
- Equations in chemistry must balance. There must be the same number of each type of atom in the products as there is in the reactants. Coefficients are used to balance chemical equations. They show how many atoms or molecules of a substance are involved in a reaction.
- Chemical equations must be balanced because matter cannot be created or destroyed. This is the law of conservation of mass. Experiments by Antoine Lavoisier led to this law.

Lesson Review Questions

Recall

1. What is a chemical equation? Give an example.
2. What is a coefficient? How are coefficients used in chemistry?
3. Describe how Antoine Lavoisier showed matter is conserved in chemical reactions.

Apply Concepts

4. Draw a sketch that shows how atoms are rearranged in the chemical reaction represented by equation 2.
5. Balance this chemical equation: $\text{Hg} + \text{O}_2 \rightarrow \text{HgO}$

Think Critically

6. Explain why it is necessary to balance chemical equations.

Points to Consider

In this lesson, you saw examples of chemical reactions in which two reactants combine to yield a single product. This is called a synthesis reaction. It is just one type of chemical reaction.

- What might be other types of chemical reactions?
- How might one reactant produce more than one product?

References

1. CK-12 Foundation. . CC-BY-NC-SA 3.0
2. . http://commons.wikimedia.org/wiki/File:David_-_Portrait_of_Monsieur_Lavoisier_and_His_Wife.jpg. Public Domain