

Chapter 4

Earth Chemistry

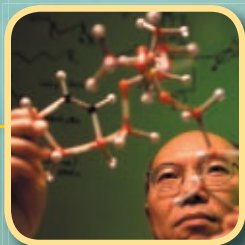
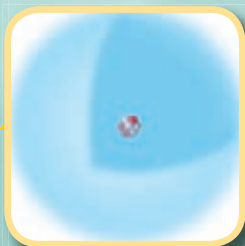
Chapter Outline

1 Matter

Properties of Matter
Atomic Structure
Atomic Number
Atomic Mass
The Periodic Table of Elements
Valence Electrons and Periodic Properties

2 Combinations of Atoms

Chemical Formulas
Chemical Equations
Chemical Bonds
Mixtures



Why It Matters

New Zealand's geothermal Champagne Pool is steaming hot, at 74 °C. Its water contains dissolved elements, such as gold, silver, mercury, and arsenic. In fact, the entire Earth is made of chemical elements. Understanding the chemical structure of elements and molecules will help you understand the properties of the substances that make up Earth.

Inquiry Lab

 20 min

Classifying Matter

Examine each of the **six solids** provided by your teacher, and record your observations. Consider properties such as mass, shininess, color, texture, size, and hardness. Determine whether the solids are made up of only one component, or two or more different components. Add each solid to a **beaker** with **water**, and observe how it behaves. Based on your observations, classify the solids into two or three groups.

Questions to Get You Started

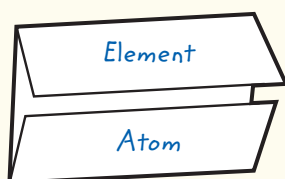
1. Some properties help you distinguish one solid from another, and some do not. Explain which properties are the most and least helpful for developing a classification system.
2. How did you decide on your classification system? Explain your reasoning.
3. Compare your classification system with another group's classification system. Explain the similarities and differences.



FoldNotes

Double-Door Fold This type of FoldNote can help you identify the similarities and differences between topics.

Your Turn Use a double-door fold to compare the terms *element* and *atom* in Section 1. For Section 2, compare the terms *compound* and *mixture*.



Note Taking

Comparison Table You can use a comparison table to organize your notes as you compare related terms or topics. A table that compares chemical and physical properties has been started for you below.

Your Turn As you read Section 1, complete a table like the one started here.

Type of Property	Physical	Chemical
How the property is observed	can be observed without changing the composition of the substance	
Examples		

Science Terms

Everyday Words Used in Science Many words that are used in science are also used in everyday speech. These words often have different or more precise meanings in science contexts than in everyday speech. Pay attention to the definitions of these words so that you can use them correctly in scientific contexts.

Your Turn As you read Chapter 4, complete a table like the one shown. For each term, write its everyday meaning and its scientific meaning.

Term	Everyday meaning	Scientific meaning
matter	a subject or problem	anything that takes up space and has mass
element	a piece or component of something	
compound		
mixture		
solution		

For more information on how to use these and other tools, see **Appendix A**.

Key Ideas

- Compare chemical properties and physical properties of matter.
- Describe the basic structure of an atom.
- Compare atomic number, mass number, and atomic mass.
- Define *isotope*.
- Describe the arrangement of elements in the periodic table.

Key Terms

matter
element
atom
proton
electron
neutron
isotope

Why It Matters

To understand the world around you, it helps to understand what Earth is made of—matter. From Earth's rocks to the oceans and air (and even your own body), matter really matters.

Every object in the universe is made of particles of some kind of substance. Scientists use the word *matter* to describe the substances of which objects are made. **Matter** is anything that takes up space and has mass. The amount of matter in any object is its *mass*.

Properties of Matter

All matter has two types of distinguishing characteristics—physical properties and chemical properties. *Physical properties* can be observed without changing the composition of the substance. Physical properties include density, color, hardness, freezing point, boiling point, and the ability to conduct an electric current.

Chemical properties describe how a substance reacts with other substances. For example, a chemical property of iron is that iron reacts with oxygen to form rust. Understanding the chemical properties of a substance requires knowing some basic information about the particles that make up all substances.

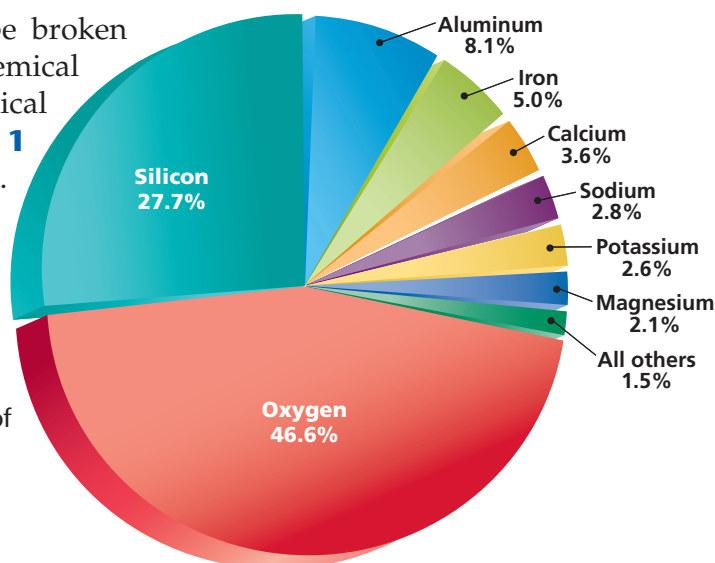
matter anything that has mass and takes up space

element a substance that cannot be separated or broken down into simpler substances by chemical means

Elements

An **element** is a substance that cannot be broken down into simpler, stable substances by chemical means. Each element has physical and chemical properties that can be used to identify it. **Figure 1** shows common elements in Earth's crust. Approximately 90 elements occur naturally on Earth. Eight of these make up more than 98% of Earth's crust.

Figure 1 This graph shows the percentage of total mass that each common element makes up in Earth's continental crust.



READING TOOLBOX

Comparison Table

As you read this page, create a comparison table for the terms *proton*, *electron*, and *neutron*.

atom the smallest unit of an element that maintains the chemical properties of that element

proton a subatomic particle that has a positive charge and that is located in the nucleus of an atom; the number of protons of the nucleus is the atomic number, which determines the identity of an element

electron a subatomic particle that has a negative charge

neutron a subatomic particle that has no charge and that is located in the nucleus of an atom

Academic Vocabulary

region (REE juhn) a specific surface or space; an area

Atoms

Elements consist of atoms. An **atom** is the smallest unit of an element that has the chemical properties of that element. Atoms cannot be broken down into smaller particles that will have the same chemical and physical properties as the atom. A single atom is so small that its size is difficult to imagine. To get an idea of how small it is, look at the thickness of this page. About a million atoms lined up side by side would be equal to that thickness.

Atomic Structure

Even though atoms are very tiny, they are made up of even smaller parts called *subatomic particles*. The three major kinds of subatomic particles are protons, electrons, and neutrons. **Protons** are subatomic particles that have a positive charge. **Electrons** are subatomic particles that have a negative charge. **Neutrons** are subatomic particles that are neutral, which means that they have no charge.

The Nucleus

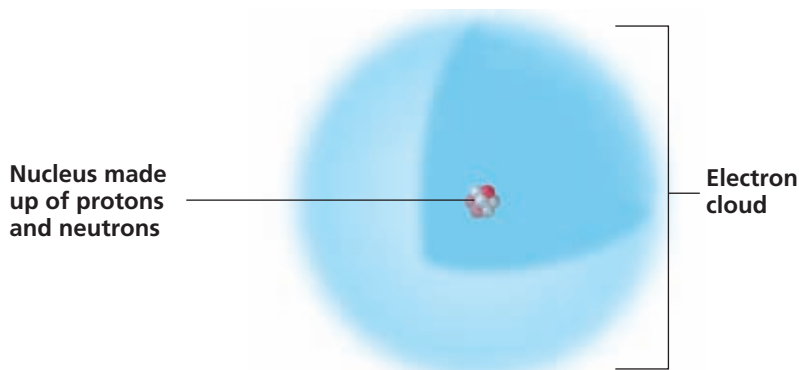
As shown in **Figure 2**, the protons and neutrons of an atom are packed close to one another. Together they form the *nucleus*, which is a small region in the center of an atom. The nucleus has a positive charge because protons have a positive charge and neutrons have no charge.

The nucleus makes up most of an atom's mass but very little of an atom's volume. If an atom's nucleus were the size of a gumdrop, the atom itself would be as big as a football stadium.

The Electron Cloud

The electrons of an atom move in a certain region of space called an *electron cloud* that surrounds the nucleus. Because opposite charges attract each other, the negatively charged electrons are attracted to the positively charged nucleus. This attraction is what holds electrons in the atom.

Figure 2 The nucleus of the atom is made up of protons and neutrons. The protons give the nucleus a positive charge. The negatively charged electrons are in the electron cloud that surrounds the nucleus.



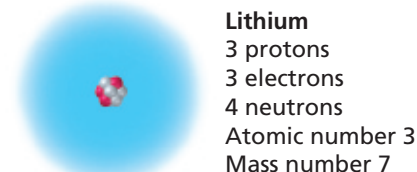
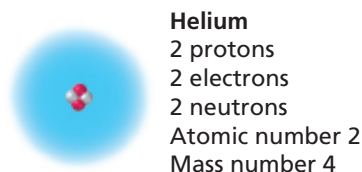
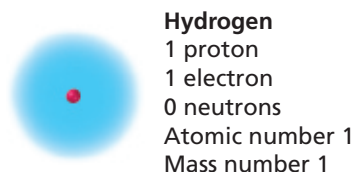


Figure 3 Hydrogen, helium, and lithium are unique, as indicated by their atomic numbers.


Atomic Number

The number of protons in the nucleus of an atom is called the *atomic number*. All atoms of any given element have the same atomic number. An element's atomic number sets the atoms of that element apart from the atoms of all other kinds of elements, as shown in **Figure 3**. Because an uncharged atom has an equal number of protons and electrons, the atomic number is also equal to the number of electrons in an atom of any given element.

Elements on the periodic table are ordered according to their atomic numbers. The *periodic table*, shown on the following pages, is a system for classifying elements. Elements in the same column on the periodic table have similar arrangements of electrons in their atoms. Elements that have similar arrangements of electrons have similar chemical properties.

Atomic Mass

The sum of the number of protons and neutrons in an atom is the *mass number*. The mass of a subatomic particle is too small to be expressed easily in grams. So, a special unit called the *unified atomic mass unit* (u) is used. Protons and neutrons each have an atomic mass that is close to 1 u. In contrast, electrons have much less mass than protons and neutrons do. The mass of 1 proton is equal to the combined mass of about 1,840 electrons. Because electrons add little to an atom's total mass, their mass can be ignored when calculating an atom's approximate mass.

 **Reading Check** What is the difference between **atomic number**, **mass number**, and **unified atomic mass unit**? (See Appendix G for answers to Reading Checks.)

Isotopes

Although all atoms of a given element contain the same number of protons, the number of neutrons may differ. For example, while most helium atoms have two neutrons, some helium atoms have only one neutron. An atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but has a different number of neutrons (and thus a different atomic mass) is called an **isotope** (IE suh TOHP).

A helium atom that has two neutrons is more massive than a helium atom that has only one neutron. Because of their different numbers of neutrons and their different masses, different isotopes of the same element have slightly different properties.

Quick Lab



10 min

Using the Periodic Table

Procedure

- 1 Use the **periodic table** to find the atomic numbers of the following elements: carbon, iron, molybdenum, and iodine.
- 2 Determine the number of protons and electrons that are in each neutral atom of the elements listed in step 1.
- 3 Find the average atomic masses of the elements listed in step 1.

Analysis

1. Use the atomic number and average atomic mass of each element to estimate the average number of neutrons in each atom of the elements listed in step 1 of this activity.
2. Which element has the largest difference between its average number of neutrons and the number of protons? Describe any trends that you observe.

isotope one of two or more atoms that have the same number of protons (atomic number) but different numbers of neutrons (atomic mass)

The Periodic Table of Elements

Period	1	<div>1 H Hydrogen 1.007 94</div>		<div>Key:</div> <div>Atomic number — 6</div> <div>Symbol — C</div> <div>Name — Carbon</div> <div>Average atomic mass — 12.0107</div>						
		Group 1	Group 2							
	2	<div>3 Li Lithium 6.941</div>	<div>4 Be Beryllium 9.012 182</div>							
	3	<div>11 Na Sodium 22.989 769 28</div>	<div>12 Mg Magnesium 24.3050</div>							
		Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9		
	4	<div>19 K Potassium 39.0983</div>	<div>20 Ca Calcium 40.078</div>	<div>21 Sc Scandium 44.955 912</div>	<div>22 Ti Titanium 47.867</div>	<div>23 V Vanadium 50.9415</div>	<div>24 Cr Chromium 51.9961</div>	<div>25 Mn Manganese 54.938 045</div>	<div>26 Fe Iron 55.845</div>	<div>27 Co Cobalt 58.933 195</div>
	5	<div>37 Rb Rubidium 85.4678</div>	<div>38 Sr Strontium 87.62</div>	<div>39 Y Yttrium 88.905 85</div>	<div>40 Zr Zirconium 91.224</div>	<div>41 Nb Niobium 92.906 38</div>	<div>42 Mo Molybdenum 95.96</div>	<div>43 Tc Technetium (98)</div>	<div>44 Ru Ruthenium 101.07</div>	<div>45 Rh Rhodium 102.905 50</div>
6	<div>55 Cs Cesium 132.905 4519</div>	<div>56 Ba Barium 137.327</div>	<div>57 La Lanthanum 138.905 47</div>	<div>72 Hf Hafnium 178.49</div>	<div>73 Ta Tantalum 180.947 88</div>	<div>74 W Tungsten 183.84</div>	<div>75 Re Rhenium 186.207</div>	<div>76 Os Osmium 190.23</div>	<div>77 Ir Iridium 192.217</div>	
7	<div>87 Fr Francium (223)</div>	<div>88 Ra Radium (226)</div>	<div>89 Ac Actinium (227)</div>	<div>104 Rf Rutherfordium (261)</div>	<div>105 Db Dubnium (262)</div>	<div>106 Sg Seaborgium (266)</div>	<div>107 Bh Bohrium (264)</div>	<div>108 Hs Hassium (277)</div>	<div>109 Mt Meitnerium (268)</div>	
						<div>58 Ce Cerium 140.116</div>	<div>59 Pr Praseodymium 140.907 65</div>	<div>60 Nd Neodymium 144.242</div>	<div>61 Pm Promethium (145)</div>	<div>62 Sm Samarium 150.36</div>
						<div>90 Th Thorium 232.038 06</div>	<div>91 Pa Protactinium 231.035 88</div>	<div>92 U Uranium 238.028 91</div>	<div>93 Np Neptunium (237)</div>	<div>94 Pu Plutonium (244)</div>

* The systematic names and symbols for elements greater than 111 will be used until the approval of trivial names by IUPAC.

THINK
central

RESOURCES

Keyword: Holt Periodic

* The systematic names and symbols for elements greater than 111 will be used until the approval of trivial names by IUPAC.



Hydrogen
Semiconductors
(also known as metalloids)

Metals

Alkali metals
Alkaline-earth metals
Transition metals
Other metals

Nonmetals

Halogens
Noble gases
Other nonmetals

(also known as metalloids)

Metals

Alkali metals

Alkaline-earth metals

Transition metals

Other metals

Nonmetals

Halogens

Noble gases

Other nonmetals

Group 10

Group 11

Group 12

Group 13

Group 14

Group 15

Group 16

Group 17

Group 18

			<div>5</div> <div>B</div> <div>Boron</div> <div>10.811</div>	<div>6</div> <div>C</div> <div>Carbon</div> <div>12.0107</div>	<div>7</div> <div>N</div> <div>Nitrogen</div> <div>14.0067</div>	<div>8</div> <div>O</div> <div>Oxygen</div> <div>15.9994</div>	<div>9</div> <div>F</div> <div>Fluorine</div> <div>18.998 4032</div>	<div>10</div> <div>Ne</div> <div>Neon</div> <div>20.1797</div>
			<div>13</div> <div>Al</div> <div>Aluminum</div> <div>26.981 5386</div>	<div>14</div> <div>Si</div> <div>Silicon</div> <div>28.0855</div>	<div>15</div> <div>P</div> <div>Phosphorus</div> <div>30.973 762</div>	<div>16</div> <div>S</div> <div>Sulfur</div> <div>32.065</div>	<div>17</div> <div>Cl</div> <div>Chlorine</div> <div>35.453</div>	<div>18</div> <div>Ar</div> <div>Argon</div> <div>39.948</div>
<div>28</div> <div>Ni</div> <div>Nickel</div> <div>58.6934</div>	<div>29</div> <div>Cu</div> <div>Copper</div> <div>63.546</div>	<div>30</div> <div>Zn</div> <div>Zinc</div> <div>65.38</div>	<div>31</div> <div>Ga</div> <div>Gallium</div> <div>69.723</div>	<div>32</div> <div>Ge</div> <div>Germanium</div> <div>72.64</div>	<div>33</div> <div>As</div> <div>Arsenic</div> <div>74.921 60</div>	<div>34</div> <div>Se</div> <div>Selenium</div> <div>78.96</div>	<div>35</div> <div>Br</div> <div>Bromine</div> <div>79.904</div>	<div>36</div> <div>Kr</div> <div>Krypton</div> <div>83.798</div>
<div>46</div> <div>Pd</div> <div>Palladium</div> <div>106.42</div>	<div>47</div> <div>Ag</div> <div>Silver</div> <div>107.8682</div>	<div>48</div> <div>Cd</div> <div>Cadmium</div> <div>112.411</div>	<div>49</div> <div>In</div> <div>Indium</div> <div>114.818</div>	<div>50</div> <div>Sn</div> <div>Tin</div> <div>118.710</div>	<div>51</div> <div>Sb</div> <div>Antimony</div> <div>121.760</div>	<div>52</div> <div>Te</div> <div>Tellurium</div> <div>127.60</div>	<div>53</div> <div>I</div> <div>Iodine</div> <div>126.904 47</div>	<div>54</div> <div>Xe</div> <div>Xenon</div> <div>131.293</div>
<div>78</div> <div>Pt</div> <div>Platinum</div> <div>195.084</div>	<div>79</div> <div>Au</div> <div>Gold</div> <div>196.966 569</div>	<div>80</div> <div>Hg</div> <div>Mercury</div> <div>200.59</div>	<div>81</div> <div>Tl</div> <div>Thallium</div> <div>204.3833</div>	<div>82</div> <div>Pb</div> <div>Lead</div> <div>207.2</div>	<div>83</div> <div>Bi</div> <div>Bismuth</div> <div>208.980 40</div>	<div>84</div> <div>Po</div> <div>Polonium</div> <div>(209)</div>	<div>85</div> <div>At</div> <div>Astatine</div> <div>(210)</div>	<div>86</div> <div>Rn</div> <div>Radon</div> <div>(222)</div>
<div>110</div> <div>Ds</div> <div>Darmstadtium</div> <div>(271)</div>	<div>111</div> <div>Rg</div> <div>Roentgenium</div> <div>(272)</div>	<div>112</div> <div>Uub*</div> <div>Ununbium</div> <div>(285)</div>	<div>113</div> <div>Uut*</div> <div>Ununtrium</div> <div>(284)</div>	<div>114</div> <div>Uuq*</div> <div>Ununquadium</div> <div>(289)</div>	<div>115</div> <div>Uup*</div> <div>Ununpentium</div> <div>(288)</div>	<div>116</div> <div>Uuh*</div> <div>Ununhexium</div> <div>(292)</div>	<div>118</div> <div>Uuo*</div> <div>Ununoctium</div> <div>(294)</div>	

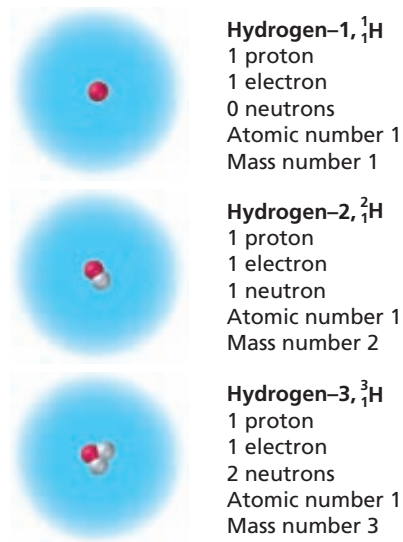


Figure 4 There are three naturally occurring isotopes of hydrogen. The main difference between these isotopes is their mass numbers.

SCILINKS

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 Topic: Valence Electrons
 Code: HQX1591

Average Atomic Mass

Because the isotopes of an element have different masses, the periodic table uses an average atomic mass for each element. The *average atomic mass* is the weighted average of the atomic masses of the naturally occurring isotopes of an element.

As shown in **Figure 4**, hydrogen has three isotopes. Each isotope has a different mass because each has a different number of neutrons. By calculating the weighted average of the atomic masses of the three naturally occurring hydrogen isotopes, you can determine the average atomic mass. As noted on the periodic table, the average atomic mass of hydrogen is 1.007 94 u.

Valence Electrons and Periodic Properties

Based on similarities in their chemical properties, elements on the periodic table are arranged in columns, which are called *groups*. An atom's chemical properties are largely determined by the number of the outermost electrons in an atom's electron cloud. These electrons are called *valence* (VAY luhns) *electrons*.

Within each group, the atoms of each element generally have the same number of valence electrons. For Groups 1 and 2, the number of valence electrons in each atom is the same as that atom's group number. Atoms of elements in Groups 3–12 have 2 or more valence electrons. For Groups 13–18, the number of valence electrons in each atom is the same as that atom's group number minus 10, except for helium, He. It has only two valence electrons. Atoms in Group 18 have 8 valence electrons. When an atom has 8 valence electrons, it is considered stable, or chemically unreactive. Unreactive atoms do not easily lose or gain electrons.

Elements whose atoms have only one, two, or three valence electrons tend to lose electrons easily. These elements have metallic properties and are generally classified as *metals*. Elements whose atoms have from four to seven valence electrons are more likely to gain electrons. Many of these elements, which are in Groups 13–17, are classified as *nonmetals*.

Section 1 Review

Key Ideas

- 1. Compare** the physical properties of matter with the chemical properties of matter.
- 2. Describe** the basic structure of an atom.
- 3. Name** the three basic subatomic particles.
- 4. Compare** atomic number, mass number, and atomic mass.
- 5. Explain** how isotopes of an element differ from each other.

Critical Thinking

- 6. Evaluating Data** Oxygen combines with hydrogen and becomes water. Is this combination a result of the physical or chemical properties of hydrogen?
- 7. Making Comparisons** What sets an atom of one element apart from atoms of all other elements?

Concept Mapping

- 8.** Use the following terms to create a concept map: *matter, element, atom, electron, proton, neutron, atomic number, and periodic table.*

Combinations of Atoms

Key Ideas

- Define *compound* and *molecule*.
- Interpret chemical formulas.
- Describe two ways that electrons form chemical bonds between atoms.
- Explain the differences between compounds and mixtures.

Key Terms

compound	covalent bond
molecule	bond
ion	mixture
ionic bond	solution

Why It Matters

Most of the matter in the universe consists of a collection of electrons and ions. This state of matter, called plasma, is used in televisions, light bulbs, and other technologies.

Elements rarely occur in pure form in Earth's crust. They generally occur in combination with other elements. A substance that is made of two or more elements that are joined by chemical bonds between the atoms of those elements is called a **compound**. The properties of a compound differ from those of the elements that make up the compound, as shown in **Figure 1**.

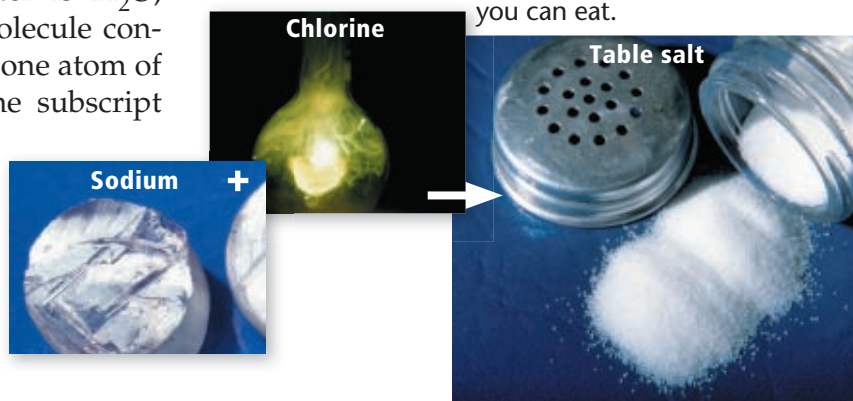
The smallest unit of a compound that can exist by itself and retain all of the compound's chemical properties is a molecule. A **molecule** is made of atoms that are chemically bonded together.

Some elements occur naturally as *diatomic molecules*, which are molecules that are made up of only two atoms. For example, the oxygen in the air you breathe is the diatomic molecule O_2 . The *O* in this notation is the symbol for oxygen. The subscript 2 indicates the number of oxygen atoms that are bonded together.

Chemical Formulas

In any given compound, the elements that make up the compound occur in the same relative proportions. Therefore, a compound can be represented by a chemical formula. A *chemical formula* is a combination of letters and numbers that shows which elements make up a compound. It also shows the number of atoms of each element that are required to make a molecule of a compound.

The chemical formula for water is H_2O , which indicates that each water molecule consists of two atoms of hydrogen and one atom of oxygen. In a chemical formula, the subscript that appears after the symbol for an element shows the number of atoms of that element that are in a molecule.

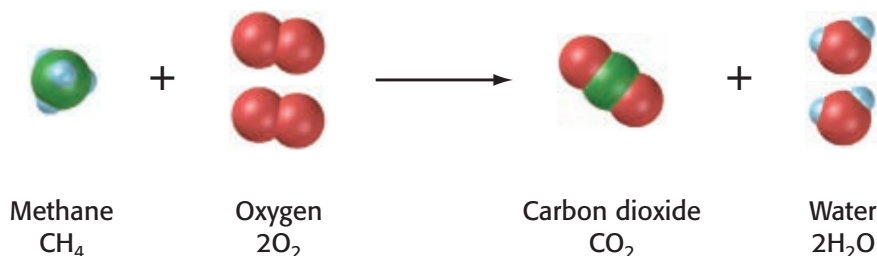


compound a substance made up of atoms of two or more different elements joined by chemical bonds

molecule a group of atoms that are held together by chemical forces

Figure 1 Sodium, a silvery metal, and chlorine, a poisonous, greenish-yellow gas, are both components of table salt, which you can eat.

Figure 2 Methane, CH₄, and oxygen gas, O₂, react during combustion to form the products carbon dioxide, CO₂, and water, H₂O. *How many hydrogen atoms are on each side of this reaction?*

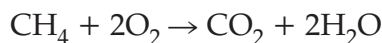


Chemical Equations

Elements and compounds often combine through chemical reactions to form new compounds. The reaction of these elements and compounds can be described in a *chemical equation*.

Equation Structure

In a chemical equation, such as the one shown below, the *reactants*, which are on the left-hand side of the arrow, form the *products*, which are on the right-hand side of the arrow. In a chemical equation, the arrow means “gives” or “yields.”



In this equation, one molecule of methane, CH₄, reacts with two molecules of oxygen, O₂, to yield one molecule of carbon dioxide, CO₂, and two molecules of water, H₂O, as shown in **Figure 2**.

Balanced Equations

Chemical equations are useful for showing the types and amounts of the products that could form from a particular set of reactants. However, the equation must be balanced to show this information. A chemical equation is balanced when the number of atoms of each element on the right side of the equation is equal to the number of atoms of the same element on the left side.

To balance an equation, you cannot change the chemical formulas. Changing the formulas would mean that different substances were in the reaction. To balance an equation, you must put numbers called *coefficients* in front of chemical formulas.

On the left side of the equation above, the methane molecule has four hydrogen atoms, which are indicated by the subscript 4. On the right side, each water molecule has two hydrogen atoms, which are indicated by the subscript 2. A coefficient of 2 is placed in front of the formula for water to balance the number of hydrogen atoms. A coefficient multiplies the subscript in a formula. For example, four hydrogen atoms are in the formula 2H₂O.

A coefficient of 2 is also placed in front of the oxygen molecule on the left side of the equation so that both sides of the equation have four oxygen atoms. When the number of atoms of each element is the same on both sides of the equation, the equation is balanced.

Math Skills

Balancing Equations

Magnesium, Mg, reacts with oxygen gas, O₂, to form magnesium oxide, MgO. Write a balanced chemical equation for this reaction by placing the coefficients that are needed to obtain an equal number of magnesium and oxygen atoms on either side of the equation.

Chemical Bonds

The forces that hold together the atoms in molecules are called *chemical bonds*. Chemical bonds form because of the attraction between positive and negative charges. Atoms form chemical bonds by either sharing or transferring valence electrons from one atom to another. Transferring or sharing valence electrons from one atom to another changes the properties of the substance. Variations in the forces that hold molecules together are responsible for a wide range of physical and chemical properties.

As shown in **Figure 3**, scientists can study interactions of atoms to predict which kinds of atoms will form chemical bonds together. Scientists do this by comparing the number of valence electrons that are present in a particular atom with the maximum number of valence electrons that are possible. For example, a hydrogen atom has only one valence electron. But because hydrogen can have two valence electrons, it will give up or accept another electron to reach a more chemically unreactive state.

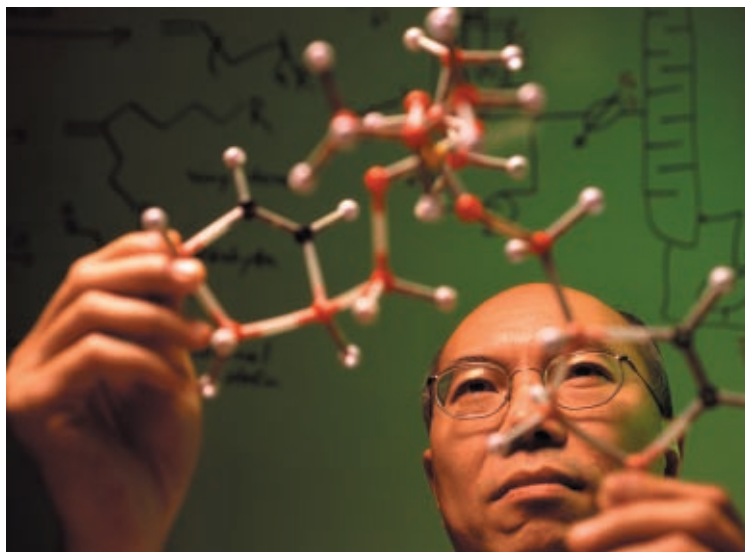


Figure 3 Scientists sometimes make physical models of molecules to better understand how chemical bonds affect the properties of compounds.

 **Reading Check** In what two ways do atoms form chemical bonds?

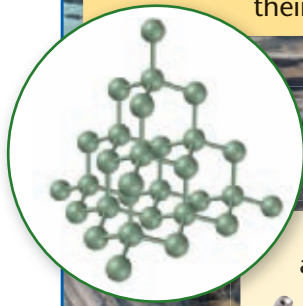
Academic Vocabulary

transfer (TRANS fuhr) to carry or cause to pass from one thing to another

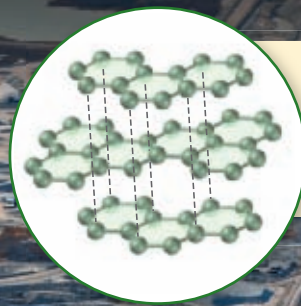
Why It Matters

How Can Diamond and Graphite Both Be Carbon?

Diamonds are valued for their sparkle, and diamond-coated blades can cut through granite. The soft black graphite in your pencil is also used in powdered form as an industrial lubricant. But diamonds and graphite are both made of pure carbon. The extreme differences in their properties are because of differences in how their carbon atoms are bonded together.



Diamond is made of carbon atoms joined in a tetrahedral arrangement, forming a rigid three-dimensional crystal.



Graphite is made of carbon atoms arranged in layers, with weak bonds between the layers.

**REAL
WORLD**

**YOUR
TURN**

ONLINE RESEARCH

Research artificial diamonds. Make a poster to display how they are made and used.

ion an atom or molecule that has gained or lost one or more electrons and has a negative or positive charge

ionic bond the attractive force between oppositely charged ions, which form when electrons are transferred from one atom or molecule to another

SCILINKS

www.scilinks.org

Topic: Covalent and Ionic Bonds

Code: HQX0362

READING TOOLBOX

Double-Door Fold

Create a double-door fold. Label one door "Ionic bond" and the other door "Covalent bond." Write notes about these terms behind each door.



Ions

When an electron is transferred from one atom to another, both atoms become charged. A particle, such as an atom or molecule, that carries a charge is called an **ion**.

Neutral sodium atoms have 11 electrons. And because a sodium atom has 1 valence electron, sodium is a Group 1 element on the periodic table. If a sodium atom loses its outermost electron, the next 8 electrons in the atom's electron cloud become the outermost electrons. Because the sodium atom now has 8 valence electrons, it is unlikely to share or transfer electrons and, therefore, is stable.

However, the sodium atom is missing the 1 electron that was needed to balance the number of protons in the nucleus. When an atom no longer has equal numbers of positive and negative charges, it becomes an ion. The sodium atom became a positive sodium ion, Na^+ , when the atom released its valence electron.

Suppose a chlorine atom accepts the electron that the above sodium atom lost. A chlorine atom has a total of 17 electrons, 7 of which are valence electrons. This chlorine atom now has a complete set of 8 valence electrons and is chemically stable. The extra electron, however, changes the neutral chlorine atom into a negatively charged chloride ion, Cl^- .

Ionic Bonds



The attractive force between oppositely charged ions that result from the transfer of electrons from one atom to another is called an **ionic bond**. A compound that forms through the transfer of electrons is called an *ionic compound*. Most ionic compounds form when electrons are transferred between the atoms of metallic and non-metallic elements.

Sodium chloride, or common table salt, is an ionic compound. The positively charged sodium ions and negatively charged chloride ions attract one another because of their opposite charges. This attraction between the positive sodium ions and the negative chloride ions is an ionic bond. The attraction creates cube-shaped crystals, such as in the table salt shown in **Figure 4**.

Figure 4

Ionic Bonds		
	A sodium atom, Na, transfers an electron to a chlorine atom, Cl, to form table salt, NaCl. The chlorine atom with the added electron becomes a negatively charged ion, Cl^- , and the sodium atom, which lost the electron, becomes a positively charged ion, Na^+ . The oppositely charged ions attract each other and form an ionic bond.	
		Table salt, NaCl

Figure 5

Covalent Bonds		
	Covalent bonds form when atoms share one or more pairs of electrons. In a covalent compound, pairs of electrons are shared between most of the atoms that make up the compound. Some elements also contain covalent bonds. In molecules of chlorine, two chlorine atoms are bonded together by sharing electrons.	

Chlorine gas, Cl_2

Covalent Bonds

A bond that is formed by the attraction between atoms that share electrons is a **covalent bond**. When atoms share electrons, the positive nucleus of each atom is attracted to the shared negative electrons, as shown in **Figure 5**. The pull between the positive and negative charges is the force that keeps these atoms joined.

Water is an example of a *covalent compound*—that is, a compound formed by the sharing of electrons. Two hydrogen atoms can share their single valence electrons with an oxygen atom that has six valence electrons. The sharing of electrons creates a bond and gives oxygen a stable number of eight outermost electrons. At the same time, the oxygen atom shares two of its electrons—one for each hydrogen atom—which gives each hydrogen atom a more stable number of two electrons. Thus, a water molecule consists of two atoms of hydrogen bonded with one atom of oxygen.

Polar Covalent Bonds

In many cases, atoms that are covalently bonded do not equally share electrons. The reason for this is that the ability of atoms of some elements to attract electrons from atoms of other elements differs. A covalent bond in which the bonded atoms have an unequal attraction for the shared electrons is called a *polar covalent bond*. Water is an example of a molecule that forms as a result of polar covalent bonds. Two hydrogen atoms bond covalently with an oxygen atom and form a water molecule. Because the oxygen atom has more ability to attract electrons than the hydrogen atoms do, the electrons are not shared equally between the oxygen and hydrogen atoms. Instead, the electrons remain closer to the oxygen nucleus, which has the greater pull. As a result, the water molecule as a whole has a slightly negative charge at its oxygen end and slightly positive charges at its hydrogen ends. The slightly positive ends of a water molecule attract the slightly negative ends of other water molecules.

 **Reading Check** Why do water molecules form from polar covalent bonds?

covalent bond a bond formed when atoms share one or more pairs of electrons

Quick Lab


10 min

Compounds



Procedure

- 1 Place **4 g of compound A** in a **clear plastic cup**.
- 2 Place **4 g of compound B** in a **second clear plastic cup**.
- 3 Observe the color and texture of each compound. Record your observations.
- 4 Add **5 mL of vinegar** to each cup. Record your observations.

Analysis

1. What physical and chemical differences between the two compounds did you record? How do physical properties and chemical properties differ?
2. Vinegar reacts with baking soda but not with powdered sugar. Which of these compounds is compound A, and which is compound B?

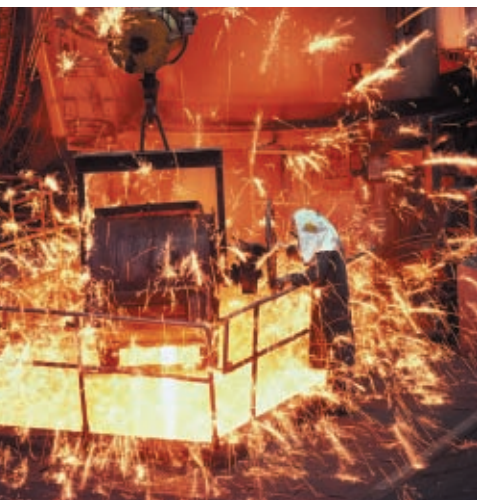


Figure 6 The steel that is being smelted in this steel mill in Iowa is a solution of iron, carbon, and various other metals such as nickel, chromium, and manganese.

mixture a combination of two or more substances that are not chemically combined

solution a homogeneous mixture throughout which two or more substances are uniformly dispersed

Mixtures

On Earth, elements and compounds are generally mixed together. A **mixture** is a combination of two or more substances that are not chemically combined. The substances that make up a mixture keep their individual properties. Therefore, unlike a compound, a mixture can be separated into its parts by physical means. For example, you can use a magnet to separate a mixture of powdered sulfur, S, and iron, Fe, filings. The magnet will attract the iron, which is magnetic, and leave behind the sulfur, which is not magnetic.

Heterogeneous Mixtures

Mixtures in which two or more substances are not uniformly distributed are called *heterogeneous mixtures*. For example, the igneous rock granite is a heterogeneous mixture of crystals of the minerals quartz, feldspar, hornblende, and biotite.

Homogeneous Mixtures

In chemistry, the word *homogeneous* means “having the same composition and properties throughout.” A homogeneous mixture of two or more substances that are uniformly dispersed throughout the mixture is a **solution**.

Any part of a given sample of the solution known as sea water, for example, will have the same composition. Sodium chloride, NaCl, (along with many other ionic compounds) is dissolved in sea water. The positive ends of water molecules attract negative chloride ions. And the negative ends of water molecules attract positive sodium ions. Eventually, all of the sodium and chloride ions become uniformly distributed among the water molecules.

Gases and solids can also be solutions. An *alloy* is a solution composed of two or more metals. The steel shown in **Figure 6** is an example of such a solution, both in liquid and solid states.

Section 2 Review

Key Ideas

1. **Define** the term *compound*.
2. **Determine** the number of each type of atom in the following chemical formula: $C_6H_{12}O_6$.
3. **Explain** why atoms join to form molecules.
4. **Describe** the difference between ionic and covalent bonds.
5. **Explain** why a water molecule has polar covalent bonds.
6. **Compare** compounds and mixtures.
7. **Identify** two common solutions.

Critical Thinking

8. **Applying Ideas** What happens to the chemical properties of a substance when it becomes part of a mixture?
9. **Evaluating Data** If you were given two mixtures and told that one is a solution, how might you determine which one is the solution?

Concept Mapping

10. Use the following terms to create a concept map: *compound, molecule, ionic compound, ionic bond, ion, covalent compound, and covalent bond*.

Not Such a Strange State



In elementary school, you learned about the three states of matter. But over 99.9% of the matter in the universe is not in the gas, liquid, or solid state. Instead, it is in a state called *plasma*. Very large amounts of energy can split gaseous atoms apart. The resulting matter is plasma—a collection of negatively charged electrons and positively charged ions. All stars, including our sun, are giant plasmas. On Earth, natural plasmas are formed in very hot fires and during lightning. Artificial plasmas are used in fluorescent lamps and flat-screen televisions.



The huge current in a lightning bolt supplies the energy to heat the air to 30,000 °C, creating a plasma.



A high voltage in a noble gas, such as neon or xenon, produces the plasma in displays like this.

Electrical energy converts mercury vapor into plasma inside the tube of a compact fluorescent lamp.



YOUR TURN

UNDERSTANDING CONCEPTS

How is a gas different from a plasma?

ONLINE RESEARCH

Find out about other applications of plasma technology, besides televisions and lights. Describe at least two of these applications.

What You'll Do

- **Design** an experiment to test the physical properties of different metals.
- **Identify** unknown metals by comparing the data you collect and reference information.

What You'll Need

balance
beakers (several)
graduated cylinder
hot plate
magnet
metal samples, unknown, similarly shaped (several)
ruler, metric
stopwatch
water
wax

Safety



Physical Properties of Elements

In this lab, you will identify samples of various metals by collecting data and comparing the data with the reference information listed in the table below. Use at least two of the physical properties listed in the table to identify each metal.

Ask a Question

- 1 How can you use an element's physical properties to identify the element?

Form a Hypothesis

- 2 Use the table below to identify which physical properties you will test. Write a few sentences that describe your hypothesis and the procedure you will use to test those physical properties.

Test the Hypothesis

- 3 With your lab partner(s), decide how you will use the available materials to identify each metal that you are given. Because there are many ways to measure some of the physical properties that are listed in the table below, you may need to use only some of the materials that are provided.
- 4 Before you start to test your hypothesis, list each step that you will need to perform.
- 5 After your teacher approves your plan, perform your experiment. Keep in mind that the more exact your measurements are, the easier it will be for you to identify the metals that you have been provided.

- 6 Record all the data that you collect and any observations that you make.

Physical Properties of Some Metals

Metal	Density (g/cm ³)	Relative hardness	Relative heat conductivity	Magnetic attraction
Aluminum, Al	2.7	28	100	No
Iron, Fe	7.9	50	34	Yes
Nickel, Ni	8.9	67	38	Slight
Tin, Sn	7.3	19	28	No
Tungsten, W	19.3	100	73	No
Zinc, Zn	7.1	28	49	No

How to Measure Physical Properties of Metals

Physical property	Description	How to measure the property
Density	mass per unit volume	If the metal is box-shaped, measure its length, height, and width, and then use these measurements to calculate the metal's volume. If the shape of the metal is irregular, add the metal to a known volume of water and determine what volume of water is displaced.
Relative hardness	how easy it is to scratch the substance	An object that has a high hardness value can scratch an object that has a lower value, but not vice versa.
Relative heat conductivity	how quickly a metal heats or cools	A metal that has a value of 100 will heat or cool twice as quickly as a metal that has a value of 50.
Magnetism	whether an object is magnetic	If a magnet placed near a metal attracts the metal, the metal is magnetic.

Analyze the Results

- 1. Summarizing Data** Make a table that lists which physical properties you compared and what data you collected for each of the metals that you tested.
- 2. Making Comparisons** Which physical properties were the easiest for you to measure and compare? Which were the most difficult to measure and compare? Explain why.
- 3. Applying Ideas** What would happen if you tried to use zinc to scratch aluminum?

Draw Conclusions

- 4. Summarizing Results** Which metals were given to you? Explain how you identified each metal.
- 5. Analyzing Methods** Explain why you would have difficulty distinguishing between iron and nickel unless you were to measure each metal's density.



Extension

Evaluating Data Suppose you find a metal fastener that has a density of 7 g/cm^3 . What are two ways to determine whether the unknown metal is tin or zinc?

Element Resources in the United States



Map Skills Activity

This map shows the distribution of five elements that are used as resources in the United States. Use the map to answer the questions below.

- Using a Key** Use the map to locate the state in which you live. Are any of the elements from the key found in your state?
- Analyzing Relationships** Can you identify any relationship between the locations of lead deposits and the locations of zinc deposits? Explain your reasoning.
- Inferring Relationships** Is it possible to use this map to find out which states have the highest production of the mineral resources that are listed on the map? Why or why not?
- Inferring Relationships** Silver is mainly recovered as a byproduct of the bulk mining of other metals such as copper, lead, zinc, and gold. Where in the United States do you think silver recovery would happen?
- Using a Key** Use the map to identify the states where uranium can be found.

Section 1



Key Ideas

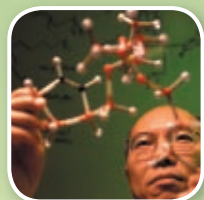
Matter

- › A physical property of matter can be observed without changing the composition of the substance. In contrast, a chemical property describes how a substance reacts with other substances to produce different substances.
- › An atom consists of electrons surrounding a nucleus that is made up of protons and neutrons.
- › The atomic number of an atom is equal to the number of protons in the atom. The mass number is equal to the sum of the protons and neutrons in the atom. Atomic mass is the mass of an atom, expressed in atomic mass units (amu). Protons and neutrons each have an atomic mass that is close to 1 amu.
- › An isotope is an atom that has the same number of protons as other atoms of the same element, but different numbers of neutrons.
- › Elements on the periodic table are arranged in groups that are based on similarities in the chemical properties of the elements.

Key Terms

matter, p. 87
element, p. 87
atom, p. 88
proton, p. 88
electron, p. 88
neutron, p. 88
isotope, p. 89

Section 2



Combinations of Atoms

- › A compound is a substance made up of atoms of two or more different elements joined by chemical bonds. A molecule is a group of atoms bonded together.
- › A chemical formula describes which elements and how many atoms of each of those elements make up a molecule of a compound.
- › Ionic bonds occur when electrons are transferred from one atom to another. Covalent bonds occur when electrons are shared between atoms.
- › A compound is a made up of atoms of two or more different elements joined by chemical bonds. A mixture consists of two or more substances that are not chemically bonded.

compound, p. 93
molecule, p. 93
ion, p. 96
ionic bond, p. 96
covalent bond, p. 97
mixture, p. 98
solution, p. 98

- 1. Everyday Words Used in Science** The words *compound* and *mixture* have different meanings in science contexts than in everyday speech. Write one sentence using each term in its science context. Write another sentence using each term in an everyday context.



USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *matter*
3. *neutron*
4. *ion*

For each pair of terms, explain how the meanings of the terms differ.

5. *atom* and *molecule*
6. *element* and *compound*
7. *proton* and *electron*
8. *compound* and *mixture*
9. *covalent bond* and *ionic bond*

UNDERSTANDING KEY IDEAS

10. Color and hardness are examples of a substance's
 - a. physical properties.
 - b. chemical properties.
 - c. atomic structure.
 - d. molecular properties.
11. Subatomic particles in atoms that do not carry an electric charge are called
 - a. neutrons.
 - b. protons.
 - c. nuclei.
 - d. ions.
12. Atoms of the same element that differ in mass are
 - a. ions.
 - b. neutrons.
 - c. isotopes.
 - d. molecules.

13. A combination of letters and numbers that indicates which elements make up a compound is a
 - a. coefficient.
 - b. reactant.
 - c. chemical bond.
 - d. chemical formula.
14. The type of chemical bond that forms between oppositely charged ions is a(n)
 - a. covalent bond.
 - b. mixture.
 - c. ionic bond.
 - d. solution.
15. Two or more elements whose atoms are chemically bonded form a(n)
 - a. mixture.
 - b. ion.
 - c. nucleus.
 - d. compound.
16. The outermost electrons in an atom's electron cloud are called
 - a. ions.
 - b. isotopes.
 - c. valence electrons.
 - d. neutrons.
17. A molecule of water, or H_2O , has one atom of
 - a. hydrogen.
 - b. oxygen.
 - c. helium.
 - d. osmium.

SHORT ANSWER

18. How do chemical properties differ from physical properties?
19. Define the term *element*.
20. Name three basic subatomic particles.
21. In terms of valence electrons, what is the difference between metallic elements and nonmetallic elements?
22. Which type of bonding includes the sharing of electrons?
23. Using the periodic table to help you to understand the following chemical formulas, list the name and number of atoms of each element in each compound: NaCl , H_2O_2 , Fe_3O_4 , and SiO_2 .

CRITICAL THINKING

- 24.** What sets an atom of one element apart from the atoms of all other elements?
- 25. Applying Ideas** Is a diatomic molecule more likely to be held together by a covalent bond or by an ionic bond? Explain your answer.
- 26. Making Inferences** Calcium chloride is an ionic compound. Carbon dioxide is a covalent compound. Which of these compounds forms as a result of the transfer of electrons from one atom to another? Explain your answer.
- 27. Analyzing Relationships** What happens to the chemical properties of a substance when it becomes part of a mixture? Explain your answer.
- 28. Classifying Information** Oxygen combines with hydrogen to form water. Is this process due to the physical or chemical properties of oxygen and hydrogen?

CONCEPT MAPPING

- 29.** Use the following terms to create a concept map: *chemical property, element, atom, electron, proton, neutron, atomic number, mass number, isotope, compound, and chemical bond.*

MATH SKILLS

Math Skills

- 30. Making Calculations** How many neutrons does a potassium atom have if its atomic number is 19 and its mass number is 39?
- 31. Using Formulas** The covalent compound formaldehyde forms when one carbon atom, two hydrogen atoms, and one oxygen atom bond. Write a chemical formula for formaldehyde.
- 32. Balancing Equations** Zinc metal, Zn, will react with hydrochloric acid, HCl, to produce hydrogen gas, H₂, and zinc chloride, ZnCl₂. Write and balance the chemical equation for this reaction.

WRITING SKILLS

- 33. Organizing Data** Choose one of the eight most common elements in Earth's crust, and write a brief report on the element's atomic structure, its chemical properties, and its economic importance.
- 34. Communicating Main Ideas** Write a brief essay that describes how an element's chemical properties determine what other elements are likely to bond with that element.
- 35. Making Comparisons** Write a brief essay that describes the differences between atoms, elements, ions, and isotopes.

INTERPRETING GRAPHICS

The table below shows the average atomic masses and the atomic numbers of five elements. Use this table to answer the questions that follow.

Element	Symbol	Average atomic mass	Atomic number
Magnesium	Mg	24.3050	12
Tungsten	W	183.84	74
Copper	Cu	63.546	29
Silicon	Si	28.0855	14
Bromine	Br	79.904	35

- 36.** If an atom of magnesium has 12 neutrons, what is its mass number?
- 37.** Estimate the average number of neutrons in an atom of tungsten and in an atom of silicon.
- 38.** Which element has the largest difference between the number of protons and the number of neutrons in the nucleus of one of its atoms? Explain your answer.

Understanding Concepts

Directions (1–4): For each question, write on a separate sheet of paper the letter of the correct answer.

1. Soil is an example of
 - A. a solution.
 - B. a compound.
 - C. a mixture.
 - D. an element.
2. Isotopes are atoms of the same element that have different mass numbers. This difference is caused by
 - F. a different number of electrons in the atoms.
 - G. a different number of protons in the atoms.
 - H. a different number of neutrons in the atoms.
 - I. a different number of nuclei in the atoms.
3. Which of the following statements best describes the charges of subatomic particles?
 - A. Electrons have a negative charge, protons have a positive charge, and neutrons have no charge.
 - B. Electrons have a positive charge, protons have a negative charge, and neutrons have a positive charge.
 - C. Electrons have no charge, protons have a positive charge, and neutrons have a negative charge.
 - D. In neutral atoms, protons, neutrons, and electrons have no charges.
4. An element is located on the periodic table according to
 - F. when the element was discovered.
 - G. the letters of the element's chemical symbol.
 - H. the element's chemical name.
 - I. the element's chemical properties.

Directions (5–6): For each question, write a short response.

5. What is the name for an atom that has gained or lost one or more electrons and has acquired a charge?
6. Scientists use atomic numbers to help identify the atoms of different elements. How is the atomic number of an element determined?

Reading Skills

Directions (7–9): Read the passage below. Then, answer the questions.

Chemical Formulas

All substances can be formed by a combination of elements from a list of about 100 possible elements. Each element has a chemical symbol. A chemical formula is shorthand notation that uses chemical symbols and numbers to represent a substance. A chemical formula shows the amount of each kind of atom present in a specific molecule of a substance.

The chemical formula for water is H_2O . This formula tells you that one water molecule is composed of two atoms of hydrogen and one atom of oxygen. The 2 in the formula is a subscript. A subscript is a number written below and to the right of a chemical symbol in a formula. When a symbol, such as the O for oxygen in water's formula, has no subscript, only one atom of that element is present.

7. What does a subscript in a chemical formula represent?
 - A. Subscripts represent the number of atoms of the chemical symbol they directly follow present in the molecule.
 - B. Subscripts represent the number of atoms of the chemical symbol they directly precede present in the molecule.
 - C. Subscripts represent the number of protons present in each atom's nucleus.
 - D. Subscripts represent the total number of atoms present in a molecule.
8. Which of the following statements can be inferred from the information in the passage?
 - F. Two atoms of hydrogen are always present in chemical formulas.
 - G. A chemical formula indicates the elements that a molecule is made of.
 - H. Chemical formulas can be used only to show simple molecules.
 - I. No more than one atom of oxygen can be present in a chemical formula.
9. How many atoms would be found in a single molecule that has the chemical formula S_2F_{10} ?

Interpreting Graphics

Directions (10–14): For each question below, record the correct answer on a separate sheet of paper.

The graphic below shows the upper right segment of the periodic table. Use this graphic to answer questions 10 through 12.

Segment of the Periodic Table

					18 2 He 4.00
13 5 B 10.81	14 6 C 12.01	15 7 N 14.01	16 8 O 16.00	17 9 F 19.00	10 Ne 20.18
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95

10. Which pair of elements would most likely have a similar arrangement of outer electrons and have similar chemical behaviors?

- A. boron and aluminum
- B. helium and fluoride
- C. carbon and nitrogen
- D. chlorine and oxygen

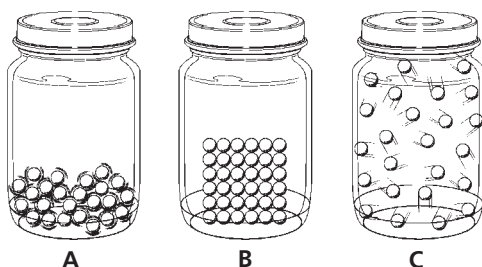
11. What is the atomic mass of helium?

- F. 0.18
- G. 0.26
- H. 2.00
- I. 4.00

12. How many neutrons does the average helium atom contain?

The graphic below shows matter in three different states. Use this graphic to answer questions 13 and 14.

States of Matter



13. In what physical state is the matter in jar A?

- A. solid
- B. liquid
- C. gas
- D. plasma

14. Explain how the positions and motions of particles determine the characteristics of each state of matter.

Test Tip

Double check (with a calculator, if permitted) all mathematical computations involved in answering a question.