Objective: 8.P.1.1

Atoms and Elements

Key Words • atom • element • pure substance • nucleus • proton • charge • neutron • electron • atomic number • ion • atomic mass • chemical symbol

Getting the Idea

Everything around you is matter. *Matter* is anything that has mass and volume. *Mass* is the amount of matter in a substance. *Volume* is the amount of space the substance occupies. All substances—everything you own, everything you touch, even you yourself—are made up of different types of matter.

Atoms and Elements

Atoms are the basic building blocks of most of the matter around you. There are different kinds of atoms. Each kind of atom is an element. An **element** is one of the basic substances that combine to form all other substances. Elements cannot be broken down into simpler substances by ordinary chemical means.

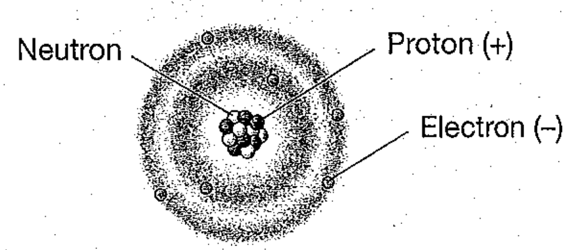
Scientists have discovered about 118 elements. About 90 of these elements are found in nature. Carbon, oxygen, gold, silver, and iron are some naturally occurring elements. The remaining elements are synthetic, or made by humans in the laboratory.

Elements are pure substances. A **pure substance** is matter that has the same chemical composition throughout and cannot be separated into its parts by physical means.

Atoms and Their Parts

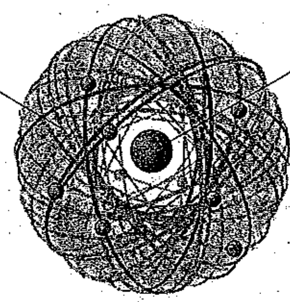
An atom is the smallest particle of an element that has all the properties of that element. Each element is made up of atoms that differ from those of every other element. The diagram below shows the structure of a carbon atom. Notice that this atom is made up of three different kinds of particles.

Carbon Atom



The center of the atom is called the **nucleus**. The nucleus of most atoms is made up of two kinds of particles: protons and neutrons. **Protons** carry a positive (+) charge. **Charge** is an electrical property that can be either positive or negative. **Neutrons** have no charge. The masses of protons and neutrons are measured in atomic mass units (amu). Each proton or neutron has a mass of about 1 amu.

Electrons are subatomic particles that exist in an area outside the nucleus called the electron cloud. Electrons have a negative (–) charge. The mass of electrons is insignificant compared to the mass of protons and neutrons.



Within the electron cloud, electrons move in areas called energy levels. An energy level is a region in which electrons having similar amounts of energy are likely to be located. Electrons can absorb and release energy. This changes their location in the atom. If an electron gains energy, it moves farther from the nucleus. If an electron loses energy, it moves closer to the nucleus. Electrons can absorb or release energy in the form of light, heat, or other types of energy.

The table below compares protons, neutrons, and electrons.

Characteristics of Subatomic Particles

Particle	Mass	Charge	Location
Proton	1 amu	+1	Nucleus
Neutron	1 amu	0	Nucleus
Electron	–	–1	Outside nucleus

Elements and Subatomic Particles

The properties, or characteristics, of an element are determined by the structure of its atoms. The main difference between different elements is atomic number. **Atomic number** is the number of protons in the nucleus of an atom. The number of protons in the nucleus is unique for each element. Therefore, no two elements have the same atomic number. Carbon, for example, has six protons and an atomic number of 6.

Look at the carbon atom on page 10 again. Notice that the number of protons in the atom is equal to the number of electrons. Because these numbers are equal, each positive charge in the nucleus is balanced by a negative charge in the electrons around the nucleus. The atom as a whole is electrically neutral—it has no overall charge. If the numbers of protons and electrons in an atom are not equal, the atom has a charge. A charged atom is called an **ion**.

Atoms have mass. The **atomic mass** of an atom is equal to the total mass of protons, neutrons, and electrons in the atom. Recall that each proton has a mass of about 1 amu. Each neutron also has a mass of 1 amu. Electrons have almost no mass. So you can find the atomic mass by counting the protons and neutrons in an atom.

The table below gives the atomic masses of several common elements.

Atomic Masses of Some Elements

Element	Protons	Neutrons	Electrons	Atomic Mass
Carbon (C)	6	6	6	12 amu
Oxygen (O)	8	8	8	16 amu
Sodium (Na)	11	12	11	23 amu
Potassium (K)	19	20	19	39 amu
Iron (Fe)	26	30	26	56 amu

Notice the letters in parentheses beside the name of each element in the table above. These letters are the chemical symbol of the element. A **chemical symbol** is a code, normally composed of one or two letters, used to represent an element. Each element has its own chemical symbol. C always represents carbon, Ca always represents calcium, Fe always represents iron, and so on.

Did You Know?

The names of elements have many sources. Some are named for planets. Uranium (U) is named for Uranus, and neptunium (Np) is named for Neptune. Other elements are named for scientists. Einsteinium (Es) is named for Albert Einstein. Places also have provided names for elements. Germanium is named for Germany, francium for France, and californium for California. Marie Curie, who discovered element number 84, named it polonium in honor of Poland.

Discussion Question

The atomic number of gold is 79. How many neutrons are there in an atom of gold that has an atomic mass of 197 amu? Explain how you got your answer.

Lesson Review

1. Which of these determines the identity of an element?

   A. number of electrons

   B. number of protons

   C. number of energy levels

   D. number of neutrons

2. Sodium is an element found in table salt. It contains 11 protons and 12 neutrons. How many electrons are found in a neutral atom of sodium?

   A. 23

   B. 12

   C. 11

   D. 1

3. Elements are described as pure substances because

   A. they are all found in nature.

   B. they cannot be separated into parts by physical means.

   C. they have no charge.

   D. they can be produced in a laboratory.

4. The nucleus of an atom contains

   A. only neutrons.

   B. protons and electrons.

   C. protons and neutrons.

   D. only electrons.

Chapter 1 • Lesson 2

The Periodic Table

Key Words • periodic table • period • group • physical property • metal • nonmetal • metalloid • chemical property • reactivity

Getting the Idea

By the 1860s, scientists had discovered 63 different elements. A Russian chemist named Dmitri Mendeleyev tried to classify these elements by their properties. He wrote each element's name and properties on a separate card. When he arranged the cards on a table, he noticed patterns in the properties. Mendeleyev began to develop a table that grouped the elements according to their properties.

The Periodic Table

Recall that atomic mass is equal to the total mass of protons, neutrons, and electrons in an atom. Mendeleyev arranged the elements in rows in order of their atomic masses. When he did this, he saw that many elements with similar properties ended up in the same column. This was the most important step in producing a useful scientific tool known as the periodic table.

The **periodic table** is a chart that organizes information about the elements. This chart is shown on the next page. It includes a key that explains the information in each box. There is a box for each element. The box contains the element's name, chemical symbol, atomic number, and atomic mass. The atomic mass given is a kind of average of the atomic masses of all the atoms of that element. Over time, the periodic table of elements has grown and developed as scientists have contributed new knowledge.

Periods and Groups

When Mendeleyev arranged the elements in order of their atomic masses, some elements did not seem to fit properly. Today, elements are arranged in order of the atomic number of each element. Remember that the atomic number of an element is the number of protons in the nucleus of each of its atoms.

Each horizontal row in the periodic table is called a **period**. Periods are numbered from 1 to 7. The atomic numbers of the elements increase from left to right across a row. A vertical column in the periodic table is a **group**. Groups are numbered from 1 to 18. A group is also called a *chemical family* because elements in the same group normally have some similar properties.

The Periodic Table

Atomic number — 14
Symbol — Si
Atomic mass — 28.086
Name — Silicon

Mass numbers in parentheses are those of the most stable or most common isotopes.

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 **H** 1.008 Hydrogen																	2 **He** 4.003 Helium
2	3 **Li** 6.941 Lithium	4 **Be** 9.012 Beryllium											5 **B** 10.811 Boron	6 **C** 12.011 Carbon	7 **N** 14.007 Nitrogen	8 **O** 15.999 Oxygen	9 **F** 18.998 Fluorine	10 **Ne** 20.179 Neon
3	11 **Na** 22.989 Sodium	12 **Mg** 24.305 Magnesium											13 **Al** 26.982 Aluminum	14 **Si** 28.086 Silicon	15 **P** 30.974 Phosphorus	16 **S** 32.066 Sulfur	17 **Cl** 35.453 Chlorine	18 **Ar** 39.948 Argon
4	19 **K** 39.098 Potassium	20 **Ca** 40.078 Calcium	21 **Sc** 44.956 Scandium	22 **Ti** 47.867 Titanium	23 **V** 50.943 Vanadium	24 **Cr** 51.996 Chromium	25 **Mn** 54.938 Manganese	26 **Fe** 55.845 Iron	27 **Co** 58.933 Cobalt	28 **Ni** 58.693 Nickel	29 **Cu** 63.546 Copper	30 **Zn** 65.390 Zinc	31 **Ga** 69.723 Gallium	32 **Ge** 72.610 Germanium	33 **As** 74.922 Arsenic	34 **Se** 78.960 Selenium	35 **Br** 79.904 Bromine	36 **Kr** 83.800 Krypton
5	37 **Rb** 85.468 Rubidium	38 **Sr** 87.620 Strontium	39 **Y** 88.906 Yttrium	40 **Zr** 91.224 Zirconium	41 **Nb** 92.906 Niobium	42 **Mo** 95.940 Molybdenum	43 **Tc** (97.907) Technetium	44 **Ru** 101.070 Ruthenium	45 **Rh** 102.906 Rhodium	46 **Pd** 106.42 Palladium	47 **Ag** 107.868 Silver	48 **Cd** 112.411 Cadmium	49 **In** 114.818 Indium	50 **Sn** 118.710 Tin	51 **Sb** 121.760 Antimony	52 **Te** 127.60 Tellurium	53 **I** 126.905 Iodine	54 **Xe** 131.293 Xenon
6	55 **Cs** 132.906 Cesium	56 **Ba** 137.327 Barium	57 **La** 138.906 Lanthanum	72 **Hf** 178.490 Hafnium	73 **Ta** 180.948 Tantalum	74 **W** 183.84 Tungsten	75 **Re** 186.207 Rhenium	76 **Os** 190.230 Osmium	77 **Ir** 192.217 Iridium	78 **Pt** 195.084 Platinum	79 **Au** 196.967 Gold	80 **Hg** 200.590 Mercury	81 **Tl** 204.383 Thallium	82 **Pb** 207.200 Lead	83 **Bi** 208.980 Bismuth	84 **Po** (208.982) Polonium	85 **At** (209.987) Astatine	86 **Rn** (222.018) Radon
7	87 **Fr** (223.019) Francium	88 **Ra** (226.025) Radium	89 **Ac** (227.028) Actinium	104 **Rf** (263.113) Rutherfordium	105 **Db** (262.114) Dubnium	106 **Sg** (266.122) Seaborgium	107 **Bh** (264.125) Bohrium	108 **Hs** (269.134) Hassium	109 **Mt** (268.139) Meitnerium	110 **Ds** (272.146) Darmstadtium	111 **Rg** (272.154) Roentgenium	112 **Cn** (285) Copernicium	113 **Uut** (286)	114 **Uuq** (289)	115 **Uup** (289)	116 **Uuh** (291)	117 **Uus** (294)	118 **Uuo** (294)

Series															
Lanthanide Series	58 **Ce** 140.116 Cerium	59 **Pr** 140.908 Praseodymium	60 **Nd** 144.242 Neodymium	61 **Pm** (144.913) Promethium	62 **Sm** 150.360 Samarium	63 **Eu** 151.964 Europium	64 **Gd** 157.250 Gadolinium	65 **Tb** 158.925 Terbium	66 **Dy** 162.500 Dysprosium	67 **Ho** 164.930 Holmium	68 **Er** 167.259 Erbium	69 **Tm** 168.934 Thulium	70 **Yb** 173.040 Ytterbium	71 **Lu** 174.967 Lutetium
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Physical Properties of Metals, Nonmetals, and Metalloids

Each element has its own set of properties. Some properties are shared by elements. Other properties are unique to each element. A **physical property** is a characteristic of a substance that can be observed directly or measured with a tool without changing the identity of the substance. Elements can be classified into three groups based on their physical properties.

More than 75 percent of the elements in the periodic table are **metals**. They are located to the left of the dark, steplike line that starts in Group 13 and ends in Group 16. Most metals

- have a shiny luster.
- are malleable—can be beaten or rolled into thin sheets.
- are ductile—can be stretched into wires.
- are solid at room temperature. (Mercury, a liquid, is an exception.)
- are good conductors of heat and electricity.

The **nonmetals** are found to the right of the steplike line. They include all the elements in Groups 17 and 18 and some of the elements in Groups 14, 15, and 16. Unlike metals, solid nonmetals do not conduct heat and electricity well. They tend to have a dull appearance, and they are often brittle, which means they are easy to break. Most nonmetals are gases or solids at room temperature. Carbon, nitrogen, oxygen, sulfur, fluorine, helium, and neon are nonmetals. One nonmetal, bromine, is a liquid at room temperature.

Metalloids have some characteristics of both metals and nonmetals. They conduct electricity better than nonmetals, but not as well as metals. The metalloids are located along the steplike line near the right side of the periodic table in groups 13, 14, 15, and 16. They include boron, silicon, germanium, arsenic, and antimony.

Metals and nonmetals have different properties. You can predict some of an element's properties from its position in the periodic table. Notice that iron and aluminum are to the left of the steplike line. That position tells you they are metals and are likely to have certain properties. Carbon and oxygen are to the right of the line, so you know they are nonmetals.

Chemical Properties of Chemical Families

A **chemical property** is a characteristic of a substance that cannot be observed without changing the identity of the substance. For example, flammability is a substance's ability to catch fire. Hydrogen is an extremely flammable element. Other flammable elements include nonmetals in the upper-right section of the periodic table, such as carbon, nitrogen, and phosphorus. When these elements catch fire, they combine with oxygen to form new substances.

An important chemical property of elements is reactivity. **Reactivity** is the tendency of a substance to undergo chemical changes, or reactions. You will read about chemical changes in Lesson 5. The more reactive an element is, the more likely it is to combine with other elements. The most reactive metals are the alkali metals in Group 1. (Although hydrogen is the first element and seems to be in Group 1, it is not an alkali metal. Hydrogen is a gas. It has properties that do not resemble those of any group of elements.)

The elements in Group 2, the alkaline earth metals, are very reactive but are slightly less reactive and harder than Group 1 metals. The reactivity of both the Group 1 and Group 2 metals increases with increasing atomic number.

Groups 3 through 12 include the transition metals. A property of transition elements is that they often give off characteristic colors when they react with other elements.

Halogens are nonmetals in Group 17. The halogens are the most reactive nonmetals. Reactivity in nonmetals generally increases as atomic number decreases, so fluorine is the most reactive nonmetal. Halogens react with alkali metals to form salts.

Noble gases, Group 18, are the least reactive of all elements. At one time, noble gases were considered *inert*, or unable to react chemically. Then, in 1962, scientists produced a substance containing xenon (Xe) and fluorine (Fl). Scientists have produced many other substances involving noble gases since then. In nature, however, the noble gases rarely react with other elements.

Discussion Question

Find the element copper (Cu) in the periodic table. What can you infer about copper's properties? Explain how its position in the periodic table helps you.

Lesson Review

Use the element box shown below to answer questions 1 and 2.

19
K
39.098
Potassium

1. What are the name and atomic number of the element represented above?

A. K, 19 **C.** potassium, 19

B. K, 39.098 **D.** potassium, 39.098

2. How many electrons would a neutral atom of the element shown above have?

A. 19 **C.** 58

B. 39 **D.** 20

3. How are the elements in the modern periodic table arranged?

A. in alphabetical order

B. by atomic mass

C. by date of discovery

D. by number of protons

4. Which elements in the periodic table are **least likely** to combine with other elements?

A. halogens

B. noble gases

C. alkaline earths

D. transition metals

5. Which of these statements is **false**?

A. The least reactive elements are in the far right column.

B. Elements at the bottom of a column have more protons than elements at the top of a column.

C. Elements on the left side of a row always have higher atomic mass than elements on the right side of that row.

D. Elements along the steplike line have some properties of metals and some properties of nonmetals.

Objective: 8.P.1.1

Molecules, Compounds, and Crystals

Key Words • molecule • compound • chemical formula • subscript • crystal

Getting the Idea

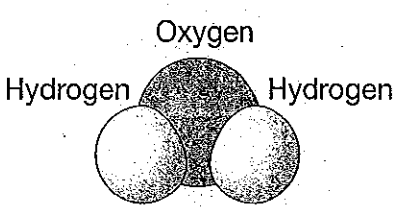
You have learned that atoms are the basic building blocks of almost all the matter around you. Each type of atom makes up a different element. Scientists have discovered only 118 elements. Yet there are far more than 118 different kinds of matter. This is because of the ways elements can combine to form new substances.

Molecules

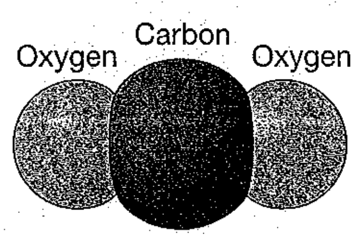
Two or more atoms can combine to form a molecule. A **molecule** is a group of two or more atoms held together by forces called chemical bonds. These bonds form between atoms that share or transfer electrons. You will learn more about chemical bonds in Lesson 5.

A molecule may contain atoms of only one element. Oxygen gas is a molecule made up of two oxygen atoms. Molecules can also form when two or more different elements join together. Look at the diagrams below. A water molecule contains two hydrogen atoms and one oxygen atom. A molecule of carbon dioxide contains one carbon atom and two oxygen atoms.

Water Molecule



Carbon Dioxide Molecule



Compounds

A **compound** is a substance that forms when two or more elements join chemically. Like elements, compounds are pure substances. The elements that make up a compound are always found in the same proportions. For example, every molecule of water is made of one oxygen atom and two hydrogen atoms. The elements in a compound cannot be separated by physical means. They can be separated only by chemical means.

A compound has different properties from those of the elements that make it up. Water is a compound made up of hydrogen and oxygen. Water is a liquid at room temperature, even though both hydrogen and oxygen are gases. Water is not flammable. This means it will not burn, even though hydrogen is flammable and oxygen allows it to burn. Table salt is made of the elements sodium and chlorine. Salt is a solid at room temperature and dissolves in water. In contrast, pure sodium is a very reactive metal that can explode when exposed to water. Chlorine is a poisonous, greenish gas at room temperature.

Naming and Identifying Compounds

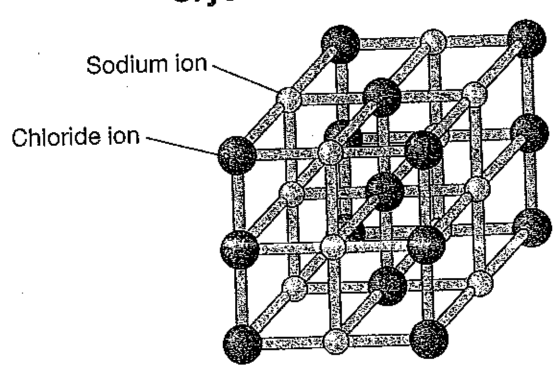
Most compounds are named for the elements they are made of. For example, carbon dioxide is named for carbon and oxygen. The prefix *di-* tells you that there are two atoms of oxygen in this compound. If you look back at the periodic table on page 15, you will see that carbon is to the left of oxygen. Usually, the element to the left appears first in the name of the compound.

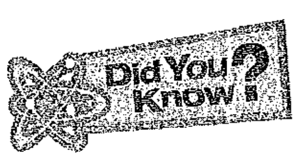
Compounds can also be identified by chemical formulas. A **chemical formula** is a group of chemical symbols and numbers that shows the number of atoms of each element in a molecule. The formula for carbon dioxide is CO_2. C is the chemical symbol for carbon. O is the chemical symbol for oxygen. The number 2 in the formula is called a **subscript.** It shows that the molecule contains two atoms of oxygen. The C has no subscript. That means that the molecule contains only one atom of carbon.

Crystals

A **crystal** is a solid made up of particles that are arranged in a regular, repeating pattern. These particles can be atoms, molecules, or ions. Recall from Lesson 1 that an ion is a charged atom. In table salt, sodium and chloride ions alternate to form a repeating cube-shaped pattern. Other crystals display different patterns.

Crystal Structure of Table Salt

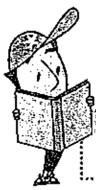




North Carolina's state stone is the emerald. Emeralds are made up of several elements including beryllium, aluminum, silicon, and oxygen. In an emerald, these elements form crystals with a repeating six-sided, or hexagonal, pattern.

Discussion Question

The chemical formula for water is H_2O. The chemical formula for hydrogen peroxide is H_2O_2. Would you expect these two substances to have the same properties? Explain your answer.



Lesson Review

1. Carbon and oxygen combine chemically to form carbon dioxide. Carbon dioxide is

A. an ion.

B. a nucleus.

C. a compound.

D. an atom.

2. Which of these statements about molecules is **true**?

A. All molecules contain atoms of only one element.

B. Two or more molecules can combine to form an atom.

C. The elements in any molecule are always present in equal proportions.

D. The atoms in a molecule cannot be separated from each other by physical means.

3. How do the properties of a compound compare to the properties of the elements that make it up?

A. The properties of the compound are the same as the properties of the elements that make it up.

B. The properties of the compound are different from the properties of the elements that make it up.

C. The properties of the compound may vary, while the properties of the elements that make it up do not change.

D. The properties of the compound are the same as the properties of only one of the elements in the compound.

4. Crystals can be made up of which of the following kinds of particles?

A. atoms only

B. atoms or ions

C. atoms, ions, or molecules

D. molecules only

Chapter 1 • Lesson 4

Objective: 8.P.1.1

Mixtures

Key Words • mixture • heterogeneous mixture • homogeneous mixture • solution • solvent • solute • sifting • filtration • evaporation • hypothesis

Getting the Idea

A salad may contain things such as lettuce, celery, carrots, and other vegetables. You can see the different parts of the salad—even when they are jumbled together on your plate. This is because each of the different substances keeps its original properties. In this lesson, you will learn about the different ways substances can be mixed together. You will also learn how the substances can be separated.

Understanding Mixtures

You have learned that elements and compounds are pure substances. Sometimes pure substances mix together. A **mixture** is matter made up of two or more substances that are combined physically. The substances in a mixture do not change or combine chemically. They keep their own properties. For example, if you mix salt and sugar together, some of the crystals will still taste sweet, and some will taste salty.

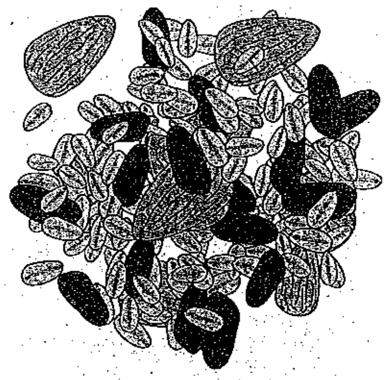
Recall that the makeup of any compound is always the same. In any molecule of the compound, the elements are always found in the same proportions. The makeup of a mixture can vary. A mixture of salt and sugar can contain more salt than sugar or more sugar than salt.

Mixtures can exist in all states of matter. Air is a mixture of gases. Alcohol and water is a mixture of two liquids. Sugar dissolves in water, making a mixture of a solid and a liquid. Steel is a mixture of two solids, iron and carbon.

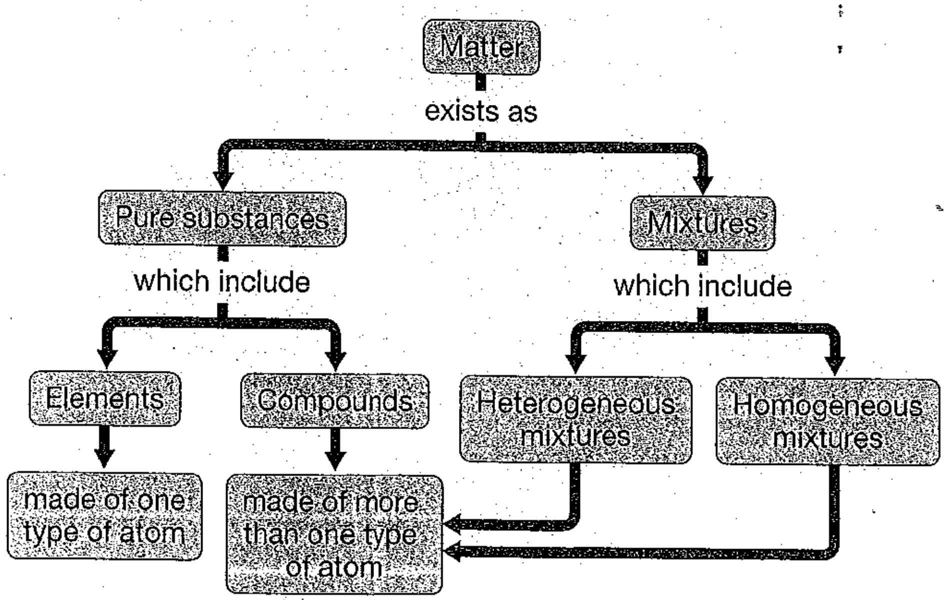
Classifying Mixtures

Mixtures can be classified into two groups: heterogeneous mixtures and homogeneous mixtures. In a **heterogeneous mixture**, substances are not distributed evenly throughout the mixture. The individual substances in a heterogeneous mixture are easy to distinguish.

A cereal such as granola is an example of a heterogeneous mixture. Each item keeps its consistency and flavor. If you divided the drawing below into fourths, you would see that the distribution of items is not even. Some parts of the sample have more almonds than other parts.



In a **homogeneous mixture**, substances are evenly distributed throughout the mixture. You cannot visibly distinguish the different parts of a homogeneous mixture from one another. The mixture has the same physical properties throughout.



Solutions

A **solution** is a homogeneous mixture in which one substance is completely dissolved in another substance. An example is sugar dissolved in water. Solutions are usually liquids. Solutions have two parts, the **solvent** and the **solute.** In a solution of sugar and water, water is the solvent and sugar is the solute. The solvent is the substance that does the dissolving. The solute is the substance that dissolves.

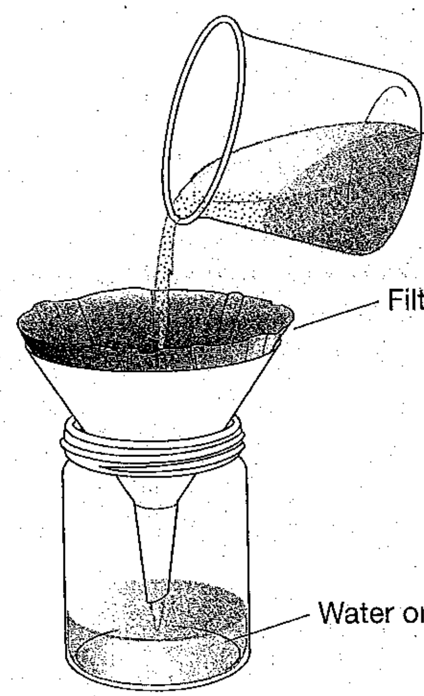
When sugar dissolves in water, water molecules are close enough to touch and slide past each other. The sugar molecules sit in the tiny spaces between water molecules. They remain evenly distributed throughout the water. However, the sugar and water are not chemically bonded.

Separating Mixtures

Unlike compounds, mixtures can be separated by physical means. The substances in a mixture have different properties that can be used to separate them. Methods used to separate mixtures include sifting, filtration, evaporation, and others.

Sifting separates the solid parts of a mixture by particle size. A screen or similar device is often used to sift materials. If you pour a mixture of sand and pebbles onto a screen, the small particles of sand will pass through the screen. The larger particles, the pebbles, will not.

Filtration separates a solid from a liquid in a heterogeneous mixture. Sand does not dissolve in water. If you pour a mixture of sand and water onto filter paper, the water will pass through the paper, but the sand will not.



Evaporation can be used to separate a solid from a liquid in a solution. Sugar dissolves when it is mixed with water, forming a solution. To separate the sugar from the water, the solution can be placed in a container and heated. As the water evaporates, or changes from a liquid to a gas, the sugar is left behind.

Lesson Review

1. Which of these is **not** made up of two or more substances that are combined physically?

   A. homogeneous mixture

   B. compound

   C. heterogeneous mixture

   D. solution

2. An unknown substance is provided in a science class. Looking at the substance, a student observes different colors and different sizes of particles unevenly distributed throughout the substance. What type of substance is this?

   A. solution

   B. compound

   C. heterogeneous mixture

   D. homogeneous mixture

3. Filtration can be used to separate a mixture of

   A. a solid and a liquid.

   B. a liquid and a gas.

   C. two liquids.

   D. two solids.

4. Which of these processes would be useful for separating a dissolved solid from a liquid?

   A. evaporation

   B. filtration

   C. sifting

   D. mixing

Objective: 8.P.1.3

Physical and Chemical Changes

Key Words • density • boiling point • boiling • melting point • solubility • physical change • chemical change • chemical bond • chemical reaction • precipitate • observation • inference

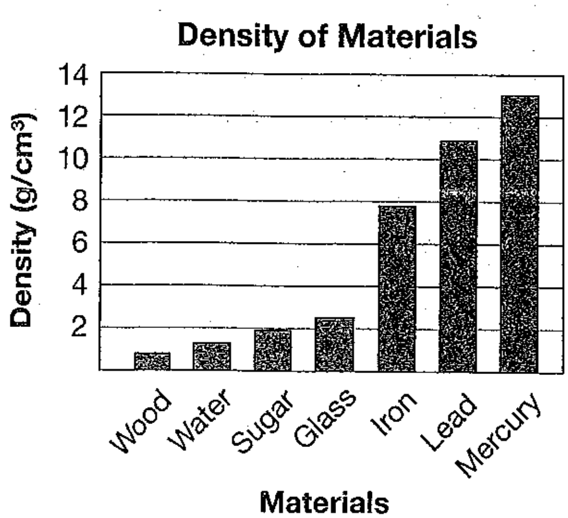
Getting the Idea

Matter can change in many ways. For example, you change the size and shape of matter if you break an object, such as a plastic spoon, into smaller pieces. Matter also changes when the gases hydrogen and oxygen join to form liquid water. These are both changes in matter, but they are very different. In this lesson, you will learn to classify changes in matter into two categories.

Physical Properties

Recall that a physical property is a characteristic that can be observed or measured without changing the identity of a substance. Examples of physical properties include color, odor, texture, density, ability to conduct electricity, and many others. Each of these properties can be observed or measured using simple tools. Every substance has its own unique set of physical properties. Thus, physical properties can help you identify a substance.

Density is a physical property that describes how much matter is found in a certain space. It is the ratio of a material's mass to its volume. Density is expressed in g/cm^3, which is read as "grams per cubic centimeter." The density of pure water is 1 g/cm^3. Most liquids have densities close to that of water. Mercury, a liquid metal, is an exception. The density of mercury is about 13.5 g/cm^3. This is more than thirteen times the density of water. The graph below shows the densities of some materials.



Melting point and boiling point are physical properties of matter. The **boiling point** of a substance is the temperature at which the substance boils. **Boiling** is a process in which a liquid changes to a gas. When a liquid boils, bubbles form throughout the liquid and rise to the surface. The boiling point of water is 100°C. The **melting point** of a substance is the temperature at which the substance changes from a solid to a liquid. The melting point of solid water, or ice, is 0°C.

Like density, melting and boiling points can be used to help identify a substance. For example, if a colorless liquid boils at 78°C, you know the substance is not water. If you look at a table that lists the boiling points of different substances, you will find that ethanol boils at 78°C. But before you can be sure that the liquid is ethanol, you need to find the density or other properties of the liquid. It is possible that another substance has a similar boiling point.

In Lesson 4, you learned that a solution is made up of a solute dissolved in a solvent. The ability of a solute to dissolve is a physical property called **solubility**. A substance's solubility indicates the amount of that substance that can dissolve in a particular solvent—for example, how much salt can dissolve in a given amount of water. If the maximum amount of solute has dissolved and more is added, the extra solute will not dissolve. It will fall to the bottom of the solution. For most substances, solubility increases with temperature. That is, more solute dissolves in a warm solvent than in a cold solvent.

Chemical Properties

Remember that a chemical property is a characteristic of a substance that cannot be observed without changing the identity of the substance. Examples of chemical properties include reactivity, the ability to burn, the ability to rust, reaction to light, and reaction with acids. Every substance has chemical properties that make it unique.

Like physical properties, chemical properties can help identify a substance. Unlike physical properties, however, chemical properties cannot be observed without changing the substance. For example, the ability to burn is a chemical property of ethanol. When ethanol burns, it combines with oxygen in the air to form new substances that have different properties.

Physical Changes

A **physical change** alters the form or appearance of a substance without changing the identity of the substance. During a physical change, no changes occur in the elements or compounds that make up the matter.

You cause physical changes all the time. For example, you can change the shape of modeling clay if you push and pull on it. You can polish a rough stone and make it smooth. You can crush a sugar cube into smaller crystals. You can dissolve the sugar in water. You can separate a mixture of sand and pebbles by sifting it with a screen. These are physical changes because the matter is changed in some way but remains the same kind of matter. Each of these changes uses energy. Whenever matter is changed, there is a change in energy.

Changes of state are physical changes. Changes of state include melting, freezing, boiling, evaporating, and condensing. When heat energy is added to liquid water and the water boils, the liquid water changes to water vapor, a gas. The state of the water has changed, but the gas is still water. When heat energy is removed from liquid water and the water freezes, the liquid water becomes ice, a solid. Again, the substance has changed state, but the substance is still water.

Physical changes can often be reversed. This means that the matter can change back to its former condition. You can freeze liquid water to form ice, and you can reverse this change by melting the ice to form liquid water.

Chemical Changes

A **chemical change** occurs when substances combine to form one or more new substances with different properties. During a chemical change, **chemical bonds,** the forces that hold atoms together in molecules, are broken and re-formed. As a result, the atoms form different molecules. As with any physical change, a chemical change involves a change in energy.

Baking a cake involves chemical changes. If you make a cake, you use ingredients such as sugar, eggs, and flour to make the batter. When you bake the batter, it becomes a cake in which the identities of the original ingredients have changed. The chemical bonds in the ingredients break, and the atoms become rearranged, forming new bonds.

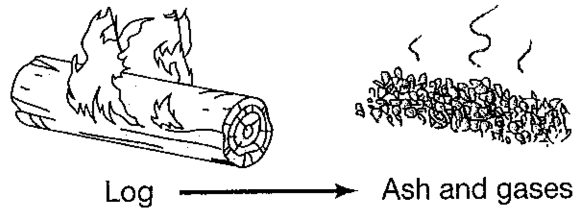
Unlike most physical changes, most chemical changes are difficult or impossible to reverse. After a cake is baked, for example, you cannot change it back to a liquid batter made of sugar, eggs, and flour.

The process by which a chemical change takes place is called a **chemical reaction**. In a chemical reaction, elements and compounds combine in new ways to form new substances. You will learn more about chemical reactions in Lesson 6. Some signs may indicate that a chemical reaction has occurred. Two common signs of a chemical reaction are a change in color and the release of heat or light. Another sign of a chemical reaction is the formation of a precipitate. A **precipitate** is a solid that forms during a chemical reaction that takes place in a solution.

Some chemical reactions cause the release of a gas. If you drop an antacid tablet into water, a chemical reaction occurs. The bubbles that you see in the water are carbon dioxide given off by a reaction between a compound in the tablet and the water. But release of gas does not always mean that a chemical reaction has taken place. Recall that when water boils, bubbles of water vapor are released. The change from liquid water to water vapor is a physical change, not a chemical change.

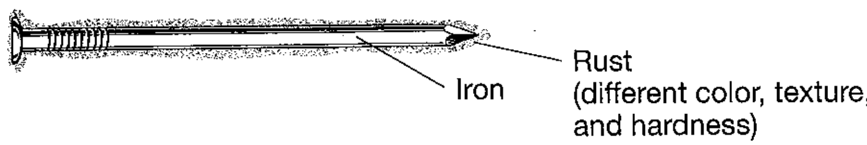
A combustion reaction is a chemical reaction in which oxygen combines with certain other substances. A combustion reaction takes place when something burns.

When wood or paper burns, water vapor and carbon dioxide are given off. Energy is given off as heat and light. The ash that remains is very different from the material that burned.



A log burning involves chemical changes.

Rusting is another example of a chemical reaction. Rusting is a slow reaction between oxygen and a metal. A nail contains iron. Over time, the iron combines with oxygen in the air to form rust. The surface of the nail changes from smooth and shiny to rough and reddish brown. The rust is a different substance from iron.



Lesson Review

1. What happens during a physical change?
   - **A.** New substances form.
   - **B.** The identity of a substance is changed.
   - **C.** A chemical reaction occurs.
   - **D.** A property of a substance changes, but its identity stays the same.

2. Which of the following is a chemical change?
   - **A.** water boiling
   - **B.** paper being cut
   - **C.** ice melting
   - **D.** iron rusting

3. Which is a clue that a chemical change has occurred?
   - **A.** A beaker becomes warm when you mix two room-temperature liquids in it.
   - **B.** A liquid forms bubbles when it reaches a high temperature.
   - **C.** Water changes color when you add food coloring to it.
   - **D.** A car door feels hot if you touch it on a summer afternoon.

4. Which of the following would cause a chemical change in a piece of wood?
   - **A.** hammering a nail into the wood
   - **B.** burning the wood
   - **C.** painting the wood
   - **D.** sawing the piece of wood in half

5. A physical change is taking place when
   - **A.** a piece of paper burns.
   - **B.** a piece of fruit rots.
   - **C.** onions are chopped.
   - **D.** a nail rusts.

Chapter 1 • Lesson 6

Objective: 8.P.1.4

Chemical Reactions and the Conservation of Mass

Key Words • reactant • product • chemical equation • coefficient • law of conservation of mass

Getting the Idea

A puddle of water evaporating and rust forming on metal are both examples of changes in matter. As you have learned, water evaporating is a physical change. Rust forms through a chemical change. In both types of changes, the total amount of matter remains the same. Matter is neither created nor destroyed, even when a new substance forms.

Chemical Equations

Recall that a chemical reaction is a process in which elements and compounds combine to form new substances. For example, iron oxide (Fe_2O_3) is a compound you know as rust. The formation of iron oxide is an example of a chemical change. Iron oxide forms when iron (Fe) reacts with oxygen gas (O_2) in the air. This reaction can be shown as a word equation. The arrow in the equation is read as "produces" or "yields."

$$\text{Iron} + \text{oxygen} \rightarrow \text{iron oxide}$$

In this reaction, iron and oxygen are the reactants. A **reactant** is a substance that is present at the beginning of a chemical reaction. Reactants are always shown to the left of the arrow. Iron oxide is the product of this reaction. A **product** is a substance that is produced during a chemical reaction. Products are always written to the right of the arrow.

The word equation above can be rewritten as a chemical equation. A **chemical equation** describes a chemical reaction using chemical formulas, subscripts, and coefficients. A **coefficient** is a number written before a chemical formula to show how many atoms or molecules of that substance are involved in the reaction. The equation for rust formation is:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

The reactants are four iron atoms and three molecules of oxygen gas (O_2). Each molecule of oxygen gas is made up of two oxygen atoms. Since the reactants include three oxygen molecules, there are a total of six oxygen atoms in the reactants. The product of this reaction is iron oxide. Two molecules of iron oxide form. Each molecule has the formula Fe_2O_3.

The formula Fe_2O_3 shows that a molecule of iron oxide contains two iron atoms and three oxygen atoms. Since there are two molecules of iron oxide, the product contains a total of four iron atoms and six oxygen atoms. If you compare this to the number of iron atoms and oxygen atoms in the reactants, you will find that the numbers are the same. This means that the chemical equation is balanced.

To find out if an equation is balanced, follow these steps:

1. Make sure that the reactants and products contain the same elements.
2. Count the number of atoms of each element in the reactants. Remember to multiply the coefficient by the subscript, if there is one.
3. Count the number of atoms of each element in the products.
4. Check that these numbers are equal. If they are, the equation is balanced.

It may help you to make a chart to compare the numbers. The chart below shows that the equation for rust formation is balanced.

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

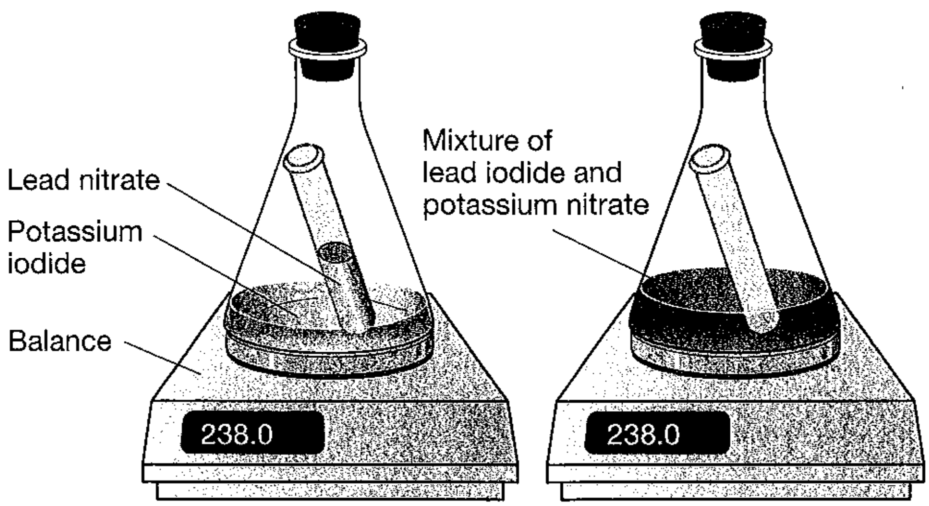
Products	=	Reactants
4 Fe atoms	=	4 Fe atoms
6 O atoms	=	6 O atoms

The Law of Conservation of Mass

When a log on a campfire burns, most of the log seems to disappear. You see only a small amount of ash left behind. You might think that most of the matter in a log is destroyed when it burns. However, in a chemical reaction, matter is not created or destroyed. In the 1700s, a French chemist named Antoine Lavoisier conducted experiments to prove this concept.

Lavoisier measured the masses of the reactants and products in reactions. He discovered that in any reaction, the total mass of the reactants is always the same as the total mass of the products. This discovery is expressed as the **law of conservation of mass**. According to this law, matter is neither created nor destroyed during a chemical change.

The diagram below shows a chemical reaction that took place in a closed container. The reactants were kept apart until a stopper was placed in the neck of the flask. The flask was tilted to allow the reactant in the test tube to mix with the other reactant. A yellow precipitate formed, which shows that a chemical reaction took place. However, the total mass did not change. This result supports the law of conservation of mass.

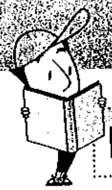


In the investigation described above, the flask was sealed with a stopper. The sealed flask is an example of a closed system. No matter can enter a closed system, and no matter can escape. It is important to study a chemical reaction in a closed system. This allows you to show that the mass of the products equals the mass of the reactants.

A log burning on a campfire is not inside a closed system. The mass of the gases released by the burning log cannot be measured, so the conservation of mass cannot be shown. However, mass is still conserved.

Discussion Question

How can a chemical reaction be compared to shuffling a deck of cards?



Lesson Review

1. According to the law of conservation of mass, which of the following is a **true** statement about any chemical reaction?

   A. The total mass of the reactants is greater than the total mass of the products.

   B. The total mass of the reactants is less than the total mass of the products.

   C. The total mass of the reactants equals the total mass of the products.

   D. In a chemical reaction, matter can be created but not destroyed.

2. Examine the following chemical equation, which shows only the reactants and one product.

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

   How many H atoms must be present in the second product that is formed?

   A. 1

   B. 2

   C. 3

   D. 4

3. Which of the following equations does **not** demonstrate the law of conservation of mass?

   A. $2Na + Cl_2 \rightarrow 2NaCl$

   B. $NaOH + HCl \rightarrow NaCl + H_2O$

   C. $P_4 + 5O_2 \rightarrow 2P_4O_{10}$

   D. $SnCl_2 + 2FeCl_3 \rightarrow 2FeCl_2 + SnCl_4$