What do numerical subscripts in a chemical formula mean?

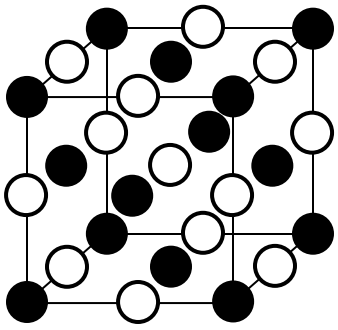
The Model: Formulas of Binary Ionic Compounds

(Reference: Sec. 2.7 and the 1st three pages in Sec. 2.8 (pp. 64-66) in Silberberg 5th ed.)

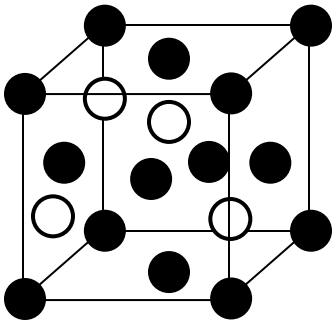
Look at the Periodic Table in your textbook that shows the elements as **metals**, **nonmetals**, and **metalloids**. (Metalloids, sometimes called **semi-metals**, behave some of the time as metals and other times as nonmetals.) A very important distinction between metals and nonmetals is their capacity to give up or accept electrons to become **ions**. When the following representative elements are involved in an exchange of electrons to form **monatomic** ions, the following are always observed (elements ordered top to bottom in columns according to their atomic number):

$Li \rightarrow Li^{+} + e^{-}$	$F + e^{-} \rightarrow F^{-}$	$Al \rightarrow Al^{3+} + 3\,e^{-}$
$N + 3\,e^{-} \rightarrow N^{3-}$	$Na \rightarrow Na^{+} + e^{-}$	$S + 2\,e^{-} \rightarrow S^{2-}$
$O + 2\,e^{-} \rightarrow O^{2-}$	$Mg \rightarrow Mg^{2+} + 2\,e^{-}$	$Cl + e^{-} \rightarrow Cl^{-}$

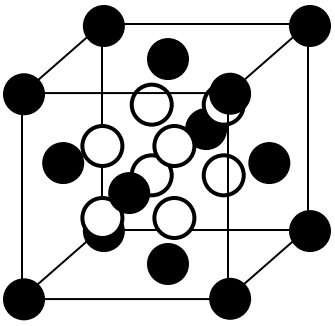
When **cations** (*i.e.*, positively-charged ions) combine with **anions** (*i.e.*, negatively-charged ions), they form **ionic compounds**. Two-dimensional projections of typical examples of binary ionic compounds are shown below. In the figures, the white spheres represent the cations and the black spheres represent the anions.



LiF



ZnS



Na_2O

Each of these cubes (called "unit cells") represents the portion of the crystalline structure that could be used to build an entire crystal of the compound by "stacking" like cubes on top of each other in all three dimensions.

Key Questions

1. In the Model, it is said that one of the ways metals and nonmetals are different is in how they are involved in the transfer of electrons to become ions. Explain how a ***metal*** differs from a ***nonmetal*** in this way, *giving specific reference to the examples in the model*.

2a. How many electrons do each of the atoms in the table below have once they have become ***monatomic ions***? (For example, Li^+ has two electrons.) Also in the table, for each ion, use the Periodic Table to identify which neutral element has a number of electrons equal to the number written in that column. (For example, He has as many electrons as Li^+.)

	Li	N	O	F	Na	Mg	Al	S	Cl
# e^- as ion	2								
element	He								

b. What do the elements you filled in the second row have in common? (Look at the Periodic Table and the positions of these elements.)

c. What does your answer to (b) say about the number of electrons another atom will gain/lose based on its position on the Periodic Table?

3. When each of the following atoms become a ***monatomic ion***, what will its charge be?

a. potassium, K _____ c. iodine, I _____ e. phosphorous, P _____

b. strontium, Sr _____ d. selenium, Se _____ f. carbon, C _____

4. Inspect the crystal structures presented in the Model of LiF, ZnS, and Na_2O. Are there "molecules" of LiF in a crystal of lithium fluoride? _____ Are there molecules of ZnS in a crystal of zinc sulfide? _____ Are there molecules of Na_2O in a crystal of sodium oxide? _____ *Explain your answer*(s).

5a. Li, Zn, and Na all belong to the same class of elements. What is that classification? (The Periodic Table in your textbook may help.)

b. F, S, and O all belong to the same class of element. What is that classification?

c. When the type of element belonging to the answer from (a) combines with an element belonging to the answer from (b), an ionic compound forms. Explain why.

6a. What is the charge (both magnitude and sign) on a sodium ion in Na_2O? _____

b. What is the charge (both magnitude and sign) on an oxygen ion in Na_2O? _____

c. Use your answers to parts (a) and (b) to explain why a crystal of sodium oxide must have two sodium cations for every one oxide anion.

d. Why is the formula for sodium oxide written as "Na_2O"?

7a. What is the charge on a sulfide ion in ZnS? (Look back to Key Question 2a.) _____

b. What must be the charge on a zinc ion in ZnS?_____ *Explain* why it must be that value despite Zn's position on the Periodic Table.

c. Provide an explanation for why the formula for zinc sulfide is "ZnS" and not "Zn_2S_2"? (It may help to look back at your answer for Key Question 4.)

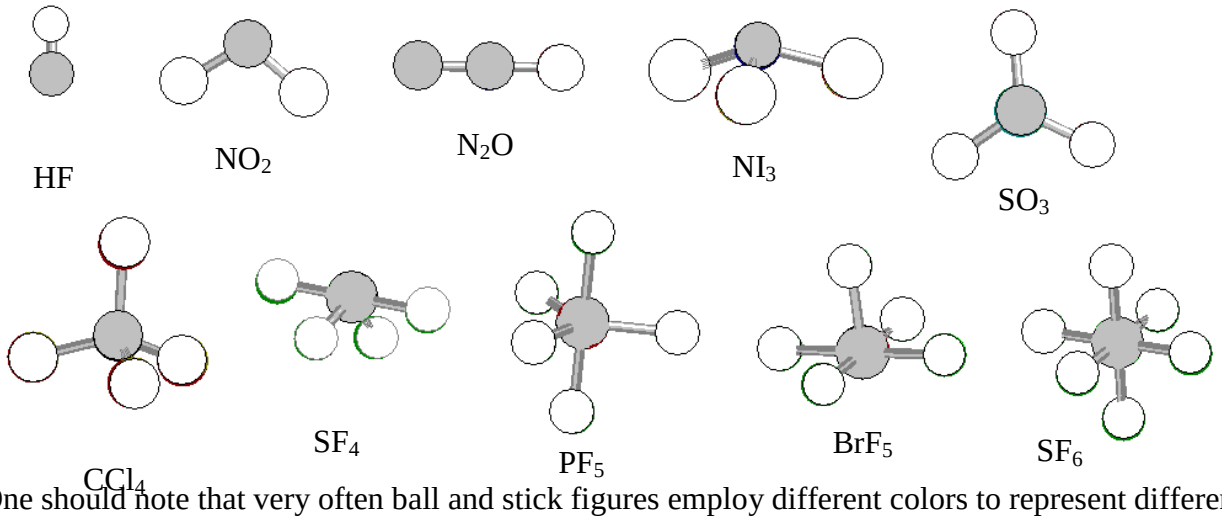
Exercises

8. Complete the table below by writing the correct formulas for the ionic compounds between the cation in the row with the anion in the column.

	Cl^-	**S^{2-}**	**N^{3-}**
K^+			
Mg^{2+}			
Al^{3+}			

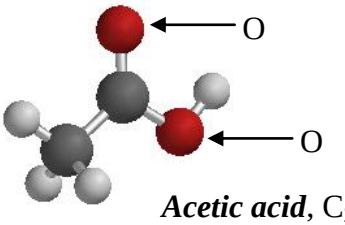
The Model: Formulas of Molecular Compounds

Atoms connected by a **covalent bond** share electrons with each other (as opposed to neighboring cations and anions, in which electrons had been transferred from the former to the latter species). Another class of compounds consists of atoms held together by nothing but covalent bonds. These are **molecular** compounds, and several are depicted here as "ball and stick" representations:

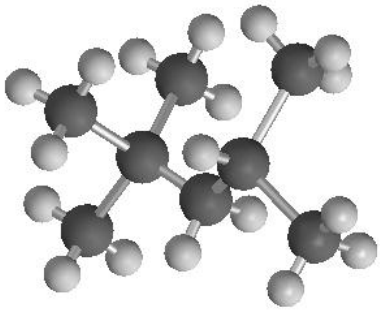


One should note that very often ball and stick figures employ different colors to represent different elements. Typically black (or dark grey) represents carbon, white (or light grey) represents hydrogen, red represents oxygen, and blue represents nitrogen. Colors such as orange-red, orange, yellow, green, and blue-green often represent phosphorous, sulfur, and the halogens (*i.e.*, fluorine, chlorine, bromine, and iodine).

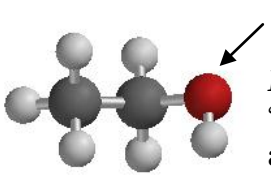
You will note that in none of the above molecules is there more than one central atom. The following are examples of molecules having three or more central atoms:



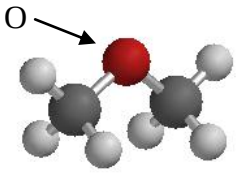
Acetic acid, $C_2H_4O_2$, the component which makes vinegar acidic.



2,2,4-Trimethyl-pentane, C_8H_{18}, what we call "***octane***", which is used in the internal combustion engines of many automobiles.



Ethanol, C_2H_6O, "drinking alcohol".



Dimethyl ether, C_2H_6O, a promising clean-burning fuel and common organic solvent.

Key Questions

9a. In virtually all of the formulas of compounds (ionic and molecular) that were presented in the Model, after the symbol of an element is a subscript number. What does this number tell the reader?

b. What does it mean when there is not a number following the elemental symbol in a formula?

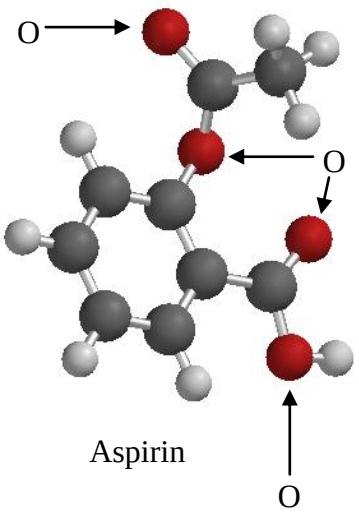
10a. Look again at all of the representations and formulas of the molecular compounds. To what class of elements do all of the atoms that are in these compounds belong?

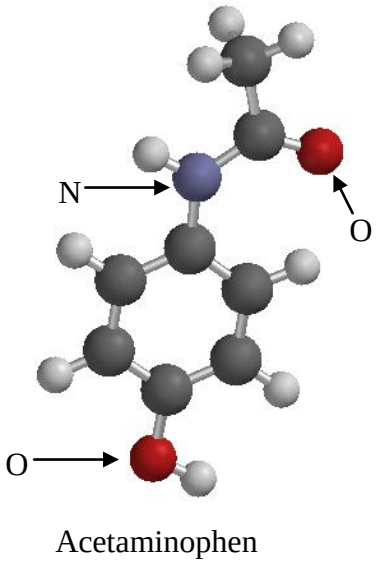
b. From the answer to part (a), it is obvious that when these atoms bond to each other they must do so covalently. (See your answer to Question 1.) *Explain why*.

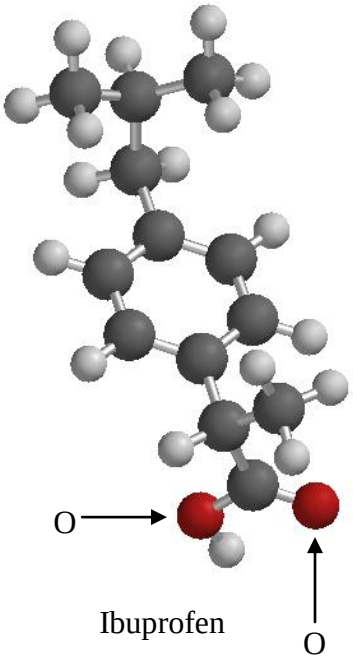
Exercises

11. Molecular representations of common over-the-counter pain relievers are depicted below. (Non-carbon, non-hydrogen atoms are pointed out.) *Write formulas for these compounds*.

a.) Aspirin: _____ b.) Acetaminophen: _____ c.) Ibuprofen _____







12. Fairly often, two molecular compounds will have the same overall formula but two very different structures. These compounds are called ***isomers***. Examples of isomers include ***ethanol*** and ***dimethyl ether*** (shown above in the Model). To help the reader know which isomer is being considered, the **structural formula** of a compound ought to be written. The structural formula of ethanol is CH_3—CH_2—OH and the structural formula of dimethyl ether is CH_3—O—CH_3.

a. Write the structural formula for ***2,2,4-trimethylpentane*** (shown above in the Model). (*Hint*: You can use five "CH_3" groups in addition to a "CH_2" and a "CH" group as you inspect the structure from left to right.)

b. Suggest one isomer of acetic acid and sketch the molecule's atomic connectivity. (*Hint*: In organic compounds C and H usually have the following number of covalent bonds: C: four and H: one)