Chapter 8

Molecules and Compounds

What do aspirin, plastic wrap, and vinegar have in common? Give up? They are all compounds made from different combinations of the same three atoms: carbon, hydrogen, and oxygen. By themselves, these atoms cannot reduce pain, keep food fresh, or season food. But when they are chemically combined in certain ways to form compounds, they can be useful in many ways. Study this chapter to learn how millions upon millions of compounds and molecules can form from combinations of less than 100 basic elements

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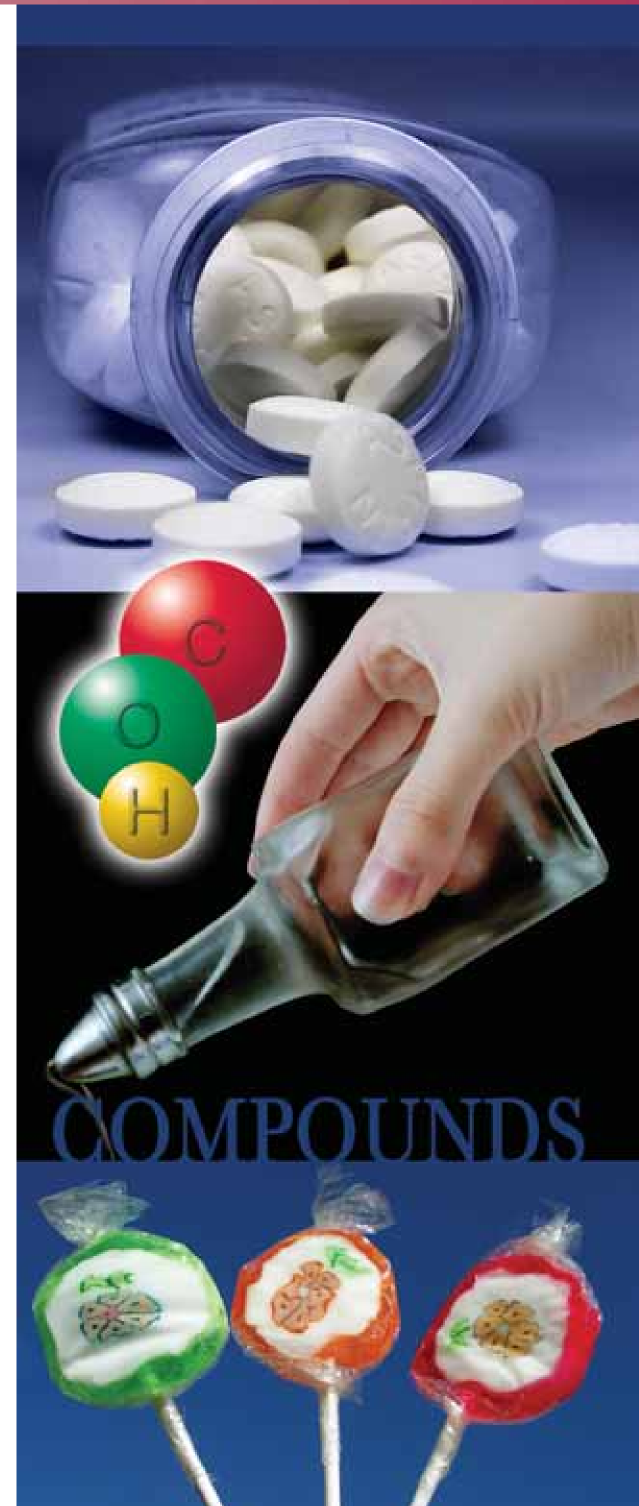
Key Questions

1. ***What does the chemical formula H_2O mean?***

2. ***What are chemical bonds, and how do they form?***

3. ***How do scientists show the shape of a molecule?***



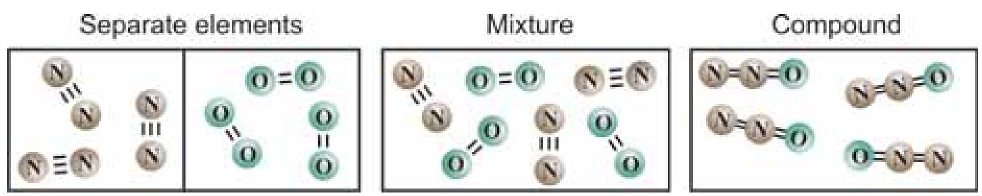
8.1 Compounds and Chemical Bonds

Most matter is in the form of compounds. If a substance is made of a pure element, chances are it will eventually combine with other elements to make a compound. For example, water, H_2O, is a compound made of hydrogen and oxygen atoms. The iron in a nail combines with oxygen in water or air to make a compound called iron oxide, better known as rust. This chapter is about how and why atoms combine into compounds.

Most matter is in the form of compounds and mixtures

Compounds and mixtures

A **compound** contains two or more different elements that are chemically bonded together. For example, water (H_2O) is a compound of hydrogen and oxygen atoms bonded together. A **mixture** contains two or more elements and/or compounds that are not chemically bonded together. The atmosphere is a mixture of oxygen and nitrogen but *not* a compound. Nitrous oxide (N_2O), is a compound because oxygen and nitrogen atoms are bonded together in a molecule.



Salt and sugar are compounds

Virtually everything you eat and everything in your kitchen is a compound. Salt is a compound of sodium and chlorine. Sugar is a compound of carbon, hydrogen, and oxygen. Animal and vegetable material are made of even more complex compounds, such as proteins and fats which may consist of hundreds or thousands of atoms.

Most matter is mixtures of compounds

Most matter is in the form of mixtures of compounds."Sugar" is actually a compound made up of a chemical bond between two simple sugars: glucose and fructose (Figure 8.1). All sugars taste sweet but fructose tastes much sweeter than glucose. There are thousands of different compounds in a single sample of animal or vegetable tissue.

VOCABULARY

compound - a substance whose smallest particles include more than one element chemically bonded together. For example, water (H_2O) is a compound of hydrogen and oxygen atoms bonded together.

mixture - a substance that includes more than one type of element and/or compound.

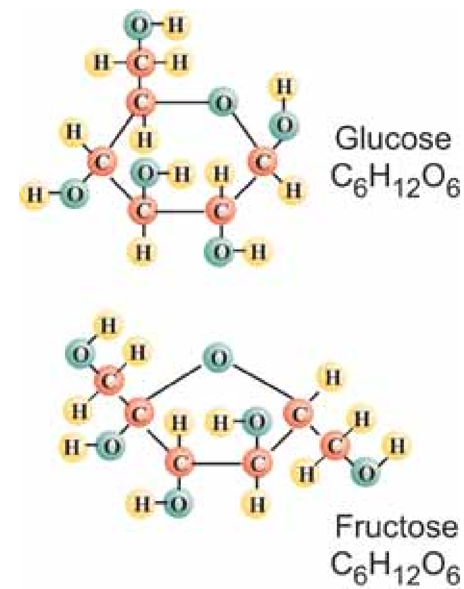


Figure 8.1: *"Pure" sugar is a compound made up of two chemically bonded simple sugars: glucose and fructose.*

Molecules and covalent bonds

Electrons form chemical bonds

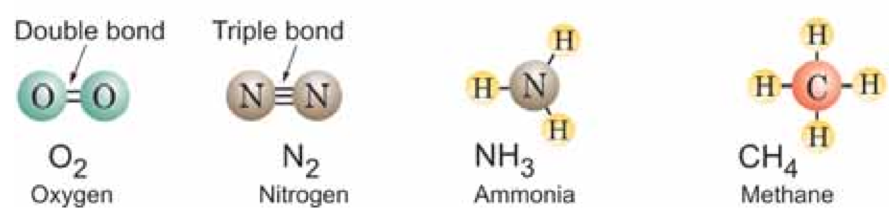
A **chemical bond** forms when atoms transfer or share electrons. Two atoms that are sharing one or more electrons are chemically bonded and move together. In a water molecule, each hydrogen atom shares its single electron with the oxygen atom at the center (Figure 8.2). Almost all the elements form chemical bonds easily. This is why most of the matter you experience is in the form of compounds.

A chemical bond forms when atoms transfer or share electrons.

Covalent bonds

A **covalent bond** is formed when atoms share electrons. The bonds between oxygen and hydrogen in a water molecule are covalent bonds (Figure 8.2). There are two covalent bonds in a water molecule, between the oxygen and each of the hydrogen atoms. Each bond represents one electron. In a covalent bond, electrons are *shared* between atoms, not transferred.

Four examples of molecules held together by covalent bonds



Molecules

A group of atoms held together by covalent bonds is called a **molecule**. Water is a molecule, and so is each of the different sugar molecules on the previous page. Other examples of molecules are methane (CH_4), ammonia (NH_3), oxygen (O_2) and nitrogen (N_2). In the case of oxygen and nitrogen, the bond between atoms is a double or triple covalent bond. A double bond involves two electrons and a triple bond involves three electrons per atom.

VOCABULARY

chemical bond - a bond formed between atoms through the sharing or transferring of electrons.

covalent bond - a type of chemical bond formed by shared electrons.

molecule - a group of atoms held together by covalent bonds in a specific ratio and shape.

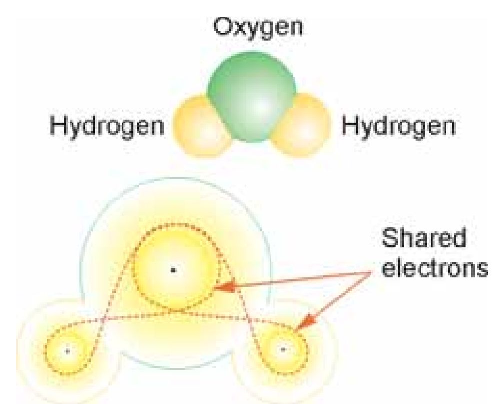
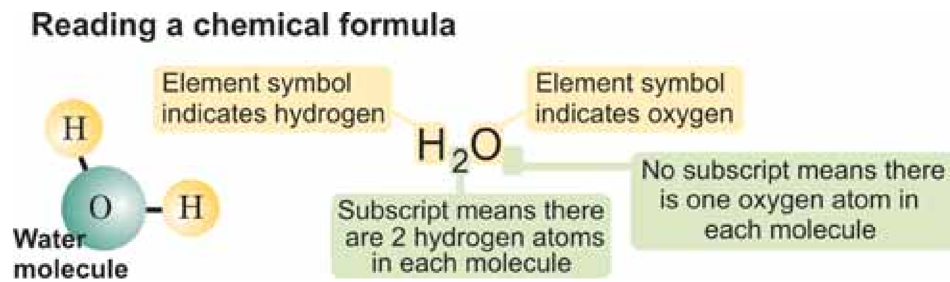


Figure 8.2: *In a covalent bond the shared electrons act like ties that hold a molecule together.*

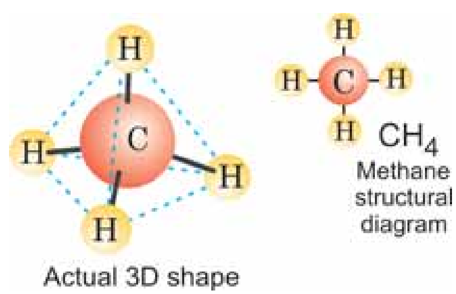
Chemical formulas and diagrams

The chemical formula

Molecules are represented by a **chemical formula**. The chemical formula tells you the precise number of each kind of atom in the molecule. For example, the chemical formula for water is H_2O. The subscript 2 indicates there are two hydrogen atoms in the molecule. The chemical formula also tells you that water always contains twice as many hydrogen atoms as oxygen atoms. This is important to know if you wish to make water from elemental oxygen and hydrogen.



The shape of a molecule is also important to its function and properties. For this reason, molecules are represented by structural diagrams which show the shape and arrangement of atoms. Single bonds between atoms are indicated by solid lines connecting the element symbols. Double and triple bonds are indicated by double and triple lines. Both the chemical formula and structural diagrams are shown in Figure 8.3.



Of course, real molecules are three-dimensional, not flat as shown in the structural diagram. For example a methane molecule has the shape of a 4-sided pyramid called a tetrahedron. Each hydrogen atom is at a corner of the tetrahedron and the carbon atom is at the center.

VOCABULARY

chemical formula - identifies the number and element of each type of atom in a compound. For example, the chemical formula Fe_2O_3 is for a compound with iron (Fe) and oxygen (O) in a ratio of 2 iron atoms for every 3 oxygen atoms.

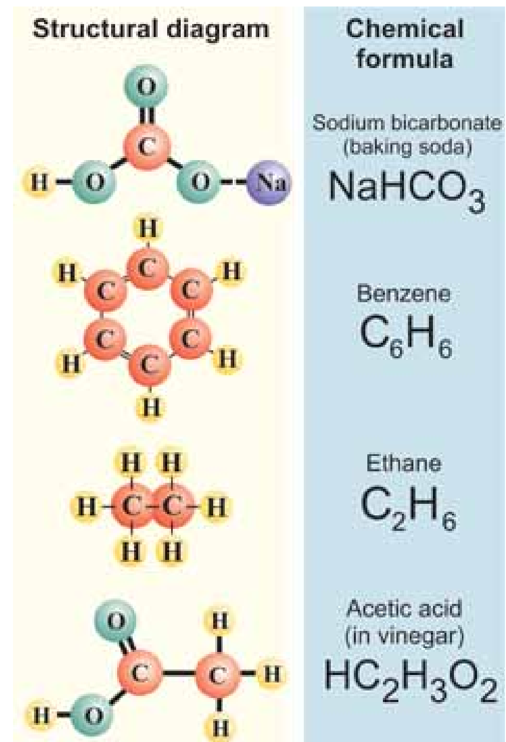


Figure 8.3: *Chemical formulas and structural diagrams.*

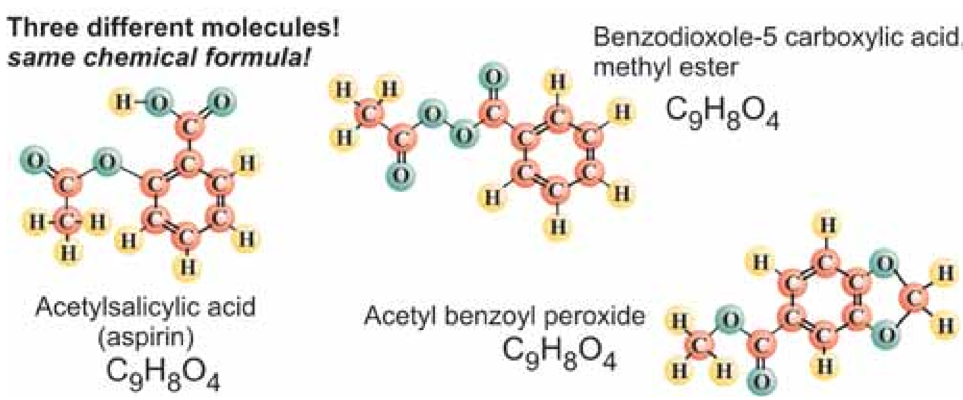
Structure and function

Properties come from the molecule

The properties of a compound depend *much* more on the exact composition and structure (shape) of its molecule than on the elements of which it is made. As a good example, aspirin (acetylsalicylic acid) is made from carbon, hydrogen, and oxygen according to the chemical formula $H_8C_9O_4$ (Figure 8.4). This compound has the property of relieving swelling and reducing pain in humans.

Properties depend on the exact chemical formula

By themselves, the elements (H, C, O) do not have the property of reducing pain. Other molecules formed from the same elements have very different properties than aspirin. For example, polyethylene plastic wrap and formaldehyde (a toxic preservative) are also made from carbon, oxygen, and hydrogen. The beneficial properties of aspirin come from the specific combination of exactly 8 hydrogen, 9 carbon, and 4 oxygen atoms. If the ratio of elements was changed, for example removing even one hydrogen, the resulting molecule would not have the properties of aspirin.



Properties also depend on molecular structure

The structure of a molecule is also important to the properties of a compound. The same 21 atoms in aspirin can be combined in other structures with the same chemical formula! The resulting molecules are something completely different (diagram above) and do not have the beneficial properties of aspirin. *Both chemical formula and structure determine the properties of a compound.*

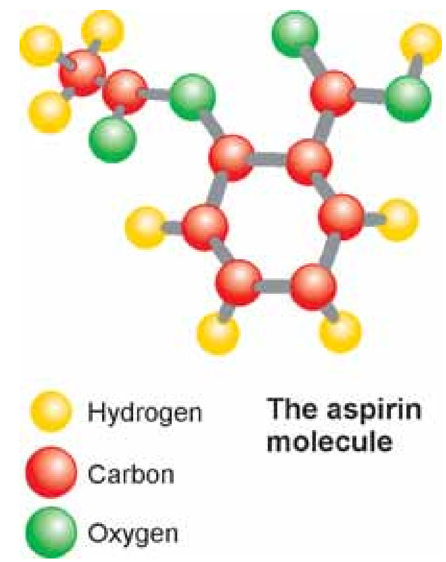


Figure 8.4: *An aspirin molecule.*

CHALLENGE

Like many modern medicines, the active ingredient in aspirin was first discovered in nature. In fact, aspirin's pain-relieving properties were known and used in its natural form long before scientists learned of it. Research the discovery of aspirin to find out the intriguing story of this widely-used medicine.

Ionic compounds

An ion is a charged atom

Not all compounds are made of molecules. For example, sodium chloride (NaCl) is a compound of sodium (Na) and chlorine (Cl) in a ratio of one sodium atom per chlorine atom. The difference is that in sodium chloride, the electron is essentially transferred from the sodium atom to the chlorine atom. When atoms gain or lose an electron they become **ions**. An ion is a charged atom. By losing an electron, the sodium atom becomes a sodium ion with a charge of +1. By gaining an electron, the chlorine atom becomes a chloride ion with a charge of -1 (when chlorine becomes an ion, the name changes to chlor*ide*).

Ionic bonds

Sodium and chlorine form an **ionic bond** because the positive sodium ion is attracted to the negative chloride ion. Ionic bonds are bonds in which electrons are transferred from one atom to another.

Ionic compounds do not form molecules

Ionic bonds are not limited to a single pair of atoms like covalent bonds. In sodium chloride each positive sodium ion is attracted to all of the neighboring chloride ions (Figure 8.5). Likewise, each chloride ion is attracted to all the neighboring sodium atoms. Because the bonds are not just between pairs of atoms, *ionic compounds do not form molecules!* In an ionic compound, each atom bonds with *all* of its neighbors through attraction between positive and negative charge.

The chemical formula for ionic compounds

Like molecular compounds, ionic compounds also have fixed ratios of elements. For example, there is one sodium ion per chloride ion in sodium chloride. This means we can use the same type of chemical formula for ionic compounds and molecular compounds.

Ions may be multiply charged

Sodium chloride involves the transfer of one electron however, ionic compounds may also be formed by the transfer of two or more electrons. A good example is magnesium chloride ($MgCl_2$). The magnesium atom gives up two electrons to become a magnesium ion with a charge of +2 (Mg^{2+}). Each chlorine atom gains one electron to become a chloride ion with a charge of -1 (Cl^-). The ion charge is written as a superscript after the element (Mg^{2+}, Fe^{3+},Cl^-, etc.).

VOCABULARY

ion - an atom that has an electric charge different from zero. Ions are created when atoms gain or lose electrons.

ionic bond - a bond that transfers an electron from one atom to another resulting in attraction between oppositely charged ions.

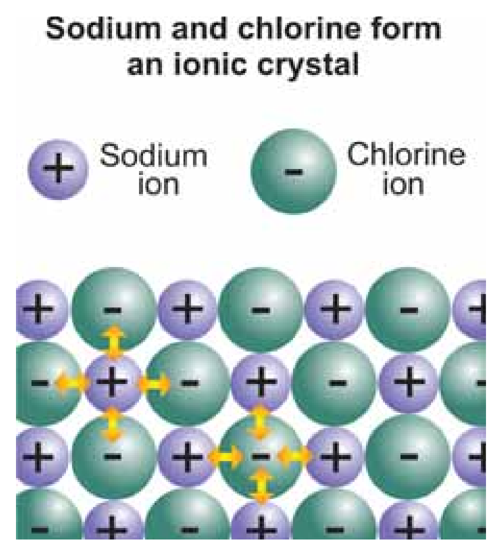


Figure 8.5: *Sodium chloride is an ionic compound in which each positive sodium ion is attracted to all of its negative chloride neighbors and vice versa.*

Why chemical bonds form

Atoms form bonds to reach a lower energy state

Imagine pulling tape off a surface. It takes energy to separate atoms that are bonded together just like it takes energy to pull tape off a surface. If it takes energy to separate bonded atoms, then the same energy must be released when the bond is formed. *Energy is released when chemical bonds form*. Energy is released because chemically bonded atoms have less total energy than free atoms. Like a ball rolling downhill, atoms form compounds because the atoms have lower energy when they are together in compounds. For example, one carbon atom and four hydrogen atoms have more total energy apart than they do when combined in a methane molecule (Figure 8.6).

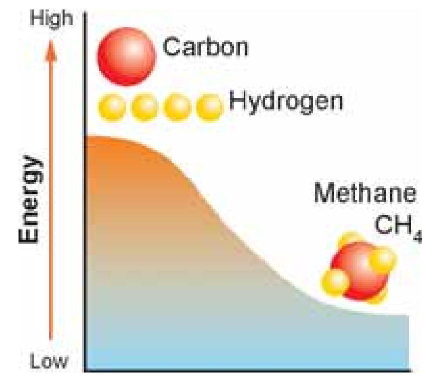
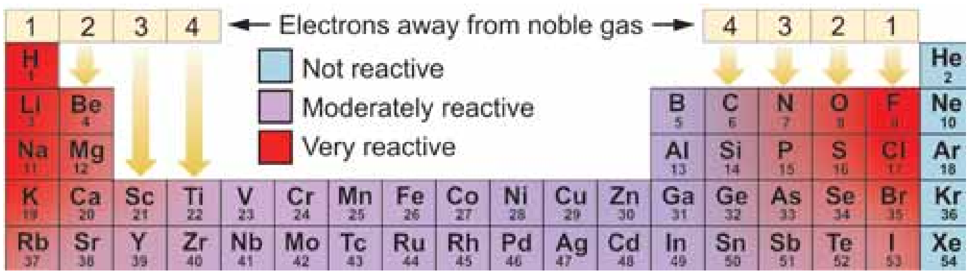


Figure 8.6: *The methane (CH_4) molecule has lower total energy than four separate hydrogen and one separate carbon atom.*

Chemical reactivity

All elements except the noble gases form chemical bonds. However, some elements are much more reactive than others. In chemistry, "reactive" means an element readily forms chemical bonds, often releasing energy. For example, sodium is a highly reactive metal. Chlorine is a highly reactive gas. If pure sodium and pure chlorine are placed together, a violent explosion occurs as the sodium and chlorine combine and form ionic bonds. The energy of the explosion is the energy given off by the formation of the chemical bonds.



Some elements are more reactive than others

The closer an element is to having the same number of electrons as a noble gas, the more reactive the element is. The alkali metals are very reactive because they are just one electron away from the noble gasses. The halogens are also very reactive because they are also one electron away from the noble gases. The beryllium group and the oxygen group are less reactive because each element in these groups is two electrons away from a noble gas.

CHALLENGE

The noble gases (He, Ne, Ar, ...) are called inert because they do not ordinarily react with anything. You can put sodium in an atmosphere of pure helium and nothing will happen. However, scientists have found that a few noble gases DO form compounds in very special circumstances. Research the topic and see if you can find a compound involving a noble gas.

8.1 Section Review

1. What is the difference between a compound and a mixture?
2. Give an example of a compound, and an example of a mixture.
3. How many atoms of chlorine (Cl) are in the carbon tetrachloride molecule (CCl_4)?
4. Which of the diagrams in Figure 8.7 is the correct structural diagram for carbon tetrachloride (CCl_4)?
5. Write a chemical formula for a compound which has two atoms of oxygen (O) and three atoms of iron (Fe).
6. What is the chemical formula for the molecule in Figure 8.8?
7. How many atoms of hydrogen are in a molecule of acetic acid ($HC_2H_3O_2$)?

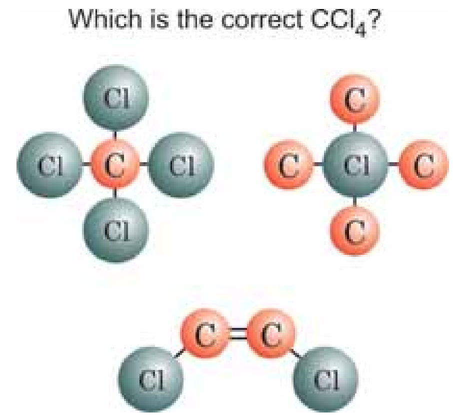
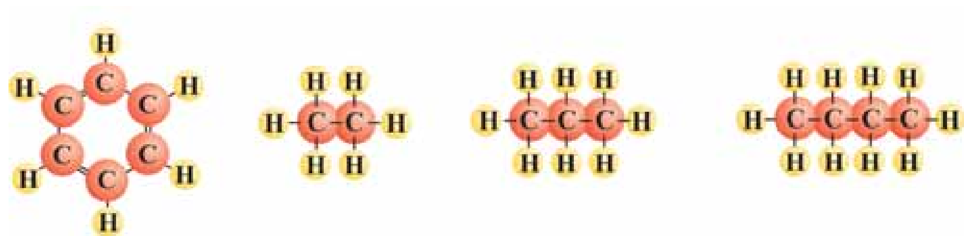


Figure 8.7: *Question 4*



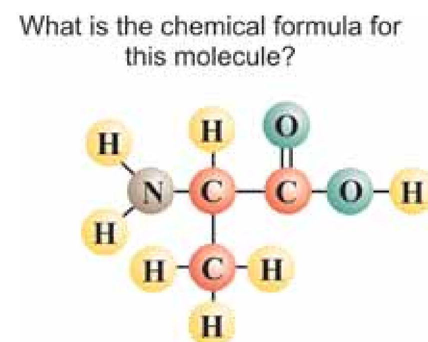


Figure 8.8: *Question 6*

8. Which of the molecules above has the chemical formula C_3H_8?
9. Which of the following statements is FALSE?
   a. The properties of a compound depend more on which elements are present and less on the structure of the molecule.
   b. The properties of a compound depend more on the structure of the molecule and less on which elements are present.
10. Chemical bonds form because
    a. The atoms have more energy bonded together than separated.
    b. The atoms have less energy bonded together than separated.

8.2 Electrons and Chemical Bonds

The discovery of energy levels in the atom solved a 2000-year-old mystery. The mystery was why elements combined with other elements only in particular ratios (or not at all). For example, why do two hydrogen atoms bond with one oxygen to make water? Why isn't there a molecule with three (H_3O) or even four (H_4O) hydrogen atoms? Why does sodium chloride have a precise ratio of one sodium ion to one chloride ion? Why do helium, neon, and argon form no compounds with any other element? The answer has to do with energy levels and electrons.

VOCABULARY

valence electrons - electrons in the highest unfilled energy level of an atom. These electrons participate in chemical bonds.

Valence electrons

Valence electrons

Chemical bonds are formed only between the electrons in the highest unfilled energy level. These electrons are called **valence electrons**. You can think of valence electrons as the outer "skin" of an atom. Electrons in the inner (filled) energy levels do not "see" other atoms because they are shielded by the valence electrons. For example, chlorine has 7 valence electrons. The first 10 of chlorine's 17 electrons are in the inner (filled) energy levels.

Most elements bond to reach 8 valence electrons

It turns out that *8 is a magic number for chemical bonding*. All the elements heavier than boron form chemical bonds to try and get to a configuration with eight valence electrons (Figure 8.10). Eight is a preferred number because 8 electrons are a complete (filled) energy level. The noble gases already have a magic number of 8 valence electrons. They don't form chemical bonds because they don't need to!

Light elements bond to reach 2 valance electrons

For elements with atomic number 5 (boron) or less, the magic number is 2 instead of 8. For these light elements, 2 valence electrons completely fills the *first* energy level. The elements H, He, Li, Be,and B, form bonds to reach the magic number of 2.

Hydrogen is special

Because of its single electron, hydrogen can also have 0 valence electrons! Zero is a magic number for hydrogen, as well as 2. This flexibility makes hydrogen a very "friendly" element; hydrogen can bond with almost any other element.

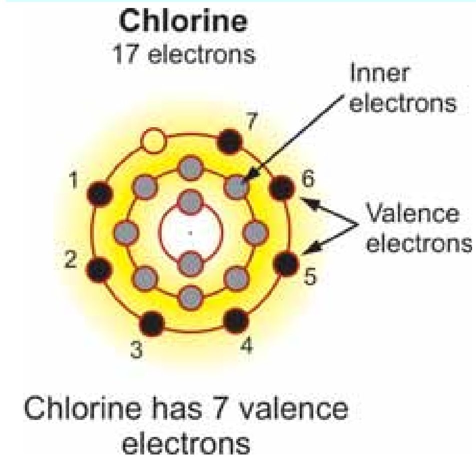


Figure 8.9: *Chlorine has 7 valence electrons. The other 10 electrons are in filled (inner) energy levels.*

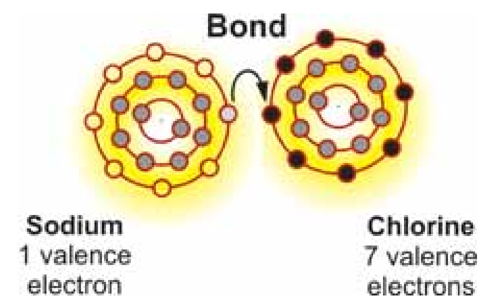


Figure 8.10: *Chlorine and sodium bond so each can reach a configuration with 8 valence electrons.*

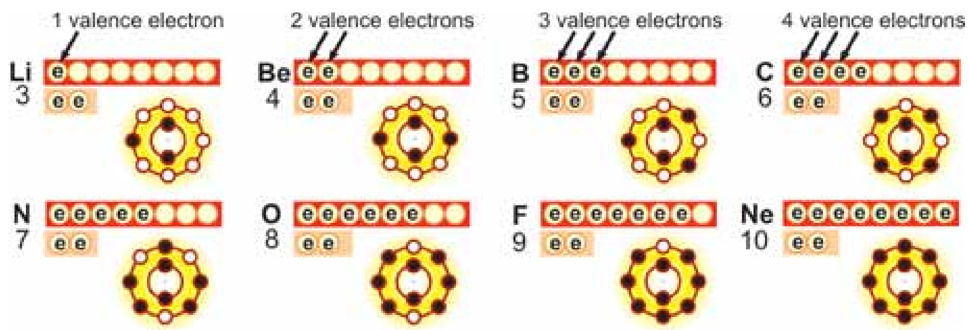
Valence electrons and the periodic table

Period 2 elements

The picture below shows how the electrons in the elements in the second period (lithium to neon) fill the energy levels. Two of lithium's three electrons go in the first energy level. Lithium has one valence electron because it's third electron is the only one in the second energy level.

Each successive element has one more valence electron

Going from left to right across a period each successive element has one more valence electron. Beryllium has two valence electrons. Boron has three and carbon has four. Each element in the second period adds one more electron until all 8 spots in the second energy level are full at atomic number 10, which is neon, a noble gas. Neon has 8 valence electrons



Bonding

Oxygen has 6 valence electrons. To get to the magic number of 8, oxygen needs to add two electrons. *Oxygen forms chemical bonds that provide these two extra electrons*. For example, a single oxygen atom combines with two hydrogen atoms because each hydrogen can supply only one electron. Oxygen combines with one beryllium atom because beryllium can supply two valence electrons to give oxygen its required number of 8 (Figure 8.11).

Double bonds share 2 electrons

Carbon has four valence electrons. That means two oxygen atoms can bond with a single carbon atom, each oxygen sharing two of carbon's four valence electrons. The bonds in carbon dioxide (CO_2) are double bonds because each bond involves 2 electrons (Figure 8.12).

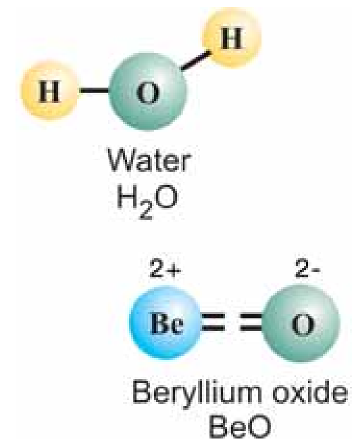


Figure 8.11: *Water (H_2O) and beryllium oxide (BeO).*

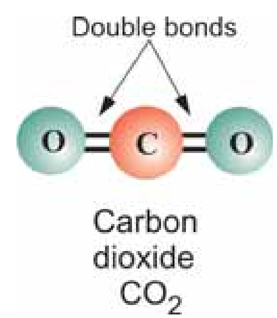


Figure 8.12: *Carbon forms two double bonds with oxygen to make carbon dioxide.*

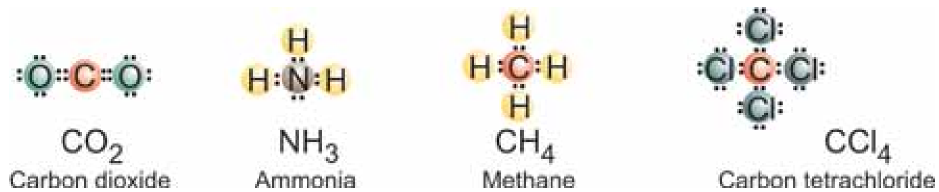
Lewis dot diagrams

Dot diagrams of the elements

A clever way to keep track of valence electrons is to draw Lewis dot diagrams. A dot diagram shows the element symbol surrounded by one to eight dots representing the valence electrons. Each dot represents one electron. Lithium has one dot, beryllium has two, nitrogen has three, etc. Figure 8.13 shows the dot diagrams for the first 10 elements.

Dot diagrams of molecules

Each element forms bonds to reach one of the magic numbers of valence electrons: 2 or 8. In dot diagrams of a complete molecule each element symbol has either 2 or 8 dots around it. Both configurations correspond to completely filled (or empty) energy levels.



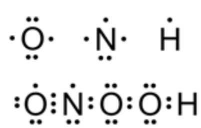
Example dot diagrams

Carbon has four dots and hydrogen has one. One carbon atom bonds with four hydrogen atoms because this allows the carbon atom to have eight valence electrons (8 dots) — four of its own and four shared from the hydrogen atoms. The picture above shows dot diagrams for carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and carbon tetrachloride (CCl_4), a flammable solvent.

Dot diagrams

Draw the dot diagram for nitric acid, HNO_3.

1. Looking for: Dot diagram
2. Given: chemical formula HNO_3
3. Relationships:
4. Solution:



This one is tricky, each element symbol has 2 or 8 dots but one of the bonds (O⁝N) is a double bond.

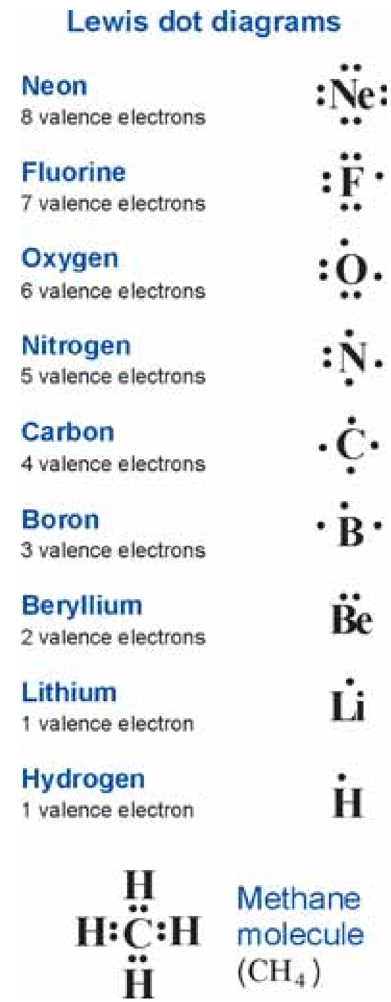


Figure 8.13: *Lewis dot diagrams show valence electrons as dots around the element symbol. Atoms form bonds to get eight valence electrons by sharing with other atoms.*

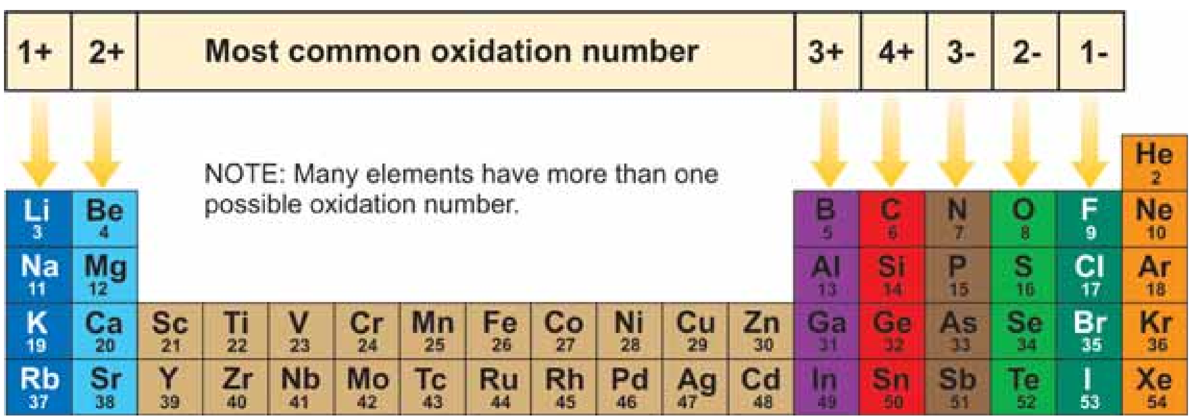
Oxidation numbers

Oxidation numbers

A sodium atom always ionizes to become Na+ (a charge of +1) when it combines with other atoms to make a compound. Therefore, we say that sodium has an **oxidation number** of 1+. An oxidation number indicates the charge on the remaining atom (ion) when electrons are lost, gained, or shared in chemical bonds. Table 8.1 shows the oxidation numbers for some elements. Notice that the convention for writing oxidation numbers is the opposite of the convention for writing the charge. When writing the oxidation number, the positive (or negative) symbol is written after the number, not before it.

Oxidation numbers and the periodic table

Oxidation numbers correspond closely to an element's group on the periodic table. All of the alkali metals have oxidation numbers of 1+ since these elements all prefer to lose one electron in chemical bonds. All of the halogens have an oxidation number of 1- because these elements prefer to gain an electron in chemical bonds. The diagram below shows the trend in oxidation numbers across the periodic table. Most transition metals have complicated oxidation numbers because they have many more electrons.



VOCABULARY

oxidation number - indicates the charge of an atom when an electron is lost, gained, or shared in a chemical bond. An oxidation number of +1 means an electron is lost, -1 means an electron is gained.

Table 8.1: Some oxidation numbers

atom	electrons gained or lost	oxidation number
K	loses 1	1+
Mg	loses 2	2+
Al	loses 3	3+
P	gains 3	3-
Se	gains 2	2-
Br	gains 1	1-
Ar	loses 0	0

SOLVE IT!

What is fluorine's oxidation number? If you think it is 1-, you are right. Like the other halogens, fluorine gains one electron, one negative charge, when it bonds with other atoms.

Predicting a chemical formula

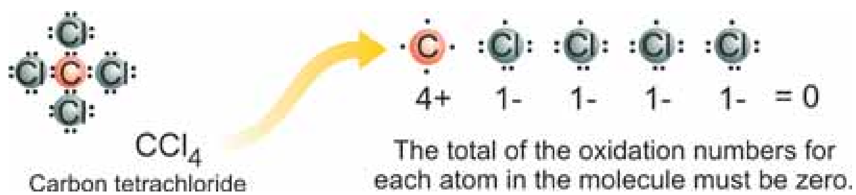
Oxidation numbers in a compound add up to zero

When elements combine in molecules and ionic compounds, the total electric charge is always zero. This is because any electron donated by one atom is accepted by another. The rule of zero charge is easiest to apply using oxidation numbers. The total of all the oxidation numbers for all the atoms in a compound must be zero. This important rule allows you to predict many chemical formulas.

The oxidation numbers for all the atoms in a compound must add up to zero

Example, carbon tetrachloride

To see how this works, consider the compound, carbon tetrachloride (CCl_4). Carbon has an oxidation number of 4+. Chlorine has an oxidation number of 1-. It takes four chlorine atoms to cancel with carbon's 4+ oxidation number.

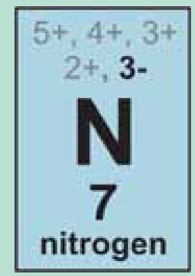


STUDY SKILLS

Multiple oxidation numbers

Many periodic tables list multiple oxidation numbers for most elements. This is because more complex bonding is possible. This course gives you the fundamental ideas but there is much more!

When multiple oxidation numbers are shown, the most common one is usually in bold type. For example, nitrogen has possible oxidation numbers of 5+, 4+, 3+, 2+ and 3- even though 3- is the most common.



Predict a chemical formula

Iron and oxygen combine to form a compound. Iron (Fe) has an oxidation number of 3+. Oxygen (O) has an oxidation number of 2-. Predict the chemical formula of this compound.

1. Looking for: Chemical formula
2. Given: oxidation numbers Fe 3+ and O 2-
3. Relationships: The oxidation numbers for all the atoms in a compound must add up to zero.
4. Solution: Three oxygen atoms contribute the total oxidation number of 6-. It takes only two iron atoms to get a total oxidation number of 6+. Therefore, the chemical formula is Fe_2O_3.

Your turn...

a. Predict the chemical formula of the compound containing beryllium (2+) and fluorine (1-). **Answer:** BeF_2

Ionic and covalent bonds

Why bonds are ionic or covalent

Whether or not a compound is ionic or covalently bonded depends on how much each element "needs" an electron to get to a magic number (2 or 8). Elements which are very close to the noble gases tend to give or take electrons rather than share them. These elements often form ionic bonds rather than covalent bonds.

Sodium chloride is ionic

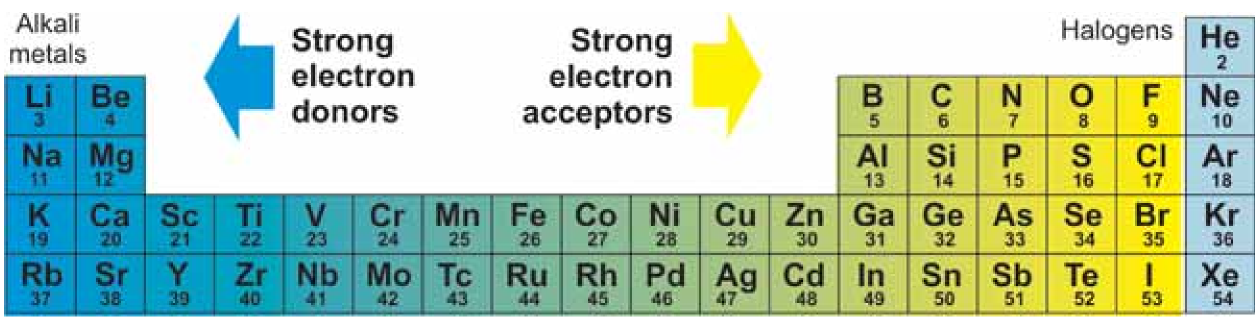
As an example, sodium has one electron more than the noble gas, neon. Sodium has a very strong tendency to give up that electron and become a positive ion. Chlorine has one electron less than argon. Therefore, chlorine has a very strong tendency to accept an electron and become a negative ion. Sodium chloride is an ionic compound because sodium has a strong tendency to give up an electron and chlorine has a strong tendency to accept an electron.

Widely separated elements form ionic compounds

On the periodic table, strong electron donors are the left side (alkali metals). Strong electron acceptors are on the right side (halogens). The farther separated two elements are on the periodic table, the more likely they are to form an ionic compound.

Nearby elements form covalent compounds

Covalent compounds form when elements have roughly equal tendency to accept electrons. Elements that are nonmetals and therefore close together on the periodic table tend to form covalent compounds with each other because they have approximately equal tendency to accept electrons. Compounds involving carbon, silicon, nitrogen, and oxygen are often covalent.



Predicting ionic or covalent bonds

Potassium (K) combines with bromine (Br) to make the salt, potassium bromide (KBr). Is this likely to be an ionic or covalently bonded compound?

1. Looking for:	ionic or covalent bond
2. Given:	K and Br
3. Relationships:	K is a strong electron donor. Br is a strong electron acceptor
4. Solution:	KBr is an ionic compound because K and Br are from opposite sides of the periodic table.

Your turn...

a. Is silica (SiO_2) likely to be an ionic or covalently bonded compound?
Answer: covalent

b. Is calcium fluoride (CaF_2) likely to be an ionic or covalently bonded compound?
Answer: ionic

8.2 Section Review

1. Atoms form chemical bonds using
   a. electrons in the innermost energy level,
   b. electrons in the outermost energy level,
   c. protons and electrons.
2. Which of the diagrams in Figure 8.14 shows an element with three valence electrons? What is the name of this element?
3. Which of the following elements will form a double bond with oxygen making a molecule with one atom of the element and one atom of oxygen.
   a. lithium
   b. boron
   c. beryllium
   d. nitrogen
4. Name two elements that have the Lewis dot diagram shown in Figure 8.15.
5. The oxidation number is
   a. the number of oxygen atoms and element bonds with,
   b. the positive or negative charge acquired by an atom in a chemical bond,
   c. the number of electrons involved in a chemical bond.
6. Name three elements that have an oxidation number of 3+.
7. What is the oxidation number for the elements shown in Figure 8.16?
8. When elements form a molecule, what is TRUE about the oxidation numbers of the atoms in the molecule.
   a. The sum of the oxidation numbers must equal zero.
   b. All oxidation numbers from the same molecule must be positive.
   c. All oxidation numbers from the same molecule must be negative

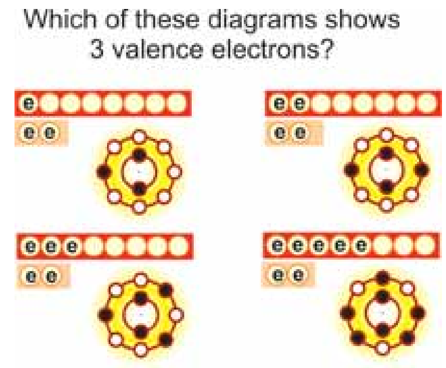


Figure 8.14: *Question 2*

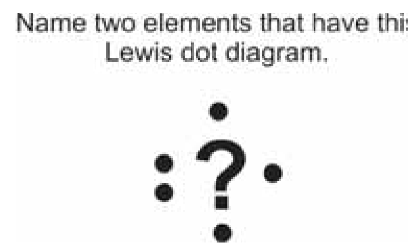


Figure 8.15: *Question 4*

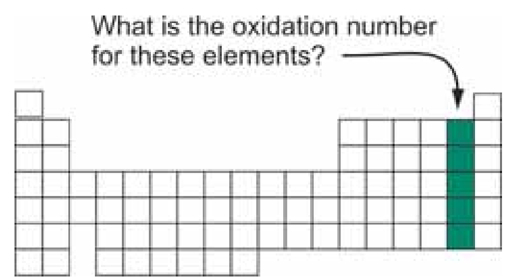


Figure 8.16: *Question 7*

GEOLOGY CONNECTION

Salt: Common, But Uncommonly Important

Timbuktu sounds like a faraway place, isolated, inaccessible - almost imaginary. In fact, it is in a remote location: at the edge of the Sahara in the West African nation of Mali. And today, Timbuktu is a ruined city, a harsh place under constant threat from desert sand and winds. It is hard to picture it as it once was - a thriving center of trade and culture. What could this old city have in common with salt?

Beginning more than 900 years ago, Timbuktu became an important crossroads of African trade. Caravans of thousands of camels crossed hundreds of miles of desert to and from the city. Two commodities, which often traded at equal value and were used as money, drove the city's fortunes: gold and salt.

Today salt is among the most common substances we know. Why was it so valuable back then, literally worth its weight in gold? There were two big reasons. First, salt was much harder to find than it is today. Second, it was very important for preserving foods. Before refrigeration, salt was used to keep meat edible for long periods of time. The use of salt as a preservative contributed to the survival and expansion of human civilization.

Salt in the modern world

Today, salt is still important, but not as a food preservative. Of course, it is commonly used to season food. It is also used as a supplement in raising livestock and poultry. Salt has many industrial uses, too, in making paper, soap, detergent, and a variety of chemicals. In many parts of the United States, huge amounts of salt are used to melt ice on highways in winter.

One of the chief ways to get salt is to mine it. Rock salt, also called halite, is mined from salt deposits which are usually deep in the ground. A mammoth salt deposit lies beneath portions of Ohio, Michigan, Pennsylvania, New York, West Virginia, and Ontario, Canada. This Great Eastern Salt Basin is one of the largest salt beds in the world. The salt was evaporated from ancient seas and deposited more than 300 million years ago. Today, in Cleveland, Ohio, this salt is mined from beneath Lake Erie. The salt mine is immense; its two main shafts are nearly 2,000 feet deep.

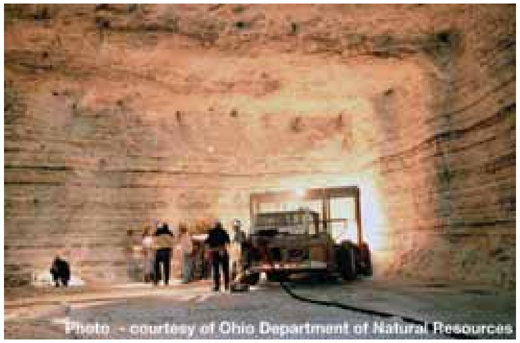


Photo - courtesy of Ohio Department of Natural Resources

The other common way to get salt is through evaporation. In the evaporation process, salt is gathered from seawater, salt marshes, or salt lakes. San Francisco Bay in California has one of the largest salt operations in the country; it is scooped from the bottom of coastal ponds. The Great Salt Lake in Utah is another huge evaporation site.

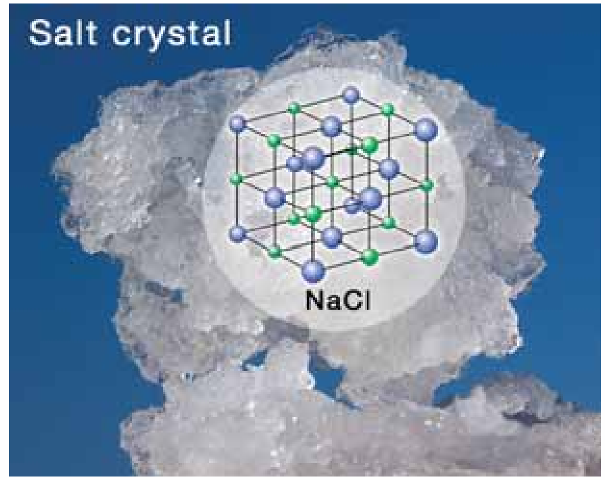
The chemistry of salt

Salt is a chemical compound composed of two elements, sodium and chlorine. It is called sodium chloride. The chemical symbol for salt is NaCl. A salt crystal contains one atom of sodium for each atom of chlorine.

Let's take a closer look at these elements. Sodium is on the left side of the periodic table of elements, a metal. Its atomic number is 11. It is soft, light, and silvery-white. Sodium is highly reactive and never found in pure form in nature. It oxidizes in air and reacts violently with water.

Chlorine is on the right side of the periodic table, a halogen. Its atomic number is 17. It is yellow-green in color and poisonous. Chlorine is commonly found in nature as a gas. In liquid form it is a powerful oxidizing and bleaching agent; it is a component of chlorine bleach. Chlorine combines easily with nearly all other elements.

Sodium chloride is a crystal. The particular crystal structure of sodium chloride is cubic. Each sodium ion is surrounded by six chlorine ions. Each chlorine ion is surrounded by six sodium ions. This is known as the halite structure and is common to many minerals.



"The salt of the Earth" is precious

Sodium chloride is one of Earth's most common compounds. It makes the oceans salty; it is found in most human tissue; it is plainly essential to life.

Yet long ago, salt was one of the most valuable substances in the world. Having it was as good as money in the bank. Wars were fought over salt. We take common table salt for granted now, but salt has been uncommonly important to human civilization and to life here on Earth.

Questions:

1. Compare the two chief methods of gathering salt.
2. How did salt affect the expansion of human civilization?
3. What are the differences between chlorine and sodium?
4. Describe the crystal structure of sodium chloride.

CHAPTER ACTIVITY Molecular Gumdrop Models

Molecules are the structures that result when two or more atoms bond by sharing electrons. In living things, almost all molecules are made from hydrogen, carbon, nitrogen, oxygen, phosphorus, and sulfur. Molecules are described using formulas. For example, H_2 is a molecule consisting of two hydrogen atoms. CH_4 is a molecule consisting of one carbon atom and four hydrogen atoms. In this activity, you will build some simple molecules out of gumdrops and toothpicks.

Materials:

Toothpicks
White, red, yellow and green gumdrops

What you will do

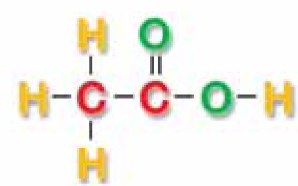
1. Colored gumdrops will represent the atoms you use to build your molecules: white (or brown) gumdrops represent nitrogen, red gumdrops represent carbon, yellow gumdrops represent hydrogen, and green gumdrops represent oxygen. Toothpicks will represent each bond in your model. Remember that hydrogen can have one bond, oxygen can have two bonds, carbon can make four bonds and nitrogen can have three bonds. The bonding between two atoms can be single, double or triple. So, carbon could make its four bonds with four single bonds, or two double bonds, or one double bond and two single bonds, or one single bond and one triple bond.
2. Build the following molecules. As you build your molecules, try to make sure each atom is as far from other atoms as possible. If a molecule has three hydrogen atoms on it, don't put all three next to each other. Space them evenly around the central atom.
3. Build the following molecules.

H_2	O_2
N_2	H_2O
CH_4	HCN
CO_2	C_2H_6O (two different versions)

Applying your knowledge

a. Once you've built your models, sketch them on paper.
b. If a bond is a pair of electrons shared between two atoms, how many electrons are being shared in H_2?
c. If a bond is a pair of electrons shared between two atoms, how many electrons are being shared in O_2?
d. Electrons are negatively charged. Charges of the same kind repel. Bonds are shared pairs of electrons. How does this explain that atoms are evenly spaced around each other in molecules?
e. There were two different ways (at least) to draw the molecule C_2H_6O. When the same formula can produce different molecules, those molecules are called isomers. Do you think the isomers of C_2H_6O have the same characteristics or different characteristics? Explain.
f. Write the formula for the molecule in the diagram:

   How many toothpicks and gumdrops (and what color!) would you need to build this molecule?



Vocabulary

Select the correct term to complete the sentences.

compound	covalent	ion
mixture	chemical bond	molecule
chemical formula	ionic bond	oxidation number
valence electrons		

Section 8.1

1. When two atoms share or trade electrons a(n) ____ is formed.
2. An atom that has acquired a positive or negative charge is called a(n) ____.
3. To represent the number and type of each element in a molecule, chemists write a ____.
4. A substance whose smallest particles include more than one element chemically bonded together is a ____.
5. The type of chemical bond formed when atoms share electrons is the ____ bond.
6. A substance made of two or more elements or compounds not chemically bonded to each other is a(n) ____.
7. A bond formed when an electron is transferred from one atom to another is a(n) ____.
8. A group of atoms held together by covalent bonds in a specific ratio form a(n) ____.

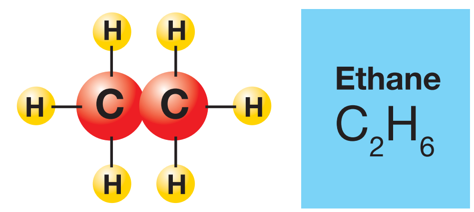
Section 8.2

9. Electrons in the highest unfilled energy level of an atom, that may participate in chemical bonds are called ____.
10. The number which indicates the charge on an atom when an electron is lost, gained or, shared is called the ____.

Concepts

Section 8.1

1. What is the chemical formula for water? What atoms make up this compound?
2. What is the difference between a compound and a mixture?
3. List 3 examples of a mixture and 3 examples of a compound.
4. Why do atoms form compounds instead of existing as single atoms?
5. What type of bond holds a water molecule together?
6. What do we call the particle that is a group of atoms held together by covalent bonds?
7. List 4 examples of a molecule.
8. What does the subscript “2” in $H_2$0 mean?
9. What do the subscripts in the formula for ethane represent?



10. Name the two most important factors in determining the properties of a compound.
11. Summarize the differences between a covalent compound and an ionic compound.
12. What happens when chemical bonds form? Why?
13. Which group of elements usually don’t form chemical bonds?
14. Name a very reactive group of metals and a very reactive group of nonmetals. Why do they behave this way?

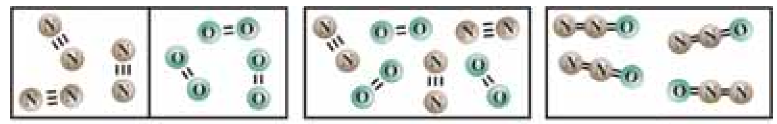
Section 8.2

15. When atoms form chemical bonds, which of their electrons are involved in the bonds?
16. How many electrons represent a complete (filled) outermost energy level for elements heavier than Boron (atomic number greater than 5)?
17. Noble gases usually don't form chemical bonds. Why?
18. What is so special about hydrogen when it comes to forming bonds?
19. Each successive element on a period table going from left to right across a period has what?
20. In a Lewis dot diagram, what is represented by the dots surrounding the element symbol?
21. How many valence electrons does oxygen have? How many more electrons are needed to fill the outermost energy level?
22. How does the oxidation number indicate if an electron will be lost or gained by the bonding atom?
23. Using the periodic table, what is the oxidation number of:
    a. calcium
    b. aluminum
    c. fluoride
24. What is the total electric charge on molecules and compounds?
25. Elements close to the noble gases tend to form what type of bond?
26. Elements that are widely separated on the periodic table tend to form____ compounds.
27. Elements that are close together on the periodic table tend to form ____ compounds.
28. Strong electron donors are on the ____ side of the periodic table, while strong electron acceptors are on the ____ side.

Problems

Section 8.1

1. Label each of the diagrams below as a mixture, compound, or separate elements.



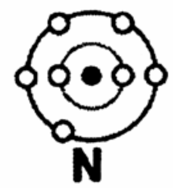
A B C

2. For each of the formulas for molecules listed below, name each element and how many of atoms of each element are in that molecule.
   a. $C_6H_{12}O_6$
   b. $CaCO_3$
   c. Al_2O_3
3. Predict the formula for a molecule containing carbon (C) with an oxidation number of 4+ and oxygen (O) with an oxidation number of 2-.
4. Which of the following would be a correct chemical formula for a molecule of N^{3-} and H^+?
   a. HNO_3
   b. H_3N_6
   c. NH_3

5. Referring to the diagram of the periodic table in chapter 7, determine which element in each pair is more active:
   a. Li or Be
   b. Ca or Sc
   c. P or S
   d. O or Ne

Section 8.2

6. In order for nitrogen to form a compound with other elements, how many additional electrons are required to give nitrogen the required number of electrons in its outermost energy level?



7. Draw Lewis dot diagrams for the following:
   a. An atom of hydrogen (one valence electron)
   b. An atom of oxygen (6 valence electrons).
   c. A molecule of water, H_2O.
   d. A molecule of carbon dioxide, CO_2.
8. Using the periodic table:
   a. Determine the oxidation number of Ca and Cl.
   b. Write the chemical formula for calcium chloride.
9. Give the most common oxidation number and how many electrons are gained or lost for the following elements:
   a. oxygen (O)
   b. boron (B)
   c. lithium (Li)
   d. potassium (Na)
   e. magnesium (Mg)
   f. aluminum (Al)
   g. carbon (C)
   h. iodine (I)
10. Use the periodic table to determine the type of bond most likely formed between the elements:
    a. carbon and oxygen
    b. lithium and fluorine
    c. carbon and carbon
    d. carbon and nitrogen
11. Carbon and oxygen combine to form a gas called carbon dioxide. Carbon (C) has an oxidation number of 4+ and oxygen (O) has an oxidation number of 2-.
    a. What is the total of the oxidation numbers for all the atoms in carbon dioxide?
    b. Predict the formula for carbon dioxide.
    c. Is carbon dioxide an ionic or covalently bonded compound?
12. Carbon and hydrogen combine to form a gas called methane. Carbon (C) has an oxidation number of 4+ and hydrogen has an oxidation number of 1-.
    a. What is the total of all the oxidation numbers for all the atoms in methane?
    b. Predict the formula for methane.
    c. Is methane an ionic or covalently bonded compound?
13. The chemical formula for a molecule of glucose is $C_6H_{12}O_6$.
    a. How many atoms of carbon are in a molecule of glucose?
    b. How many atoms of hydrogen are in a molecule of glucose?
    c. How many atoms of oxygen are in a molecule of glucose?