13.2 Chemical Formulas

In the previous section, you learned how and why atoms form chemical bonds with one another. You also learned that atoms combine in certain ratios with other atoms. These ratios determine the chemical formula for a compound. In this section, you will learn how to write the chemical formulas for compounds. You will also learn how to name compounds based on their chemical formulas.

VOCABULARY

oxidation number - a quantity that indicates the charge on an atom when it gains, loses, or shares electrons during bond formation.

Chemical formulas and oxidation numbers

Ionic compounds Recall that the chemical formula for sodium chloride is NaCl. This formula indicates that every formula unit of sodium chloride contains one atom of sodium and one atom of chlorine; it's a 1:1 ratio. Why do sodium and chlorine combine in a 1:1 ratio? When sodium loses an electron, it becomes an ion with a charge of +1. When chlorine gains an electron, it becomes an ion with a charge of –1. When these two ions combine to form an ionic bond, the net electrical charge is zero (Figure 13.11). This is because (+1) + (–1) = 0.

All compounds have an electrical charge of zero. This means they are neutral.

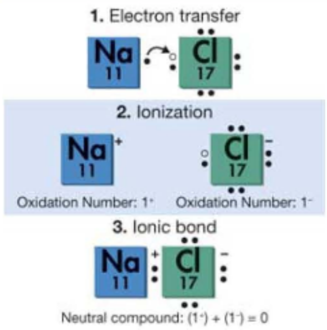


Figure 13.11: *Sodium and chlorine combine in a 1:1 ratio.*

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 electric charge on an atom when electrons are lost, gained, or shared during chemical bond formation. 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.

What is chlorine's oxidation number? If you think it is 1–, you are right. This is because chlorine gains one electron, one negative charge, when it bonds with other atoms. Figure 13.12 shows the oxidation numbers for some of the elements.

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–

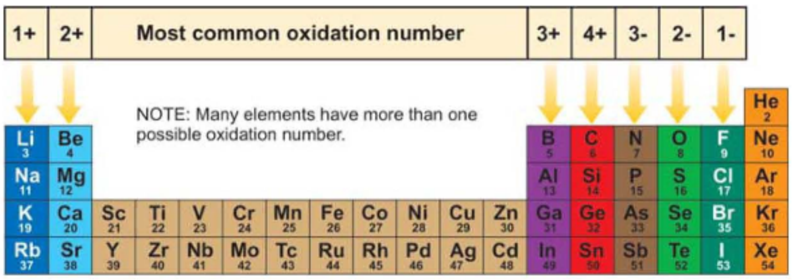
Figure 13.12: *Oxidation numbers of some common elements.*

Predicting oxidation numbers from the periodic table

Valence electrons and oxidation numbers In the last section, you learned that you can tell how many valence electrons an element has by its location on the periodic table. If you can determine how many valence electrons an element has, you can predict its oxidation number. An oxidation number corresponds to the need of an atom to gain or lose electrons (Figure 13.13).

Beryllium has an oxidation number of 2+ For example, locate beryllium (Be) on the periodic table below. It is in the second column, or Group 2, which means beryllium has two valence electrons. Will beryllium get rid of two electrons, or gain six in order to obtain a stable number? Of course, it is easier to lose two electrons. When these two electrons are lost, beryllium becomes an ion with a charge of +2. Therefore, the most common oxidation number for beryllium is 2+. In fact, the most common oxidation number for all elements in Group 2 is 2+.

The periodic table The periodic table below shows the most common oxidation numbers of most of the elements. The elements known as *transition metals* (in the middle of the table) have variable oxidation numbers.



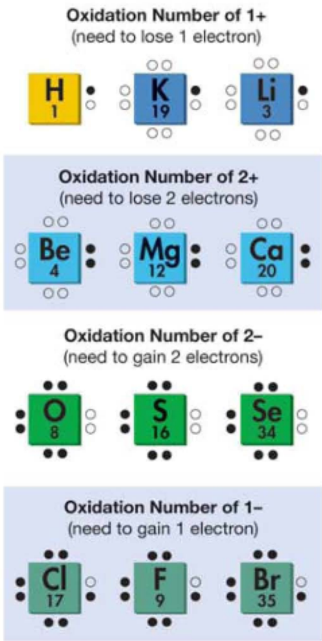


Figure 13.13: *Oxidation numbers correspond to the need to gain or lose electrons.*

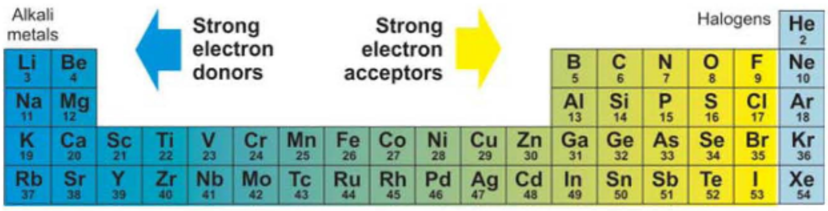
Predicting ionic and covalent bonds

Why bonds are ionic or covalent Whether a compound is ionic or covalently bonded depends on how much each element "needs" an electron to get to a magic number (two or eight). Elements that 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.

Forming ionic compounds On the periodic table, strong electron donors are on 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.

Forming 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.



SOLVE IT!

You can use the periodic table to predict whether two elements will form ionic or covalent compounds. For example, potassium combines with bromine to make potassium bromide (KBr). Are the chemical bonds in this compound likely to be ionic or covalent? To solve this problem, look at the periodic table at the left.

K is a strong electron donor and Br is a strong electron acceptor. KBr is an ionic compound because K and Br are from opposite sides of the periodic table.

Now you try the following.

1. Are the chemical bonds in silica (SiO_2) likely to be ionic or covalent?
2. Are the chemical bonds in calcium fluoride (CaF_2) likely to be ionic or covalent?

Oxidation numbers and chemical formulas

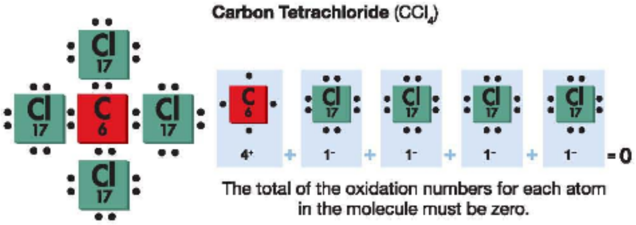
Oxidation numbers in a compound add up to zero

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 carbon's 4+ oxidation number.

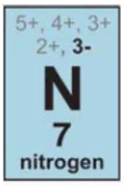


Element	Oxidation Number
copper (I)	Cu^+
copper (II)	Cu^{2+}
iron (II)	Fe^{2+}
iron (III)	Fe^{3+}
chromium (II)	Cr^{2+}
chromium (III)	Cr^{3+}
lead (II)	Pb^{2+}
lead (IV)	Pb^{4+}

Figure 13.14: *In some cases, roman numerals are used to distinguish the oxidation number for an element with multiple numbers.*

Most elements have more than one possible oxidation number

Some periodic tables list multiple oxidation numbers for most elements. This is because more complex bonding is possible. 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 (shown at the right). In some reference materials, roman numerals are used to distinguish the oxidation number. Figure 13.14 shows a few of these elements.



Predicting chemical formulas for binary compounds

Rules for predicting chemical formulas

Once you know how to find the oxidation numbers of the elements, you can predict the chemical formulas of binary compounds (Figure 13.15). A **binary compound** is a compound that consists of two elements. Sodium chloride (NaCl) is a binary compound. To predict and write the chemical formula of a binary compound, use the following rules.

1. Write the symbol for the element that has a positive oxidation number first. Do not write the oxidation number.
2. Write the symbol for the element that has a negative oxidation number second. Do not write the oxidation number.
3. Find the least common multiple between the oxidation numbers to make the sum of their charges equal zero. Use the numbers you multiply the oxidation numbers by as subscripts.

Solving Problems: Binary Compounds

Iron (III) (3+) and oxygen (2–) combine to form a compound. Predict the chemical formula of this compound.

1. Looking for: Chemical formula for a binary compound

2. Given: Elements and oxidation numbers: Fe (III) = 3+ and O = 2–

3. Relationships: Write the subscripts so that the sum of the oxidation numbers equals zero.

4. Solution: The least common multiple between 3 and 2 is 6.
For iron (III): 2 × (3+) = 6+. For oxygen: 3 × (2–) = 6 – (6+) + (6–) = 0. The chemical formula is Fe_2O_3 because it took 2 Fe atoms and 3 O atoms to make a neutral compound.

Your turn...

a. Predict the chemical formula of the compound containing beryllium (2+) and fluorine (1–).

b. Predict the chemical formula of the compound containing lead (IV) and sulfur (2–).

VOCABULARY

binary compound - a chemical compound that consists of two elements.

Predict the chemical formula for a compound made from iron (oxidation number 3+) and oxygen (oxidation number 2–).

1. Write the symbol for the element that has a positive oxidation number first. Do not write the oxidation number.

Fe

2. Write the symbol for the element that has a negative oxidation number second. Do not write the oxidation number.

O

3. Add subscripts so that the sum of the oxidation numbers of all the atoms in the formula is zero.

$2 \times Fe^{3+} = 6+$
$3 \times O^{2-} = 6-$
$(6+) + (6-) = 0$
Chemical formula: Fe_2O_3

Figure 13.15: *The steps to predict the chemical formula of a binary compound.*

SOLVE FIRST LOOK LATER

a. BeF_2

b. PbS_2

Compounds with more than two elements

Not all compounds are made of only two types of atoms

Have you ever taken an antacid for an upset stomach? Many antacids contain calcium carbonate, or $CaCO_3$. How many types of atoms does this compound contain? You are right if you said three: calcium, carbon, and oxygen. Some compounds contain more than two elements. Some of these types of compounds contain polyatomic ions. A **polyatomic ion** contains more than one atom. The prefix *poly-* means "many." Figure 13.16 lists some common polyatomic ions. The example below illustrates how to write chemical formulas for these types of compounds.

Solving Problems: More Chemical Formulas

Aluminum (3+) combines with sulfate (SO_4^{2-}) or the sulfate ion to make aluminum sulfate. Write the chemical formula for aluminum sulfate.

1. Looking for: Chemical formula for a compound containing more than two elements

2. Given: Al 3^+ and SO_4^{2-}

3. Relationships: The oxidation numbers for all of the atoms in the compound must add up to zero.

4. Solution: Two aluminum ions have a charge of 6+. It takes three sulfate ions to get a charge of 6–. To write the chemical formula, parentheses must be placed around the polyatomic ion. The subscript is placed on the outside of the parentheses. The formula is: $Al_2(SO_4)_3$

Your turn...

a. Write the chemical formula for hydrogen (1+) peroxide (O_2^{2-}).

b. Write the chemical formula for calcium (2+) phosphate (PO_4^{3-}).

VOCABULARY

polyatomic ion - an ion that contains more than one atom.

Oxidation Number	Name of Ion	Formula
1+	ammonium	NH_4^+
1–	acetate	$C_2H_3O_2^-$
2–	carbonate	CO_3^{2-}
2–	chromate	CrO_4^{2-}
1–	hydrogen carbonate	HCO_3^-
1+	hydronium	H_3O^+
1–	hydroxide	OH^-
1–	nitrate	NO_3^-
2–	peroxide	O_2^{2-}
3–	phosphate	PO_4^{3-}
2–	sulfate	SO_4^{2-}
2–	sulfite	SO_3^{2-}

Figure 13.16: *Oxidation numbers of some common polyatomic ions.*

SOLVE FIRST LOOK LATER

a. H_2O_2

b. $Ca_3(PO_4)_2$

Naming compounds

Naming binary ionic compounds

By using the following rules, you can name a binary ionic compound if you are given its chemical formula. A *binary ionic compound* is held together by ionic bonds. *Binary molecular compounds* consist of covalently bonded atoms. Naming binary molecular compounds is discussed in the *Solve It!* on the next page. To name a binary ionic compound:

1. Write the name of the first element.
2. Write the root name of the second element.
3. Add the suffix *-ide* to the root name.

What is the name of $MgBr_2$?

$MgBr_2$ is *magnesium* (name of first element) plus *-brom* (root name of second element) plus *-ide* = magnesium bromide (Figure 13.17, top).

If the positive element has more than one oxidation number, you must first figure out that number. Then, use a roman numeral to indicate the oxidation number. For example, $FeCl_3$ = iron (III) chloride because iron (III) has a charge of 3+. It would take three chloride ions (oxidation number = 1–) to make the sum of the oxidation numbers equal zero.

Naming compounds with polyatomic ions

Naming compounds with polyatomic ions is easy.

1. Write the name of the first element or polyatomic ion first. Use the periodic table or ion chart (Figure 13.16, previous page) to find its name.
2. Write the name of the second element or polyatomic ion second. Use the periodic table or ion chart (Figure 13.16, previous page) to find its name. If the second one is an element, use the root name of the element with the suffix *-ide*.

What is the name of NH_4Cl?

NH_4Cl is *ammonium* (the name of the polyatomic ion from Figure 13.16) plus *-chlor* (root name of the second element) plus *-ide* = ammonium chloride (Figure 13.17, bottom).

Again, if an element has more than one oxidation number, you must figure out that number. For example, Cu_2SO_3 would be named copper (I) sulfite and $CuSO_3$ would be copper (II) sulfite.

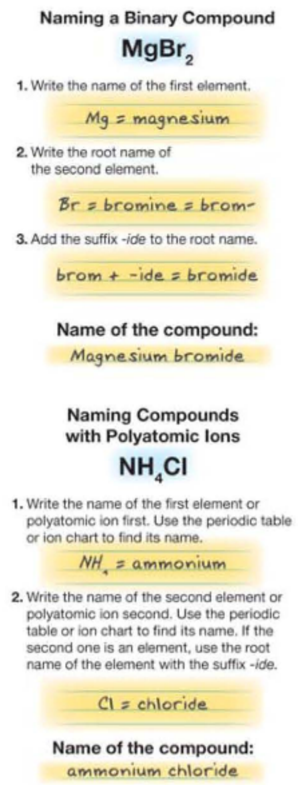


Figure 13.17: *Naming compounds.*

Section 13.2 Review

1. The oxidation number is:
   a. the number of oxygen atoms an 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.
2. Name three elements that have an oxidation number of 3+.
3. What is the oxidation number for the elements in Group 17?
4. 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.
5. True or False: All oxidation numbers from the same molecule must be negative.
6. Which of the following elements will bond with oxygen, resulting in a 1:1 ratio of oxygen and the element?
   a. lithium
   b. boron
   c. beryllium
   d. nitrogen
7. Name the following compounds.
   a. $NaHCO_3$
   b. $BaCl_2$
   c. LiF
   d. $Al(OH)_3$
   e. SrI
8. Would a bond between potassium and iodine most likely be covalent or ionic? Explain your answer.

SOLVE IT!

Naming Binary Molecular Compounds

Naming binary molecular compounds is similar to the methods used in naming binary ionic compounds described on the previous page. However, in this case, the *number* of each type of atom (the subscript) is also specified in the name of the compound. From 1 to 10, the Greek prefixes are: *mono*, *di*, *tri*, *tetra*, *penta*, *hexa*, *hepta*, *octa*, *nona*, *deca*.

To name a binary molecular compound, specify the number of each type of atom using the Greek prefix. As with binary ionic compounds, the ending of the name of the second element in the compound is modified by adding the suffix *-ide* as shown in the example below.

N_2O_4

dinitrogen tetraoxide

If the first element in the compound does not have a subscript, do not use a Greek prefix for that element, but use one for the second element. For example, CO_2 is carbon dioxide.

Name the following binary molecular compounds.

(a) CCl_4 (b) N_4O_6 (c) S_2F_{10}