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):

\[
\begin{align*}
\text{Li} & \rightarrow \text{Li}^+ + e^- \\
\text{F} + e^- & \rightarrow \text{F}^- \\
\text{Al} & \rightarrow \text{Al}^{3+} + 3 e^- \\
\text{N} + 3 e^- & \rightarrow \text{N}^{3-} \\
\text{Na} & \rightarrow \text{Na}^+ + e^- \\
\text{S} + 2 e^- & \rightarrow \text{S}^{2-} \\
\text{O} + 2 e^- & \rightarrow \text{O}^{2-} \\
\text{Mg} & \rightarrow \text{Mg}^{2+} + 2 e^- \\
\text{Cl} + e^- & \rightarrow \text{Cl}^-
\end{align*}
\]

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](image1.png)  ![ZnS](image2.png)  ![Na2O](image3.png)

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⁺.)

<table>
<thead>
<tr>
<th></th>
<th>Li</th>
<th>N</th>
<th>O</th>
<th>F</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>S</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td># e⁻ as ion</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>element</td>
<td>He</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Na₂O. 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 Na₂O 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 Na₂O? _______

b. What is the charge (both magnitude and sign) on an oxygen ion in Na₂O? _______

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 “Na₂O”?

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 “Zn₃S₂”? (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.

<table>
<thead>
<tr>
<th></th>
<th>Cl⁻</th>
<th>S²⁻</th>
<th>N³⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al³⁺</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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:

2,2,4-Trimethyl-pentane, C₈H₁₈, what we call “octane”, which is used in the internal combustion engines of many automobiles.

Acetic acid, C₂H₄O₂, the component which makes vinegar acidic.

Ethanol, C₂H₆O, “drinking alcohol”.

Dimethyl ether, C₂H₆O, 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 CH₃—CH₂—OH and the structural formula of dimethyl ether is CH₃—O—CH₃.

a. Write the structural formula for 2,2,4-trimethylpentane (shown above in the Model). (Hint: You can use five “CH₃” groups in addition to a “CH₂” 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)