3 Properties of Matter: Opposites Attract

Learning Objectives

As you work through this chapter you will learn how to:

- classify materials as pure substances or mixtures.
- distinguish between chemical and physical changes.
- describe the subatomic composition of atoms and ions.
- identify fundamental properties of the chemical elements.
- distinguish between ionic and molecular compounds.
- write correct chemical formulas and names for compounds.

3.1 Classification of Matter

Two of the principal goals of **chemistry** are to identify the composition of **matter**, any substance that has mass and occupies space, and to provide an explanation for the chemical and physical properties of various substances. **Chemical properties** are those that involve a substance undergoing a change into a new substance. In contrast, **physical properties** are inherent characteristics of a substance and do not involve a change in composition. For example, two of the chemical properties of aluminum are its tendency to react with acids to produce hydrogen gas and its tendency to react with oxygen with the release of a large amount of energy. Aluminum's physical properties include its silver-gray metallic appearance, a density of 2.7 g/cm^3 and a melting point of 660 °C. Chemists have developed a useful classification system that allows us to anticipate the composition and properties of a wide range of common materials. The first stage of this classification system is shown in Figure 3.1.

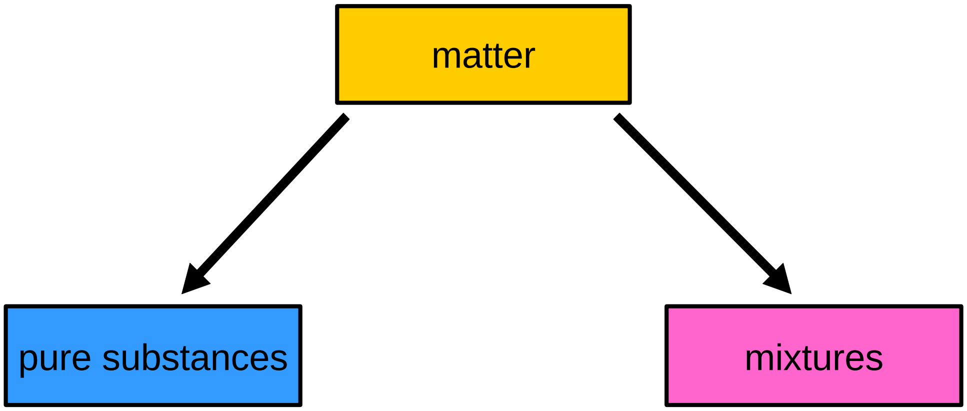


Figure 3.1 Basic classification of matter

Pure substances have a fixed composition and, because of this, have very specific properties like our aluminum example. Since the composition is always the same, a unique chemical formula can be written for a pure substance. There are two categories of pure substances, **elements** and **compounds**.

Chemical elements are the basic building blocks of matter. An **atom** is the smallest unit of an element that can exist. The atoms of each element are unique in their composition and properties, and, according to atomic theory, all atoms of a given element have the same chemical properties. Presently there are 118 known elements.[1] Each element has a unique name and chemical symbol. The names and symbols for a number of common elements are shown in Table 3.1. It is important that you learn the names and symbols for these elements. You will be using them throughout the course.

pictures of common elements

[1]There are 94 naturally-occurring elements and 24 elements that have been made by nuclear reactions. More information can be found at **http://www.webelements.com/**.

Table 3.1 Names and Chemical Symbols of Common Elements

Names and Symbols of Common Elements[‡]					
Element	Symbol	Element	Symbol	Element	Symbol
Aluminum	Al	Gold	Au	Phosphorus	P
Argon	Ar	Helium	He	Platinum	Pt
Arsenic	As	Hydrogen	H	Potassium	K
Barium	Ba	Iodine	I	Rubidium	Rb
Boron	B	Iron	Fe	Silicon	Si
Bromine	Br	Lead	Pb	Silver	Ag
Cadmium	Cd	Lithium	Li	Sodium	Na
Calcium	Ca	Magnesium	Mg	Strontium	Sr
Carbon	C	Manganese	Mn	Sulfur	S
Chlorine	Cl	Mercury	Hg	Tin	Sn
Chromium	Cr	Neon	Ne	Titanium	Ti
Cobalt	Co	Nickel	Ni	Uranium	U
Copper	Cu	Nitrogen	N	Zinc	Zn
Fluorine	F	Oxygen	O		

[‡]The chemical symbols for the elements are either one or two letters. The single letter symbol or the first letter of a two-letter symbol is always capitalized. Some symbols are derived from earlier names (usually in Latin) for the element; for example, Na for sodium comes from the Latin *natrium*.

Chemical compounds are pure substances containing two or more chemically combined elements. Hydrogen peroxide and sodium chloride are examples of chemical compounds. Compounds are formed by chemical reactions between elements and/or other compounds.

3.2 How Matter Changes

A **chemical reaction**, or **chemical change**, is a process that produces one or more new substances by rearrangement of the atoms present. Usually the new substances produced in chemical reactions have properties very different than the original material so you can readily identify that a chemical change has occurred. However, in some instances the formation of a new substance may be difficult to detect and a chemical analysis is needed to confirm this. When an iron nail rusts it reacts with oxygen in the air to form a reddish-brown material that flakes off the surface of the nail. This rust has a very different appearance and properties compared to the nail so you expect that a new substance was formed by a chemical change. In a similar way, the formation of carbon dioxide and water in the combustion of gasoline suggests that a chemical reaction has occurred.

On the other hand, a **physical change** is a process that does not produce a new substance. The melting of ice is a physical change because the ice and the liquid that forms are both water even though its appearance has changed. When sugar is dissolved in water the composition of both the sugar and the water do not change and no new substance is formed. If you allow the water to evaporate from a glass of sugar water, the solid that remains is sugar. If you gently heat the sugar water and allow the gas that comes off to condense in a separate container you can recover the water. You can distinguish between chemical and physical changes by remembering:

Chemical changes produce new substances, physical changes do not.

Check for Understanding 3.1

Solutions

1. Indicate whether each of the following is primarily a chemical change or a physical change.

a) painting a wall
b) boiling water
c) frying an egg
d) grating cheese
e) burning a match

2. Indicate one chemical property and one physical property of the element hydrogen.

3.3 Mixtures

In contrast to pure substances, **mixtures** have a variable composition so their properties are not as well defined and they do not have a specific chemical formula. They are created by mechanically blending together different substances. For example, you can create a potting soil mixture by combining various amounts of sand and peat moss depending upon the needs of your plants. As you change the proportions of sand and peat moss, properties like drainage change. This variation in properties with a variation in composition is typical of all mixtures.

Mixtures are further classified as homogeneous or heterogeneous. A **homogeneous mixture**, also known as a **solution**, has a uniform composition throughout. It, like pure substances, consists of a single phase.[2] If a teaspoon of salt is completely dissolved in water and thoroughly mixed, it forms a homogeneous mixture. A sample from any part of this mixture will have the same composition. However, if you put an excessive amount of salt in a glass of water, not all of the salt will dissolve no matter how much mixing you do. You have created a **heterogeneous mixture**. A heterogeneous mixture does not have a uniform composition throughout. In this case, there is a liquid phase with the salt dissolved in the water that has a very different composition than the undissolved salt portion. Heterogeneous mixtures have two or more distinct phases. Figure 3.2 shows an expanded classification scheme for matter.

Metal alloys like steel are solid homogeneous mixtures of elements. Steel is primarily iron mixed with a small amount of carbon. White gold is an alloy of gold, nickel and palladium. In both instances the composition of the mixture is uniform throughout and therefore only a single phase is present.

pictures of homogeneous and heterogeneous mixtures

---

[2]A **phase** refers to a portion of a substance with a specific composition and hence appearance. It does not have to be a different **physical state** (solid, liquid or gas) than another phase.

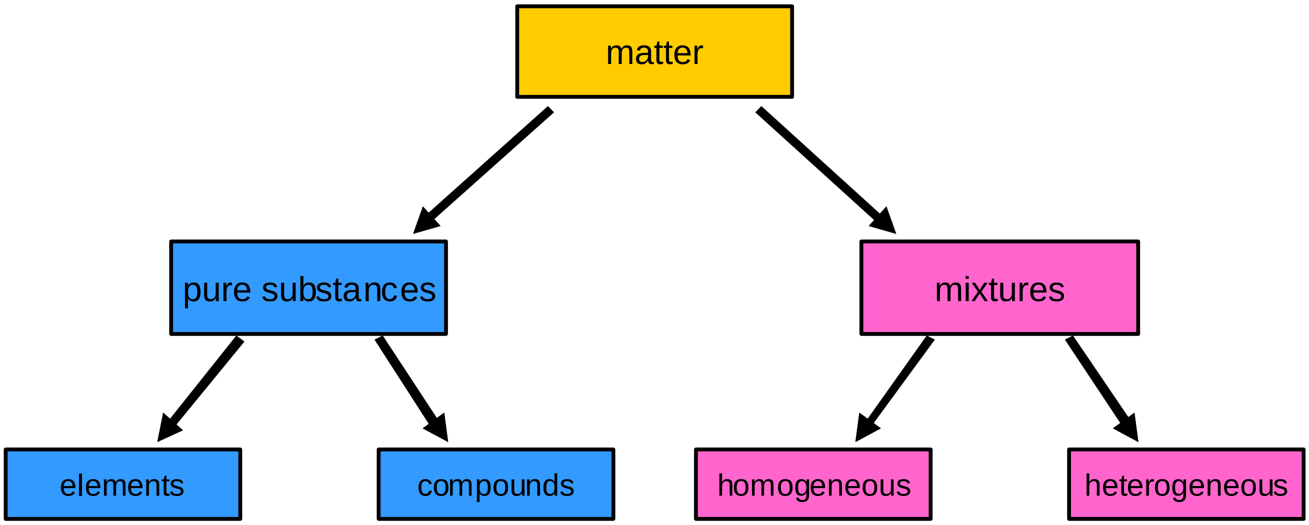


Figure 3.2 Expanded classification scheme for matter

Sometimes it is difficult to identify distinct phases when the phases occur on the microscopic level. For example, how would you classify blood? First, you expect blood to be a mixture because there are many different blood cells and substances in blood, and the composition of blood can vary for a given individual from hour to hour (for example, your blood sugar level is not constant throughout the day). Classifying blood as homogeneous or heterogeneous is not as obvious. It looks rather uniform, however, under a microscope a drop of blood clearly displays different phases; there is a liquid phase that contains solids (cells and cell fragments) of different composition. Consequently, blood is classified as a heterogeneous mixture. For our discussions we will consider a mixture as heterogeneous if it displays more than one phase upon visual inspection with the naked eye.

When chemists perform experiments they try to control as many variables as possible. One important control is having information about all of the substances involved in an experiment. Thus, chemists use pure substances in their experiments as much as possible. Since the composition of a pure substance is known, the chemist has more information about what is involved in the experiment than if a mixture is used. A chemist may also choose to use a homogeneous mixture (a solution) if it is carefully prepared with a known composition. Most materials that you encounter every day are not pure substances but are mixtures. Can you think of any common items around the home that are pure substances?

Check for Understanding 3.2 **Solutions**

1. Indicate whether each of the following is a pure substance or a mixture.

   a) gold c) rubbing alcohol e) carbon monoxide

   b) flour d) stainless steel f) lead

2. Indicate whether each of the following is a homogeneous or heterogeneous mixture.

   a) wood b) Jell-O c) vodka d) silver-plated jewelry

3.4 Atomic Structure

Have you ever walked across a carpet on a dry day and gotten a shock when you touched someone or something? The shock you felt was a result of **static electricity**. Static electricity is the accumulation of electric charge on an object. The shock occurred as the accumulated charge was released. This is the same phenomenon that occurs with lightning discharges. One might wonder where this charge comes from.

There are two forms of electric charge in nature, positive and negative. You may know that opposite charges (positive and negative) attract and that like charges repel each other. The **electrostatic force** (F) of attraction or repulsion between two charges is described by **Coulomb's law**, which can be represented mathematically by

$$F = k\frac{q_1 q_2}{r^2} \tag{3.1}$$

where k is a numerical constant;
q_1 and q_2 are the magnitudes (sizes) of the electric charges;
r is the distance between charge centers.

This equation indicates that the force of attraction or repulsion increases as the size of the charges increases (bigger q_1 and q_2) and as the charges get closer (smaller r). This law, first published in 1783 by the French physicist Charles Augustin de Coulomb, is an especially important one in chemistry. Essentially all of the interactions that are of interest to chemists involve the attractions and repulsions of electric charges.

As incredibly small as atoms are, they are composed of even smaller units called **subatomic particles**. The **electron** is the lightest, stable subatomic particle that is known. It carries an electric charge that is believed to be the basic negative charge in nature. All atoms contain electrons, however, since atoms are electrically neutral, there must also be a source of positive electric charge present. A **proton** is the subatomic particle with a positive electric charge, equal in magnitude to the charge of an electron. The number of electrons in an atom always equals the number of protons present. There is another subatomic particle found in atoms, the **neutron**. A neutron has no net electric charge. These subatomic particles differ in a number ways other than their electric charge. The proton and neutron are very similar in mass (the neutron mass is just slightly larger) and they are almost 2000 times heavier than the electron. Protons and neutrons are found in the very dense center of the atom called the **atomic nucleus** while the electrons are in motion outside the nucleus. These properties are summarized in Table 3.2.

Table 3.2 Electric charge, location and mass properties of the proton, neutron and electron

Particle (symbol)	Location in atom	Relative electric charge‡	Mass (g)
proton (p)	nucleus	+1	1.673×10^{-24}
neutron (n)	nucleus	0	1.675×10^{-24}
electron (e^-)	outside the nucleus	-1	9.109×10^{-28}

‡The SI unit of electric charge is the coulomb (C). The magnitude of the electric charge carried by a proton or an electron equals 1.602×10^{-19} C.

As was mentioned, an individual atom is incredibly small. In fact, you could fit about 5 million atoms across the period at the end of this sentence. Yet these incredibly small entities make up all matter. A useful physical model is to picture the electrons outside the nucleus forming a cloud of negative charge resembling a sphere (see Fig. 3.3). This cloud represents the size of the atom. The diameter of a typical atom is on the order of 10^{-10} m (100 pm). The nucleus, at the center of this charge cloud, is even smaller with a diameter on the order of 10^{-15} m.

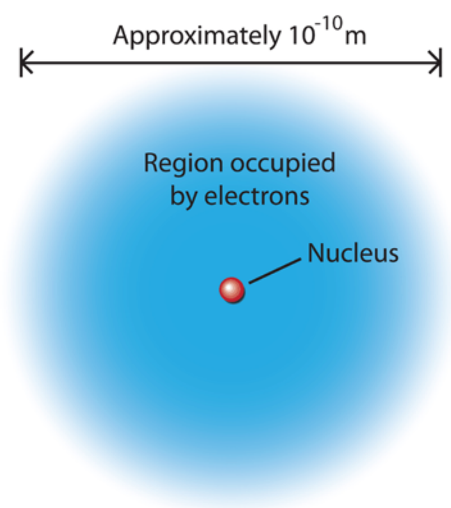


Figure 3.3 Representation of an atom (not to scale)

In order for an electric charge to accumulate on an object, either positive charge (protons) or negative charge (electrons) must be gained or lost. Electrons are more readily removed or added to atoms because the primary force holding them in place is the electrostatic attraction of the electrons to the positive charge of the nucleus. Protons, on the other hand, are bound together in the nucleus by the **nuclear force**. The nuclear force is an attractive force that acts between protons and neutrons. It is so strong that it prevents the positively-charged protons from repelling each other and leaving the nucleus. The number of protons and neutrons in an atom is not altered by chemical or physical changes, only by nuclear reactions. As you walk across the carpet on a dry day, your body picks up extra electrons that accumulate on your person until you touch some other object and the excess electrons are released when you get a shock. Although the atom's nucleus is important, it is the number and arrangement of the electrons in an atom that determine the chemical properties of an element.

You might wonder why the electrons are not eventually drawn to the opposite charge of the protons and end up in the nucleus. This question puzzled scientists for many years around the turn of the twentieth century. A simple but somewhat misleading explanation is that the motion of the electrons is what keeps them from being drawn into the nucleus. However, the factors responsible for atomic structure are much more complex than this. We will discuss some of this complexity in Chapter 7.

3.5 Chemical Elements and the Periodic Table

The atoms of each chemical element are unique in terms of subatomic particle composition. The **atomic number** (Z) is defined as the number of protons that are present in an atom. This number is what defines an atom as being a specific element. Each element has a unique atomic number. For example, if an atom has 6 protons it must be an atom of carbon because the atomic number of carbon is 6. Since the number of electrons always equals the number of protons in an atom, knowing the atomic number also provides us with the electron count. Thus, you can associate a specific number of protons and electrons with each element. In order to fully characterize the subatomic particle composition of an atom the number of neutrons must also be known. This is available from the **mass number** (A) of an atom. The mass number is the total number of protons plus neutrons in an atom. The number of neutrons is obtained by subtracting the atomic number from the mass number (number of neutrons = A - Z).

A shorthand notation (see Fig. 3.4) is used to provide information about the composition of an atom. The notation consists of the symbol of the element with the mass number on the upper left and the atomic number on the lower left. Since the chemical symbol fixes the atomic number, the lower number is often omitted. Thus, ^{14}C stands for an atom of carbon that has 6 protons, 6 electrons and 8 neutrons.

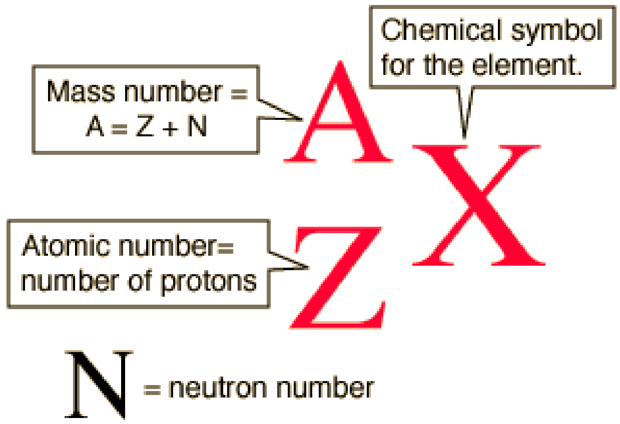


Figure 3.4 Shorthand notation for designating specific atoms

One of the most familiar images in chemistry textbooks, classrooms and laboratories is the **periodic table of the elements**. It is a visual representation of the chemical elements arranged into **groups** (vertical columns) and **periods** (horizontal rows). When the elements are arranged this way, it reflects regular trends in their properties. The Russian chemist Dmitri Mendeleev is credited with first proposing, in 1869, a periodic table consistent with the modern version. His arrangement of the known elements of the time allowed him to anticipate the discovery of as yet unknown elements. Figure 3.5 shows a simple version of the modern table. The elements are arranged according to increasing atomic number starting with hydrogen (Z=1) and moving from the left to right across the periods. Each element is assigned a location which is designated with the chemical symbol and atomic number of the element. Additional information about each element is displayed on more detailed periodic tables.

metals

nonmetals

metalloids

26 atomic number (Z)
Fe chemical symbol

1A	2A	3B	4B	5B	6B	7B		8B		1B	2B	3A	4A	5A	6A	7A	8A
1 **H**																	2 **He**
3 **Li**	4 **Be**											5 **B**	6 **C**	7 **N**	8 **O**	9 **F**	10 **Ne**
11 **Na**	12 **Mg**											13 **Al**	14 **Si**	15 **P**	16 **S**	17 **Cl**	18 **Ar**
19 **K**	20 **Ca**	21 **Sc**	22 **Ti**	23 **V**	24 **Cr**	25 **Mn**	26 **Fe**	27 **Co**	28 **Ni**	29 **Cu**	30 **Zn**	31 **Ga**	32 **Ge**	33 **As**	34 **Se**	35 **Br**	36 **Kr**
37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 **Xe**
55 **Cs**	56 **Ba**	57 **La***	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl**	82 **Pb**	83 **Bi**	84 **Po**	85 **At**	86 **Rn**
87 **Fr**	88 **Ra**	89 **Ac‡**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Ds**	111 **Rg**	112 **Cn**	113 **Uut**	114 **Fl**	115 **Uup**	116 **Lv**	117 **Uus**	118 **Uuo**

*	58 **Ce**	59 **Pr**	60 **Nd**	61 **Pm**	62 **Sm**	63 **Eu**	64 **Gd**	65 **Tb**	66 **Dy**	67 **Ho**	68 **Er**	69 **Tm**	70 **Yb**	71 **Lu**
‡	90 **Th**	91 **Pa**	92 **U**	93 **Np**	94 **Pu**	95 **Am**	96 **Cm**	97 **Bk**	98 **Cf**	99 **Es**	100 **Fm**	101 **Md**	102 **No**	103 **Lr**

Figure 3.5 Periodic Table of the elements

Elements in the same group tend to have similar physical and chemical properties. Notice that in Figure 3.5 the groups (or families) are labeled with a number and a letter designation.[3] The periods are numbered consecutively 1 through 7 (not shown) starting with the top row. The "A groups" are known as the **main group elements** and the "B groups" are the **transition elements**. Several of the A groups have common names.

Group	Common name
1A	**alkali metals** (except hydrogen)
2A	**alkaline earth metals**
7A	**halogens**
8A	**noble gases**

The most important distinction to make among the chemical elements is that between the **metals** and **nonmetals**. Note that the elements to the left of the bold "stair step" line are the metallic elements. They have the physical and chemical properties that you expect for metals like copper and gold. They tend to be shiny, good conductors of electricity and heat, dense and malleable (able to be shaped). All of the metals are solids at room temperature except mercury which is a liquid. Chemically, metals tend to react with acids, oxygen and nonmetals. In contrast, the nonmetallic elements tend to be brittle nonconductors with low melting points and densities. Many nonmetals, like oxygen and nitrogen, are gases at room temperature. Chemically they tend to react with metals and with other nonmetals.

There are a few elements, the **metalloids**, that exist in several physical forms. One form tends to have properties similar to those of metals while another form has properties characteristic of nonmetals. Many of the metalloids, for example, silicon (Si) and germanium (Ge), are semiconductor materials and are important in the technology industry. The chemistry of the metalloids will not be emphasized in this class.

[3]On some periodic tables the groups are numbered 1 through 18, starting on the left.

For most elements the smallest stable unit is an individual atom of the element. For some nonmetals, though, the basic unit is not an atom but a two-atom unit called a **diatomic molecule**. A **molecule** is two or more atoms chemically bonded together. It is the smallest unit of a molecular compound, or of an element that does not consist of individual atoms. For example, a sample of oxygen gas does not consist of individual atoms of oxygen, but instead has diatomic molecules of oxygen with the chemical formula O_2. The subscript (2) indicates the number of oxygen atoms in the molecule. The common **diatomic elemental forms** are H_2, N_2, O_2, F_2, Cl_2, Br_2 and I_2. Unless you are specifically referring to a single atom of these elements, you should always use the chemical formula for the diatomic molecule to represent these elements.

Check for Understanding 3.3 Solutions

1. Indicate the chemical symbol for each of the following elements.

   a) silver b) lead c) potassium d) silicon

2. Indicate the name of each of the following elements.

   a) Br b) Cu c) Au d) Ca

3. Indicate name of the element and determine the number of protons, neutrons and electrons present for each of the following. You may consult the periodic table.

   a) ^{127}I b) ^{40}Ar c) ^{235}U

3.6 Gaining and Losing Electrons

When an atom gains or loses electrons an imbalance of electric charge is created and a charged entity called an **ion** is formed. An ion is an atom or a group of atoms with a net electric charge. A **cation** is a positively-charged ion. An **anion** is a negatively-charged ion. In order to form a cation electrons must be removed from an atom. For example, a zinc atom normally has 30 protons, 30 electrons and some number of neutrons, and is electrically neutral. If two electrons are removed from a zinc atom there are now 30 positive charges in the nucleus and only 28 negative charges, so a cation with a +2 charge is formed. This zinc cation is represented like this: Zn^{2+}. In a similar way, removing one electron from a potassium atom forms K^+ (19 p, 18 e^-), a potassium cation. Note that the number of neutrons present is not important as far as the ion charge is concerned so we can ignore them.

In a similar way, electrons are added to an atom to form an anion. Adding one electron to a chlorine atom (17p, 17e^-) forms the chloride ion Cl^- (17p, 18e^-). Likewise, adding two electrons to a sulfur atom (16p, 16e^-) forms the sulfide ion S^{2-} (16p, 18e^-).

All of the ions mentioned thus far are **monatomic** (single atom) **ions**. Notice that the anions are named differently than the cations. Monatomic cations are named using the full element name followed by the word "ion".

Zn^{2+} zinc ion K^+ potassium ion

Monatomic anions, however, are named using part of the element name with an *-ide* suffix and the word "ion".

Cl^- chlorine + ide + ion ➔ chloride ion

S^{2-} sulfur + ide + ion ➔ sulfide ion

Notice that in our examples so far, the cations were formed from atoms of metals and the anions were formed from atoms of nonmetals. This is an important trend for you to know.

Metal atoms tend to lose electrons to form cations.

Nonmetals tend to gain electrons to form anions.

Since you are able to identify metallic and nonmetallic elements based on their location in the periodic table, you are now able to anticipate whether an atom is likely to form a cation or an anion. The major exception to these trends is hydrogen. Although it is classified as a nonmetal, it has a number of chemical properties similar to that of metals, including the tendency to lose its electron to form H^+, a hydrogen ion.

Now what about the ion charge? It would be very useful (and impressive!) if you could also anticipate the exact charge of a monatomic ion. Using the periodic table you can! The guidelines below are two other important trends for you to know.

The "A" group metals tend to lose electrons to form cations with a charge equal to the group number.

The nonmetals tend to gain electrons to form anions with a charge equal to the group number minus 8.

These important trends are illustrated in Examples 3.1 and 3.2.

Example 3.1

Problem

Write the correct chemical formula and the name for the likely monatomic ion formed from the element strontium.

Solution

Strontium (Sr) is a metal located in Group 2A. Therefore, it is expected to form a cation (since it is a metal) with a +2 charge (equal to the group number). The ion name is just the name of the element + ion.

Sr^{2+} strontium ion

Example 3.2

Problem

Write the correct chemical formula and the name for the likely monatomic ion formed from the element nitrogen.

Solution

Nitrogen (N) is a nonmetal located in Group 5A. Therefore, it is expected to form an anion (since it is a nonmetal) with a -3 charge (equal to the group number - 8). The ion name is formed by adding *-ide* to part (nitrogen) of the element name.

N^{3-} nitride ion

Unfortunately, this connection between the ion charge and group number does not work for the "B" group metals. In fact, many transition elements form more than one type of ion. For example, iron forms Fe^{2+} and Fe^{3+} ions. Along with different formulas, these two distinct ions of iron have different properties. In order to differentiate them, they are named with the element name following by a Roman numeral (in parentheses) equal to the ion charge. Thus, Fe^{2+} is known as iron(II) ion (pronounced *iron two ion*) and Fe^{3+} is iron(III) ion. A number of common transition element ions will be identified in Section 3.8.

Check for Understanding 3.4 **Solutions**

1. How does one form Fe^{3+} from an Fe atom?

2. Write the correct chemical formula and the name for the likely monatomic ion formed from each of the following elements. You may consult the periodic table.

   a) iodine b) barium c) lithium d) selenium

3.7 Chemical Compounds

As noted before, chemical compounds are pure substances formed by chemical reactions between elements and/or other compounds. Since compounds are pure substances, they have a specific composition. Regardless of the source of a compound, it is always found to consist of the same elements in the same proportions. These observations are summarized by the **law of constant composition**.

All samples of a specific compound contain the same proportions of their constituent elements.

This means that a unique **chemical formula** can be written for each compound. You may be familiar with the formulas for chemical compounds like H_2O (water) and NaCl (sodium chloride). The chemical symbols in the formula indicate what elements are present. The subscripts indicate the amounts of the constituent elements. For example, the formula for water indicates that it is composed of two elements, hydrogen and oxygen, and there are 2 hydrogen atoms for every oxygen atom (the subscript 1 is assumed when no subscript is used). Depending on the type of compound, the chemical formula will also indicate additional information that we will consider shortly. When elements chemically combine to form compounds the properties of the compound are different than those of the individual elements. For example, liquid water results from the combination of two colorless gases, hydrogen and oxygen. Sodium chloride, a relatively stable and harmless solid, is formed from a very reactive metal (Na) and a poisonous gas (Cl_2).

There are two general categories of compounds, ionic and molecular. It is very important to be able to identify into which category a specific compound belongs because this will enable you to anticipate important physical and chemical properties of the compound. But how will you be able to distinguish between them? The characteristics of ionic and molecular compounds, including how to identify and name them, are discussed in the next two sections.

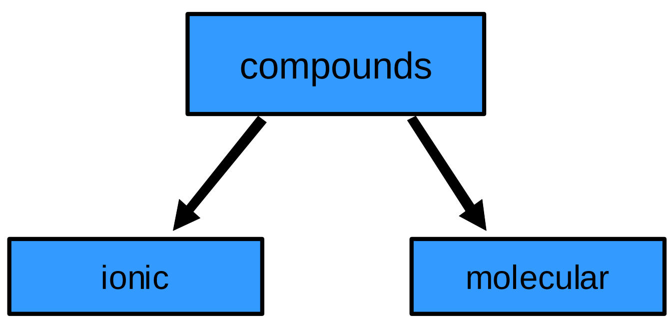


Figure 3.6 General categories of chemical compounds

3.8 Ionic Compounds

An **ionic compound** (also known as a **salt**) is formed when a metal reacts with a nonmetal in a chemical reaction. Ionic compounds consist of a 3-dimensional arrangement of cations (formed from the metal) and anions (formed from the nonmetal) that are held together by strong electrostatic attractions between the oppositely charged ions. These attractions are referred to as **ionic bonds**. Figure 3.7 is a representation of this array of ions where the smaller (purple) spheres represent the cations and the larger (green) spheres represent the anions. One of the most common ionic compounds is sodium chloride (NaCl), the major component in table salt. Like sodium chloride, ionic compounds are solids at room temperature, and, when they dissolve in water they form a mixture that can conduct electricity.

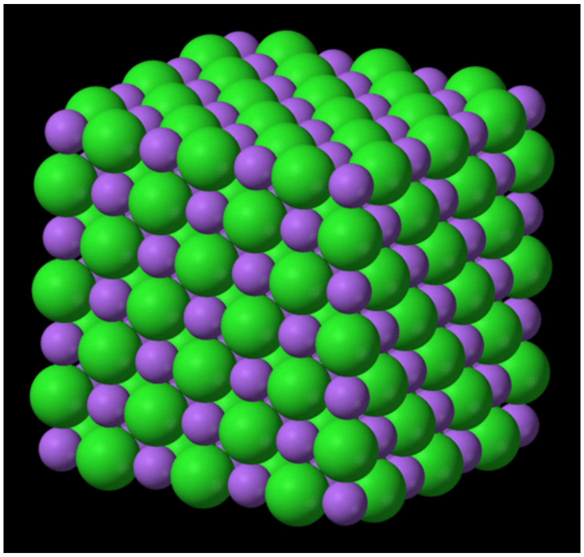


Figure 3.7 Packing of ions in an ionic compound

Since both cations and anions are needed for an ionic compound, you will generally find both a metal and nonmetal(s) present. Usually the cation will be an ion formed from a metallic element.[4] In fact, the presence of a metal is the main feature that distinguishes the ionic and molecular compounds that we will consider.

If a metal is present, the compound is ionic.

In ionic compounds the number of positive charges is exactly balanced by the number of negative charges so the ionic compound is electrically neutral. The chemical formula of an ionic compound indicates the simplest ratio of the ions needed to achieve a

[4]We will encounter only one situation where the cation is not formed from a metallic element.

balance of charges. Since an ionic compound is an array of ions that might be very large or very small depending on the sample you have, there is no basic unit of an ionic compound like atoms are for elements. Instead, the **formula unit** is used. The formula unit for an ionic compound is the cation-anion grouping represented by the ionic formula. For example, NaCl is the formula unit for sodium chloride.

Formulas for ionic compounds are written in the general form $(\text{cation})_x(\text{anion})_y$ where *x* is the smallest whole number of cations and *y* is the smallest whole number of anions needed for charge balance. It is also important to note that the charges of the ions are never shown explicitly in the ionic formula. Ionic compounds are named using the cation name followed by the anion name. Example 3.3 illustrates the naming of ionic compounds and Example 3.4 shows how to determine the chemical formula and name for an ionic compound.

Example 3.3

Problem

Write the correct name for the following ionic compounds.

A. BaF_2 B. Fe_2S_3

Solution

Notice that these ionic compounds involve a combination of a metal and nonmetal. The compound name is obtained by using the cation name followed by the anion name. The subscripts used for charge balance do not play a role in the naming of ionic compounds.

A. BaF_2

Barium is a metal located in Group 2A. Therefore, it is expected to form a cation with a +2 charge (Ba^{2+}) and is named **barium ion**.

Fluorine is a nonmetal located in Group 7A. Therefore, it is expected to form an anion with a -1 charge (F^{-}) and is named **fluoride ion**.

The compound name is obtained by using the cation name followed by the anion name. Therefore, the name of BaF_2 is **barium fluoride**.

B. Fe_2S_3

Sulfur is a nonmetal located in Group 6A. Therefore, it is expected to form an anion with a -2 charge (S^{2-}) and is named **sulfide ion**.

We have already learned that iron forms Fe^{2+} and Fe^{3+} ions. To determine which ion is involved, look at the charge balance that is indicated in the formula. The three -2 anion charges are balanced by two cations. Therefore, the charge on the iron ion must be +3 and Fe^{3+} is named **iron(III) ion**.

The compound name is obtained by using the cation name followed by the anion name. Therefore, the name of Fe_2S_3 is **iron(III) sulfide**.

Example 3.4

Problem

Write the correct chemical formula and name for the compound formed between magnesium and bromine.

Solution

Magnesium (Mg), a metal, is reacting with bromine (Br_2), a nonmetal, so one should expect an ionic compound to form. The formula will take the general form Mg_xBr_y.

In order to get the correct subscripts you need to note the charge of the cation and anion involved. Magnesium is a metal located in Group 2A. Therefore, it is expected to form a cation with a +2 charge. **Mg^{2+}** **magnesium ion**

Bromine is a nonmetal located in Group 7A. Therefore, it is expected to form an anion with a -1 charge. **Br^-** **bromide ion**

In order to achieve charge balance you will need 2 bromide ions (Br^-) for each magnesium ion (Mg^{2+}). Thus, the formula becomes **$MgBr_2$**.

The name is obtained by using the cation name followed by the anion name. Therefore, the name of $MgBr_2$ is **magnesium bromide**.

Note: When the charges of the cation and anion are not the same, you can use a shortcut to indicate charge balance with the smallest set of subscripts. Use the value of the anion charge as the subscript for the cation and use the value of the cation charge as the subscript for the anion.

$$\mathbf{Mg^{2+}} \quad \text{and} \quad \mathbf{Br^{-1}} \quad \rightarrow \quad \mathbf{Mg_1Br_2} \quad \rightarrow \quad \mathbf{MgBr_2}$$

When the charges of the cation and anion are the same, a 1:1 ratio of ions is needed and both the cation and anion will have a subscript of 1.

Thus far, we have only considered ions formed from single atoms. However, there are many instances where a group of atoms that are chemically bonded together either gains or loses electrons to form a **polyatomic** (many atom) **ion**. Polyatomic ions will be found in many of the compounds you will encounter in this course. Ionic compounds containing polyatomic ions are also named using the name of the cation followed by the name of the anion. The important difference to consider with polyatomic ions is that whenever more than one is needed to balance charge, the formula for the polyatomic ion is enclosed in parentheses before attaching the subscript. This eliminates confusion with any subscripts associated with the polyatomic ion. For example, the formula for calcium chlorate is $Ca(ClO_3)_2$ and $Fe_3(PO_4)_2$ is the formula for iron(II) phosphate.

Table 3.3 contains a list of names and formulas for common cations. Table 3.4 contains a similar list for common anions. It is important that you learn the names and formulas for all of these ions. Example 3.5 illustrates how to write the chemical formula for a compound that contains a polyatomic ion.

Example 3.5

Problem

Write the correct chemical formula and the name for the compound formed between Cu^{2+} and nitrate ion.

Solution

From Table 3.4 on p. 86, we see that nitrate has the formula NO_3^-. Therefore, it takes two nitrates for each Cu^{2+} to balance the charges. Since the nitrate ion is a polyatomic ion, it is enclosed in parentheses with the subscript 2. The formula is $Cu(NO_3)_2$.

Copper is a transition element with more than one common ionic charge. The possible charges are shown in Table 3.3) on p. 85. Therefore, the name for Cu^{2+} is copper(II) and the name of the compound is copper(II) nitrate.

$Cu(NO_3)_2$ copper(II) nitrate

Table 3.3 Names and Formulas of Common Cations

CATIONS					
Plus One Charge		Plus Two Charge			
Symbol	Name	Symbol	Name	Symbol	Name
H^+	hydrogen	Mg^{2+}	magnesium	Mn^{2+}	manganese(II)
Na^+	sodium	Ca^{2+}	calcium	Sn^{2+}	tin(II)
K^+	potassium	Sr^{2+}	strontium	Pb^{2+}	lead(II)
Ag^+	silver	Ba^{2+}	barium		
NH_4^+	ammonium‡	Zn^{2+}	zinc		
		Cd^{2+}	cadmium		
		Ni^{2+}	nickel		
Plus One or Two Charge		Plus Two or Three Charge		Plus Three Charge	
Symbol	Name	Symbol	Name	Symbol	Name
Cu^+	copper(I)	Fe^{2+}	iron(II)	Al^{3+}	aluminum
Cu^{2+}	copper(II)	Fe^{3+}	iron(III)		
Hg_2^{2+}	mercury(I)	Co^{2+}	cobalt(II)		
Hg^{2+}	mercury(II)	Co^{3+}	cobalt(III)		
		Cr^{2+}	chromium(II)		
		Cr^{3+}	chromium(III)		

‡Ammonium ion is the only cation we will encounter that does not involve a metallic element.

Table 3.4 Names and Formulas of Common Anions

ANIONS					
Minus One Charge		Minus Two Charge		Minus Three Charge	
Symbol	Name	Symbol	Name	Symbol	Name
F^-	fluoride	O^{2-}	oxide	PO_4^{3-}	phosphate
Cl^-	chloride	O_2^{2-}	peroxide		
Br^-	bromide	S^{2-}	sulfide		
I^-	iodide	SO_3^{2-}	sulfite		
OH^-	hydroxide	SO_4^{2-}	sulfate		
NO_2^-	nitrite	CO_3^{2-}	carbonate		
NO_3^-	nitrate	$C_2O_4^{2-}$	oxalate		
$C_2H_3O_2^-$	acetate	SiO_3^{2-}	silicate		
CN^-	cyanide	CrO_4^{2-}	chromate		
ClO^-	hypochlorite	$Cr_2O_7^{2-}$	dichromate		
ClO_2^-	chlorite	$S_2O_3^{2-}$	thiosulfate		
ClO_3^-	chlorate	HPO_4^{2-}	hydrogen phosphate		
ClO_4^-	perchlorate				
HCO_3^-	hydrogen carbonate‡				
HSO_3^-	hydrogen sulfite‡				
HSO_4^-	hydrogen sulfate‡				
MnO_4^-	permanganate				

‡These ions are also known as bicarbonate (HCO_3^-), bisulfite (HSO_3^-) and bisulfate (HSO_4^-).

Check for Understanding 3.5 **Solutions**

It is important to be able to solve the following problems using only a periodic table.

1. Indicate the chemical formula and name for the common ion formed from each of the following elements.

   a) silver b) oxygen c) lead d) aluminum

2. Indicate whether each of the following compounds is ionic or molecular.

   a) CS_2 b) HCl c) MnO_2 d) $Ba(OH)_2$

3. Indicate the name or formula, as appropriate, for each of the following compounds.

   a) Al_2O_3

   b) iron(III) chloride

   c) potassium carbonate

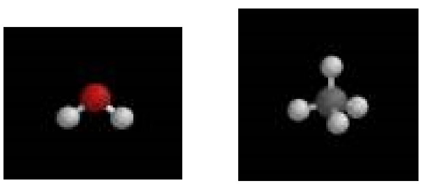
   d) $Zn(NO_2)_2$

3.9 Molecular Compounds

Molecular compounds consist of molecules composed of two or more different atoms bonded together by **covalent bonds**. A covalent bond forms when two atomic nuclei have strong electrostatic attractions for the same electron charge cloud. The two nuclei are said to be *sharing a pair of electrons* when they form a covalent bond.

Molecular compounds are composed of nonmetal atoms (including hydrogen) and usually do not contain metals. The chemical formula for a molecular compound indicates the number of atoms of each type that are present in each molecule of the compound. For example, the formula for the fuel *propane* is C_3H_8. This means that each molecule of propane contains 3 atoms of carbon and 8 atoms of hydrogen.

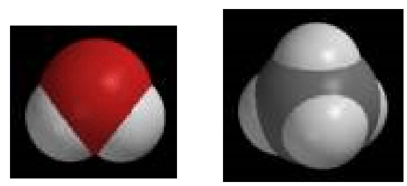
Just as spheres were used to represent the packing of cations and anions in an ionic compound, they are frequently used to indicate the bonding of atoms in a molecule. In Figures 3.8 and 3.9 molecules of water (H_2O) and methane (CH_4) are represented using two different models. A **ball-and-stick molecular model** (Fig. 3.8) is the traditional means of illustrating how the atoms in a molecule are bonded together. Atoms are represented as spheres connected by sticks that represent the covalent bonds between atoms. The model for water (Fig. 3.8a) shows that the oxygen atom is bonded to the two hydrogen atoms and that the three atoms form a bent structure. A **space-filling molecular model** (Fig. 3.9) also indicates the orientation of the bonded atoms but is more indicative of the relative size of the atoms in the molecule.



(a) (b)

Figure 3.8 Ball-and-stick molecular model for (a) water and (b) methane

Images by Alan Shusterman, Reed College, 2011, reproduced with permission.



(a) (b)

Figure 3.9 Space-filling molecular model for (a) water and (b) methane

Images by Alan Shusterman, Reed College, 2011, reproduced with permission.

Molecules are not static entities as suggested by these models. At room temperature the atoms in a molecule are constantly vibrating and the entire molecule is rotating. However, such concrete models serve an important role for chemists as they test hypotheses about the detailed structure and properties of complex molecular systems. For example, James Watson and Francis Crick, the scientists who in 1953 proposed the double helix structure of DNA, used models to work out the details of their proposed structure (see Fig. 3.10).

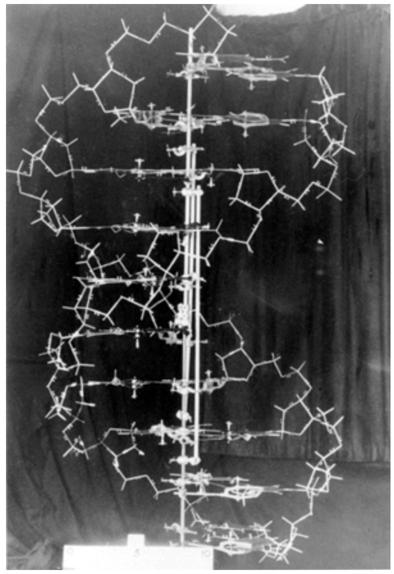


Figure 3.10 The original DNA model constructed by Watson and Crick.
James Watson Collection, Cold Spring Harbor Laboratory Archives, reproduced with permission.

The properties of molecular compounds are quite distinct from those of ionic compounds. A molecular compound may be a solid, liquid or gas at room temperature. Small molecules (fewer than 10 atoms) tend to be gases or liquids while larger molecules tend to be liquids or solids. Pure molecular substances are nonconductors of electricity and tend to be nonconductors even when dissolved in water. Important exceptions are the acids. An **acid** is a molecular substance that when dissolved in water produces H^+ ions. Acids and water form a solution that conducts electricity. A comparison of the properties of ionic and molecular compounds is given in Table 3.5.

Table 3.5 Comparison of the Properties of Ionic and Molecular Compounds

Property	Ionic Compounds	Molecular Compounds
composition	chemical combination of metals and nonmetals	chemical combination of different nonmetals
structure	3-dimensional packing of cations and anions	discrete molecules composed of a specific number and type of atoms
chemical formula	indicates smallest ratio of ions needed for charge balance	indicates exact composition of a single molecule
usual physical state at room temperature	solid	small molecules: gas or liquid large molecules: liquid or solid
electrical conductivity	pure substance: nonconducting dissolved in water: conducting	pure substance: nonconducting dissolved in water: nonconducting, except for acids

There are three important classes of molecular compounds that are distinguished by their composition and the rules used to assign them names.

Binary molecular compounds

Binary molecular compounds consist of molecules containing two nonmetals and no hydrogen. The general chemical formula is X_aY_b where *X* and *Y* are the chemical symbols of the nonmetals and *a* and *b* indicate the specific number of each atom present in each molecule. Carbon dioxide is a binary molecular compound with the formula CO_2. Each molecule of carbon dioxide contains 1 atom of carbon bonded to 2 atoms of oxygen. The name for this binary molecular compound uses the entire element name for the first nonmetal atom in the formula (carbon) plus part of the element name (stem) with an -*ide* suffix for the second nonmetal atom in the formula (ox-ide). Binary molecular compound names also indicate the number of atoms of each type present in each molecule of the compound. This is done by attaching a Latin or Greek number prefix to the element name to indicate how many atoms of the element are present. The common prefixes, along with their numerical values, are shown below. Adding prefixes results in the name monocarbon dioxide. However, when there is only one atom of the first nonmetal element no prefix is used, so finally we have carbon dioxide.

Prefix	Number
mono	1
di	2
tri	3
tetra	4
penta	5
hexa	6
hepta	7
octa	8
nona	9
deca	10

Now we can see that the name for a binary molecular compound is constructed of 5 parts.

number prefix for first nonmetal	+	first element name		number prefix for second nonmetal	+	stem of second element name	+	-ide suffix

Use of the naming structure for binary molecular compounds is illustrated in Examples 3.6 and 3.7.

Example 3.6

Problem

Given the formula PCl_3, how is this binary molecular compound named?

Solution

Since there is only one atom of the first nonmetal (P) no prefix is used before the element name (phosphorus). There are 3 atoms of the second nonmetal (Cl) so the prefix *tri-* is used along with part of element name (chlorine) and the suffix *-ide*. Putting these pieces together yields

number prefix for first nonmetal	+	first element name	number prefix for second nonmetal	+	stem of second element name	+	-ide suffix
no prefix needed	+	phosphorus	tri-	+	chlor-	+	-ide

PCl_3 phosphorus trichloride

Example 3.7

Problem

Given the name dinitrogen monoxide, what is the chemical formula of this binary molecular compound?

Solution

The prefix *di-* indicates there are 2 atoms of the first nonmetal nitrogen (N). The prefix *mono-* indicates there is 1 atom of the second nonmetal oxygen (O). Thus the formula is N_2O.

dinitrogen monoxide N_2O

Note: This example illustrates the practice of dropping the ending vowel (*o* or *a*) from a prefix when it is used with the element oxygen. This avoids awkward names like *monooxide* or *pentaoxide*.

Binary acids

Binary acids are molecular compounds with the general formula $H_nX(aq)$ where *X* is a nonmetal element bonded to *n* hydrogen atoms. The *(aq)* designation stands for **aqueous solution** and indicates that the compound is dissolved in water. The acid secreted by the stomach to help us digest our food is a binary acid, HCl(aq). The name of this acid is hydrochloric acid. The names of binary acids consist of the 4-part structure shown below.

hydro- prefix	+	stem of nonmetal element name	+	-ic suffix	acid

Examples 3.8 and 3.9 illustrate use of this naming convention for binary acids.

Example 3.8

Problem

Given the formula $H_2S(aq)$, how is this binary acid named?

Solution

The name begins with the prefix *hydro*- followed by the stem of the nonmetal element (S) name followed by the suffix -*ic*. In this case, the full name *sulfur* is used to avoid a harsh sounding name (hydrosulfic). The word *acid* is added to complete the name. Putting these pieces together yields

hydro- prefix	+	stem of nonmetal element name	+	-ic suffix	acid
hydro-	+	sulfur	+	-ic	acid

$H_2S(aq)$ hydrosulfuric acid

It is important to note that the subscript 2 for hydrogen in the formula does not affect the naming.

Example 3.9

Problem

Given the name hydrofluoric acid, what is the formula for this binary acid?

Solution

The *hydro*- prefix indicates that this is a binary acid and the stem *fluor*- tells you that the nonmetal fluorine is bonded to hydrogen. Thus, the binary acid formula will look like $H_nF(aq)$. In order to determine the value for *n*, remember that in water this molecule will break up to form H^+ ions and fluoride anions. The charge on the cation must be balanced by the charge on the anion that is formed. Since fluorine is in Group 7A we expect it to form an anion with a minus one charge (F^-). Thus, only one H^+ is needed for each F^- so $n = 1$.

So the correct formula for hydrofluoric acid is HF(aq).

Oxoacids

The third category of molecular compounds we will consider is that of oxoacids. An **oxoacid** has the general formula H_mXO_n. That is, an oxoacid contains at least one oxygen atom and at least one hydrogen atom bonded to oxygen, plus one atom of another nonmetal element (X). Carbonic acid (H_2CO_3) is an oxoacid formed by dissolving carbon dioxide (CO_2) in water. This is the acid present in all carbonated beverages. Although oxoacids are generally dissolved in water, the *(aq)* designation is not normally used after the chemical formula as was the case for binary acids. This difference is because the name for an oxoacid is the same whether it is dissolved in water or not. However, the name of a binary acid is different when it is not dissolved in water. For example, the gas HCl is named *hydrogen chloride* (similar to the naming pattern for binary molecular compounds) instead of *hydrochloric acid* used for the dissolved form HCl(aq)[5].

---

[5]The physical state of a substance is often designated by using the first letter of the state (solid, liquid or gas) in parentheses after the chemical formula. Thus, hydrogen chloride *gas* would be written as HCl(g) and sodium chloride *solid* would be NaCl(s).

The name for an oxoacid is derived from the name of the anion that forms when one or more hydrogen ions break away from the original oxoacid molecule. For example, if you remove two H^+ ions from a molecule of carbonic acid, you are left with CO_3^{2-}. The name of this anion is *carbonate* (recall Table 3.4). To get the oxoacid name you replace the -*ate* suffix with -*ic* and add the word *acid*. Thus carbon*ate* becomes carbon*ic* and we add the word *acid* to form carbonic acid. When the resulting anion has an -*ite* suffix, this is replaced by -*ous* to give the acid name. This naming pattern for oxoacids is illustrated in Examples 3.10 and 3.11.

Example 3.10

Problem

Given the formula HNO_2, how is this oxoacid named?

Solution

Recall that the name of an oxoacid is linked to the name of the anion formed when the acid loses H^+. Removing a H^+ ion from this molecule leaves the nitrite anion NO_2^-. The -*ite* suffix is replaced by -*ous* and the word *acid* is added. This results in the name *nitrous acid*.

HNO_2 nitrous acid

Example 3.11

Problem

Given the name perchloric acid, what is the chemical formula for this oxoacid?

Solution

You can recognize this as an oxoacid because *hydro-* is not in the acid name. The *-ic* suffix indicates the anion name is *perchlorate* (ClO_4^-). Since this anion has a -1 charge only one H^+ is needed to create the neutral oxoacid molecule. Thus, the formula is $HClO_4$.

perchloric acid $HClO_4$

Check for Understanding 3.6 Solutions

1. Indicate to which category of molecular compounds each of the following belongs and write the chemical name of the compound.

   a) HBr(aq) b) $HClO_2$ c) SF_6 d) H_2SO_4

2. Write the chemical formula for each of the following molecular compounds.

   a) carbon disulfide b) nitric acid c) hydroiodic acid

chemical nomenclature flashcards and review tests

3.10 Compound Naming Summary

It is very important that you are able to distinguish between ionic and molecular compounds and properly write the name and chemical formula for a compound. Consider the following steps when given the name or formula of a chemical compound.

1. Identify the compound as ionic or molecular. Look for the presence of a metal, it indicates an ionic compound.

2. Ionic compound names consist of the cation name followed by the anion name. Ionic compound formulas take the basic form $(\text{cation})_x(\text{anion})_y$. The ion subscripts are the smallest whole numbers needed to achieve charge balance.

3. If the compound is molecular, identify which type of molecular compound it is (binary, binary acid, oxoacid), then apply the appropriate naming structure to writing the name or chemical formula.

<u>binary molecular compounds</u>

number prefix for first nonmetal	+	first element name

number prefix for second nonmetal	+	stem of second element name	+	-ide suffix

<u>binary acids</u>

hydro- prefix	+	stem of nonmetal element name	+	-ic suffix

acid

<u>oxoacids</u>

-ate anions ➔ *-ic* acids

-ite anions ➔ *-ous* acids

Chapter 3 Keywords

Glossary

chemistry	proton	ion
matter	neutron	cation
chemical property	atomic nucleus	anion
physical property	nuclear force	monatomic ion
pure substance	atomic number	law of constant composition
chemical element	mass number	chemical formula
compound	periodic table	ionic compounds
atom	groups	salt
chemical change	periods	ionic bonds
chemical reaction	main group elements	formula unit
mixture	transition elements	polyatomic ion
homogeneous mixture	alkali metals	covalent bond
solution	alkaline earth metals	ball-and-stick model
heterogeneous mixture	halogens	space-filling model
phase	noble gases	acid
physical state	metals	binary molecular compound
static electricity	nonmetals	binary acid
electrostatic force	metalloids	aqueous solution
Coulomb's law	diatomic molecule	oxoacid
electron	molecule	
subatomic particle	diatomic elemental forms	

Supplementary Chapter 3 *Check for Understanding* questions

Chapter 3 Exercises

Answers

1. Which of the following are pure substances?

   (a) vitamin tablet
   (b) glass
   (c) carbon monoxide
   (d) wine
   (e) helium

2. What is the fundamental difference between pure substances and mixtures?

3. Distinguish between homogeneous and heterogeneous mixtures. Give a specific example of each. Do not use examples given in the text.

4. Explain the difference between a phase and a physical state.

5. Which of the following are homogeneous mixtures?

(a) chocolate chip ice cream
(b) clean, dry air
(c) popcorn
(d) mercury
(e) steel

6. Which one of the following describes a chemical property of gold?

A. Gold is a yellow metal.
B. Gold is a nonreactive metal.
C. Gold is a soft metal.
D. Gold is a very dense metal.
E. Gold is a good conductor of heat and electricity.

7. Which of the following are primarily chemical changes?

(a) grinding rocks into sand
(b) leaves turning red in autumn
(c) instant coffee dissolving in water
(d) evaporating alcohol
(e) explosion of a firecracker
(f) hard-boiling of an egg

8. Distinguish between the electrostatic force and the nuclear force.

9. Complete the following table with the appropriate data. Unless indicated otherwise, assume each line refers to a neutral atom.

Element	Symbol	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
		25	55			
bromine					44	
	$^{197}Au^{3+}$					
					42	33
			31	15		18

10. Where is most of the mass of an atom found?

11. Describe how cations and anions are formed.

12. What are the two primary types of chemical compounds? How do they differ from each other?

13. Determine the name or formula for each of the following.

barium acetate ____________________ $CuSO_4$ __________________________

oxalic acid ________________________ CCl_4 ____________________________

iron(III) hydroxide ________________ K_2S _____________________________

ammonium carbonate ______________ H_2SO_3 ___________________________

sodium phosphate _________________ NO_2 ____________________________

14. Identify each of the following substances as ionic or molecular.

    HCN __________ NH_3 __________ CS_2 __________ $KClO_3$ __________

15. Write the formula of the compound that is likely to form between:

    silver and oxygen _____________

    zinc and iodine _____________

16. How many hydrogen atoms are there in each molecule of $(C_2H_5)_2NH$?

17. What is the fundamental difference between a chemical and physical change?

18. A single compound that is a liquid at room temperature is most likely what type of compound (ionic or molecular)? Indicate two likely general properties of this compound.

19. In your own words state the law of constant composition. What does this suggest about the effectiveness of generic drugs?

20. What is meant by an aqueous solution? To what specific category of matter do aqueous solutions belong?

21. Prepare an expanded classification scheme of matter that includes all of the distinctions made in this chapter.

22. Indicate at least five regular chemistry patterns described in this chapter.

23. What are the differences between the substances in each of the following pairs?

a) CO and Co

b) SO_3 and SO_3^{2-}

24. The correct formula for a compound made from copper and oxygen is:

A. CuO B. Cu_2O C. Cu_2O_3 D. Cu_3O_2 E. both A and B

25. One of the following formulas is *incorrect*. Write the correct formula for this compound and determine its correct name.

A. $Ba(OH)_2$ B. $KMnO_4$ C. Na_2O D. CaCl

Chapter 3

Check for Understanding 3.1

1. Indicate whether each of the following is primarily a chemical change or a physical change.

a) painting a wall
b) boiling water
c) frying an egg
d) grating cheese
e) burning a match

Answers:
a) physical change
b) physical change
c) chemical change
d) physical change
e) chemical change

Solutions

Recall that the fundamental difference between physical and chemical changes is that a new substance is formed in a chemical change but not in a physical change.

a) Although some chemical changes may accompany the drying of paint, the process of applying paint to a wall does not produce a new substance. Thus it is a physical change.

b) When water boils and forms a gas it is still water with the same composition as in the liquid state. Thus it is a physical change, as are all changes of physical state.

c) Many new substances are formed as an egg cooks. You sense this because the appearance and properties of the egg change significantly. Thus it is a chemical change.

d) The grated cheese is not a new substance, only a change in its physical form. Thus it is a physical change.

e) Many new substances are formed when a match burns. You can detect some of these by their different properties (for example, odor, appearance). Thus it is a chemical change.

2. Indicate one chemical property and one physical property of the element hydrogen.

Answers: physical properties - colorless odorless gas, density less than air

chemical property - reacts with oxygen gas to form water

Solutions

A physical property of a substance does not involve a change in its composition whereas a chemical property does. There are many physical and chemical properties of hydrogen. The most familiar ones are listed.

Check for Understanding 3.2

1. Indicate whether each of the following is a pure substance or a mixture.

a) gold	c) rubbing alcohol	e) carbon monoxide
b) flour	d) stainless steel	f) lead

Answers:

a) pure substance	d) mixture
b) mixture	e) pure substance
c) mixture	f) pure substance

Solutions

A pure substance (an element or compound) has a fixed composition while a mixture does not.

a) Gold is a chemical element so it is a pure substance.

b) Flour is a fine powder prepared from grains such as wheat and barley plus other additives such as iron and vitamins. There are various grades of flour. Thus it is a mixture.

c) Rubbing alcohol is a homogeneous mixture of two compounds, isopropyl alcohol and water.

d) Stainless steel is an alloy of iron, carbon, and usually other metals such as nickel. Alloys are homogeneous mixtures.

e) Carbon monoxide is a compound containing carbon and oxygen. Thus it is a pure substance.

f) Lead is a chemical element so it is a pure substance.

2. Indicate whether each of the following is a homogeneous or heterogeneous mixture.

a) wood b) Jell-O c) vodka d) silver-plated jewelry

Answers: a) heterogeneous mixture

b) homogeneous mixture

c) homogeneous mixture

d) heterogeneous mixture

Solutions

A homogeneous mixture has a single phase with a uniform composition throughout whereas a heterogeneous mixture has two or more phases of varying composition.

a) The grain and knots found in wood indicate phases of different composition so wood is a heterogeneous mixture.

b) Jell-O is a homogeneous mixture because it consists of a single phase.

c) Vodka is a homogeneous mixture because it consists of a single phase.

d) The silver plating over a cheaper metal core represents two phases. Thus silver-plated jewelry is a heterogeneous mixture.

Check for Understanding 3.3

1. Indicate the chemical symbol for each of the following elements.

a) silver b) lead c) potassium d) silicon

Answers: a) Ag c) K

b) Pb d) Si

Solutions

You should memorize the names and symbols of the common elements shown in Table 3.1.

2. Indicate the name of each of the following elements.

a) Br b) Cu c) Au d) Ca

Answers: a) bromine c) gold

b) copper d) calcium

Solutions

You should memorize the names and symbols of the common elements shown in Table 3.1.

3. Indicate name of the element and determine the number of protons, neutrons and electrons present for each of the following. You may consult the periodic table.

a) ^{127}I b) ^{40}Ar c) ^{235}U

Answers: a) iodine b) argon c) uranium

	^{127}I	^{40}Ar	^{235}U
number of protons	53	18	92
number of neutrons	74	22	143
number of electrons	53	18	92

Solutions

The number of protons equals the number of electrons and both are equal to the atomic number (Z) of the element. The number of neutrons equals the mass number (shown as the superscript) minus the atomic number.

a) The atomic number of iodine is 53, so the number of protons equals 53 and the number of electrons equals 53. The number of neutrons for ^{127}I is determined by 127-53 = 74.

b) The atomic number of argon is 18, so the number of protons equals 18 and the number of electrons equals 18. The number of neutrons for ^{40}Ar is determined by 40-18 = 22.

c) The atomic number of uranium is 92, so the number of protons equals 92 and the number of electrons equals 92. The number of neutrons for ^{235}U is determined by 235-92 = 143.

Check for Understanding 3.4

1. How does one form Fe^{3+} from an Fe atom?

Answer: Remove 3 electrons from an iron atom.

Solution

Cations are formed from atoms by the removal of electrons. In order to get an ion of +3 charge, three electrons must be removed from an iron atom.

2. Write the correct chemical formula and the name for the likely monatomic ion formed from each of the following elements. You may consult the periodic table.

a) iodine b) barium c) lithium d) selenium

Answers: a) I^- iodide ion

b) Ba^{2+} barium ion

c) Li^+ lithium ion

d) Se^{2-} selenide ion

Solutions

a) Iodine is a nonmetal and nonmetals tend to gain electrons to form anions with a charge equal to the group number minus 8. Since iodine is in Group 7A its ion charge should be 7-8 = -1. Monatomic anions are named using part of the element name with an -*ide* suffix and the word "ion". This leads to I^- (iodide ion).

b) Barium is a metal and the "A" group metals tend to lose electrons to form cations with a charge equal to the group number. Since barium is in Group 2A its ion charge should be +2. Monatomic cations are named using the full element name followed by the word "ion". This leads to Ba^{2+} (barium ion).

c) Lithium is a metal and the "A" group metals tend to lose electrons to form cations with a charge equal to the group number. Since lithium is in Group 1A its ion charge should be +1. Monatomic cations are named using the full element name followed by the word "ion". This leads to Li^{+} (lithium ion).

d) Selenium is a nonmetal and nonmetals tend to gain electrons to form anions with a charge equal to the group number minus 8. Since selenium is in Group 6A its ion charge should be 6-8 = -2. Monatomic anions are named using part of the element name with an *-ide* suffix and the word "ion". This leads to Se^{2-} (selenide ion).

Check for Understanding 3.5

It is important to be able to solve the following problems using only a periodic table.

1. Indicate the chemical formula and name for the common ion formed from each of the following elements.

   a) silver b) oxygen c) lead d) aluminum

Answers:
a) Ag^{+} silver ion

b) O^{2-} oxide ion

c) Pb^{2+} lead(II) ion

d) Al^{3+} aluminum ion

<u>Solutions</u>

a) Silver is a transition element. These metals tend to form cations of various charge. You should memorize the formula of the common silver ion (Ag^{+}) that is shown in Table 3.3.

b) Oxygen is a nonmetal and nonmetals tend to gain electrons to form anions with a charge equal to the group number minus 8. Since oxygen is in Group 6A its ion charge should be 6-8 = -2. Monatomic anions are named using part of the element name with an *-ide* suffix and the word "ion". This leads to O^{2-} (oxide ion).

c) Lead is a transition element. These metals tend to form cations of various charge. You should memorize the formula of the common lead ion (Pb^{2+}) that is shown in Table 3.3.

d) Aluminum is an “A” group metal and the “A” group metals tend to lose electrons to form cations with a charge equal to the group number. Since aluminum is in Group 3A its ion charge should be +3. Monatomic cations are named using the full element name followed by the word “ion”. This leads to Al^{3+} (aluminum ion).

2. Indicate whether each of the following compounds is ionic or molecular.

a) CS_2 b) HCl c) MnO_2 d) $Ba(OH)_2$

Answers:
a) molecular

b) molecular

c) ionic

d) ionic

Solutions

a) This combination of nonmetals forms a molecular compound.

b) This combination of nonmetals forms a molecular compound.

c) This combination of a metal (Mn) and nonmetal (O) forms an ionic compound.

d) This combination of a metal (Ba) and nonmetals (O and H) forms an ionic compound.

3. Indicate the name or formula, as appropriate, for each of the following compounds.

   a) Al_2O_3

   b) iron(III) chloride

   c) potassium carbonate

   d) $Zn(NO_2)_2$

Answers: a) aluminum oxide

b) $Fe(Cl)_3$

c) K_2CO_3

d) zinc nitrite

Solutions

Note that since all of these compounds involve a combination of a metal and nonmetal(s) they are ionic. Thus the name is gotten from the cation name followed by the anion name. The formula is gotten by indicating the simplest ratio of cations and anions to produce charge balance.

a) The metal cation is aluminum ion and the anion name is oxide ion. Thus the compound name is *aluminum oxide*.

b) The Roman numeral indicates that the cation is Fe^{3+}. The chloride ion formula is Cl^-. Since it takes three chloride ions to balance the charge on the cation, the compound formula is $FeCl_3$.

c) The metal cation is K^+. The polyatomic anion formula is CO_3^{2-}. Since it takes two cations to balance the charge on the anion, the compound formula is K_2CO_3.

d) The metal cation is zinc ion and the polyatomic anion is nitrite ion. Thus the compound name is *zinc nitrite*.

Check for Understanding 3.6

1. Indicate to which category of molecular compounds each of the following belongs and write the chemical name of the compound.

   a) HBr(aq) b) $HClO_2$ c) SF_6 d) H_2SO_4

Answers: a) binary acid - hydrobromic acid

b) oxoacid - chlorous acid

c) binary molecular compound - sulfur hexafluoride

d) oxoacid acid - sulfuric acid

Solutions

a) This is a binary acid because it follows the general formula $H_nX(aq)$. The name begins with the prefix *hydro-* followed by the stem of the nonmetal element name (brom-) followed by the suffix *-ic*. The word *acid* is added to complete the name. Putting these pieces together results in the name *hydrobromic acid*.

b) This is an oxoacid because it has the general formula H_mXO_n. The name of an oxoacid is linked to the name of the anion formed when the acid loses H^+. Removing a H^+ ion from this molecule leaves the chlorite anion ClO_2^-. The *-ite* suffix is replaced by *-ous* and the word *acid* is added. This results in the name *chlorous acid*.

c) This is a binary molecular compound because it has the general chemical formula is X_aY_b where *X* and *Y* are nonmetals. Since there is only one atom of the first nonmetal (S) no prefix is used before the element name (sulfur). There are 6 atoms of the second nonmetal (F) so the prefix *hexa-* is used along with part of element name (fluorine) and the suffix *-ide*. Putting these pieces together results in the name *sulfur hexafluoride*.

d) This is an oxoacid because it has the general formula H_mXO_n. The name of an oxoacid is linked to the name of the anion formed when the acid loses H^+. Removing two H^+ ions from this molecule leaves the sulfate anion SO_4^{2-}. The *-ate* suffix is dropped and *sulf-* is replaced by *sulfur* before adding the *-ic* suffix and the word *acid*. This results in the name *sulfuric acid*.

2. Write the chemical formula for each of the following molecular compounds.

a) carbon disulfide b) nitric acid c) hydroiodic acid

Answers: a) CS_2

b) HNO_3

c) HI(aq)

Solutions

a) Since the name does not contain the word *acid*, this must be a binary molecular compound. Each molecule contains atoms of carbon and sulfur and has the general formula C_aS_b. The absence of a prefix for the first nonmetal (C) indicates there is 1 atom of this element in each molecule. The prefix *di*- indicates there are 2 atoms of the second nonmetal (S). Thus the formula is CS_2.

b) This as an oxoacid because *hydro*- is not in the acid name. The -*ic* suffix indicates the anion name is *nitrate* (NO_3^-). Since this anion has a -1 charge only one H^+ is needed to create the neutral oxoacid molecule. Thus, the formula is HNO_3.

c) The *hydro*- prefix indicates that this is a binary acid and the stem *iod*- tells you that the nonmetal iodine is bonded to hydrogen. Thus, the binary acid formula will look like $H_nI(aq)$. In order to determine the value for n, remember that in water this molecule will break up to form H^+ ions and iodide anions. The charge on the cation must be balanced by the charge on the anion that is formed. Since iodine is in Group 7A we expect it to form an anion with a minus one charge (I^-). Thus, only one H^+ is needed for each I^- so n = 1 and the formula is HI(aq).

Chapter 3

1. (c) and (e)

2. Pure substances have a definite composition and mixtures do not.

3. Homogeneous mixtures have a uniform composition (single phase) throughout. Heterogeneous mixtures contain more than one phase.

   Examples

   homogeneous mixtures: 14-karat gold, gasoline, container of oxygen gas and helium

   heterogeneous mixtures: granola bar, vinaigrette salad dressing, cloudy sky

4. A phase is a portion of a substance having a uniform composition throughout. A physical state characterizes a substance as a solid, liquid or gas.

5. (b) and (e)

6. B

7. (b), (e) and (f)

8. The electrostatic force is the force acting between objects having a net electric charge. It can be attractive or repulsive. The nuclear force is the short-range attraction acting between subatomic particles (protons and neutrons) in the nucleus of an atom.

9.

Element	Symbol	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
manganese	^{55}Mn	25	55	25	30	25
bromine	^{79}Br	35	79	35	44	35
gold	$^{197}Au^{3+}$	79	197	79	118	76
arsenic	^{75}As	33	75	33	42	33
phosphorus	$^{31}P^{3-}$	15	31	15	16	18

10. in the nucleus of the atom

11. Cations are formed by loss of electrons. Anions are formed by the gain of electrons.

12. see Table 3.5

13. barium acetate ____$Ba(C_2H_3O_2)_2$____ $CuSO_4$ ____copper(II) sulfate____

oxalic acid ____$H_2C_2O_4$____ CCl_4 ____carbon tetrachloride____

iron(III) hydroxide ____$Fe(OH)_3$____ K_2S ____potassium sulfide____

ammonium carbonate ____$(NH_4)_2CO_3$____ H_2SO_3 ____sulfurous acid____

sodium phosphate ____Na_3PO_4____ NO_2 ____nitrogen dioxide____

14. HCN _molecular_ NH_3 _molecular_ CS_2 _molecular_ $KClO_3$ __ionic__

15. silver and oxygen ___Ag_2O___

zinc and iodine ___ZnI_2___

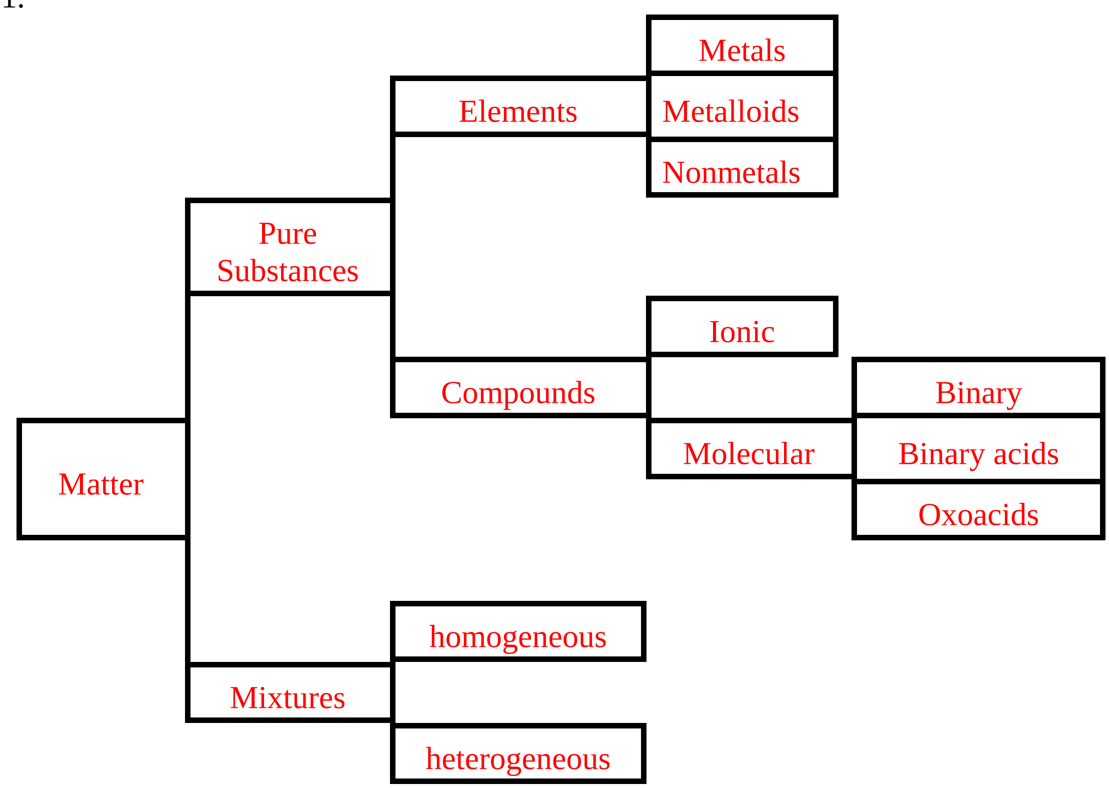
16. 11

17. A chemical change results in the formation of at least one new substance. No new substances are formed in physical changes.

18. molecular - a nonconductor that does not contain any metallic elements

20. An aqueous solution is a homogeneous mixture that has one or more substances dissolved in water.

21.



23. a) CO is a molecular compound (carbon monoxide) composed of carbon and oxygen. Co is a chemical element (cobalt).

b) SO_3 is a molecular compound (sulfur trioxide) composed of sulfur and oxygen. SO_3^{2-} is an anion (sulfite).

24. E

25. D $CaCl_2$ calcium chloride