Skills to Develop

- Write the chemical formula for a simple ionic compound.
- Recognize polyatomic ions in chemical formulas.

We have already encountered some chemical formulas for simple ionic compounds. A chemical formula is a concise list of the elements in a compound and the ratios of these elements. To better understand what a chemical formula means, we must consider how an ionic compound is constructed from its ions.

Ionic compounds exist as alternating positive and negative ions in regular, three-dimensional arrays called crystals (Figure 1). As you can see, there are no individual NaCl “particles” in the array; instead, there is a continuous lattice of alternating sodium and chloride ions. However, we can use the ratio of sodium ions to chloride ions, expressed in the lowest possible whole numbers, as a way of describing the compound. In the case of sodium chloride, the ratio of sodium ions to chloride ions, expressed in lowest whole numbers, is 1:1, so we use NaCl (one Na symbol and one Cl symbol) to represent the compound. Thus, NaCl is the chemical formula for sodium chloride, which is a concise way of describing the relative number of different ions in the compound. A macroscopic sample is composed of myriads of NaCl pairs; each pair called a formula unit. Although it is convenient to think that NaCl crystals are composed of individual NaCl units, Figure 1 shows that no single ion is exclusively associated with any other single ion. Each ion is surrounded by ions of opposite charge.

![Figure 1](Image)

**Figure 1** A Sodium Chloride Crystal. A crystal contains a three-dimensional array of alternating positive and negative ions. The precise pattern depends on the compound. A crystal of sodium chloride, shown here, is a collection of alternating sodium and chlorine ions.

Note

In Section 3.2, we encountered LiBr and MgO, which are formulas for other ionic compounds.

The formula for an ionic compound follows several conventions. First, the cation is written before the anion. Because most metals form cations and most nonmetals form anions, formulas typically list the metal first and then the nonmetal.
Second, charges are not written in a formula. Remember that in an ionic compound, the component species are ions, not neutral atoms, even though the formula does not contain charges. Finally, the proper formula for an ionic compound always obeys the following rule: the total positive charge must equal the total negative charge. To determine the proper formula of any combination of ions, determine how many of each ion is needed to balance the total positive and negative charges in the compound.

Note

This rule is ultimately based on the fact that matter, overall, is electrically neutral.

Note

By convention, assume that there is only one atom if a subscript is not present. We do not use 1 as a subscript.

If we look at the ionic compound consisting of lithium ions and bromide ions, we see that the lithium ion has a 1+ charge and the bromide ion has a 1− charge. Only one ion of each is needed to balance these charges. The formula for lithium bromide is LiBr.

When an ionic compound is formed from magnesium and oxygen, the magnesium ion has a 2+ charge, and the oxygen atom has a 2− charge. Although both of these ions have higher charges than the ions in lithium bromide, they still balance each other in a one-to-one ratio. Therefore, the proper formula for this ionic compound is MgO.

Now consider the ionic compound formed by magnesium and chlorine. A magnesium ion has a 2+ charge, while a chlorine ion has a 1− charge:

\[ \text{Mg}^{2+} \text{Cl}^- \]

Combining one ion of each does not completely balance the positive and negative charges. The easiest way to balance these charges is to assume the presence of two chloride ions for each magnesium ion:

\[ \text{Mg}^{2+} \text{Cl}^- \text{Cl}^- \]

Now the positive and negative charges are balanced. We could write the chemical formula for this ionic compound as MgClCl, but the convention is to use a numerical subscript when there is more than one ion of a given type—MgCl₂. This chemical formula says that there are one magnesium ion and two chloride ions in this formula. (Do not read the “Cl₂” part of the formula as a molecule of the diatomic elemental chlorine. Chlorine does not exist as a diatomic element in this compound. Rather, it exists as two individual chloride ions.) By convention, the lowest whole number ratio is used in the formulas of ionic compounds. The formula Mg₂Cl₄ has balanced charges with the ions in a 1:2 ratio, but it is not the lowest whole number ratio.

Note

By convention, the lowest whole number ratio of the ions is used in ionic formulas. There are exceptions for certain ions, such as Hg₂²⁺.
Write the chemical formula for an ionic compound composed of each pair of ions.

1. the sodium ion and the sulfur ion
2. the aluminum ion and the fluoride ion
3. the 3+ iron ion and the oxygen ion

**SOLUTION**

1. To obtain a valence shell octet, sodium forms an ion with a 1+ charge, while the sulfur ion has a 2− charge. Two sodium 1+ ions are needed to balance the 2− charge on the sulfur ion. Rather than writing the formula as NaNaS, we shorten it by convention to Na₂S.

2. The aluminum ion has a 3+ charge, while the fluoride ion formed by fluorine has a 1− charge. Three fluorine 1− ions are needed to balance the 3+ charge on the aluminum ion. This combination is written as AlF₃.

3. Iron can form two possible ions, but the ion with a 3+ charge is specified here. The oxygen atom has a 2− charge as an ion. To balance the positive and negative charges, we look to the least common multiple—6: two iron 3+ ions will give 6+, while three 2− oxygen ions will give 6−, thereby balancing the overall positive and negative charges. Thus, the formula for this ionic compound is Fe₂O₃.

**Exercise \(\PageIndex{1}\)**

Write the chemical formula for an ionic compound composed of each pair of ions.

a. the calcium ion and the oxygen ion
b. the 2+ copper ion and the sulfur ion
c. the 1+ copper ion and the sulfur ion

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**Polyatomic Ions**

Some ions consist of groups of atoms bonded together and have an overall electric charge. Because these ions contain more than one atom, they are called polyatomic ions. Polyatomic ions have characteristic formulas, names, and charges that should be memorized. For example, NO₃⁻ is the nitrate ion; it has one nitrogen atom and three oxygen atoms and an overall 1− charge. Table \(\PageIndex{1}\) lists the most common polyatomic ions.

**Table \(\PageIndex{1}\): Some Polyatomic Ions**

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>ammonium ion</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>acetate ion</td>
<td>C₂H₃O₂⁻ (also written CH₃CO₂⁻)</td>
</tr>
<tr>
<td>carbonate ion</td>
<td>CO₃²⁻</td>
</tr>
<tr>
<td>chromate ion</td>
<td>CrO₄²⁻</td>
</tr>
<tr>
<td>dichromate ion</td>
<td>Cr₂O₇²⁻</td>
</tr>
<tr>
<td>Name</td>
<td>Formula</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>hydrogen carbonate ion (bicarbonate ion)</td>
<td>HCO$_3^-$</td>
</tr>
<tr>
<td>cyanide ion</td>
<td>CN$^-$</td>
</tr>
<tr>
<td>hydroxide ion</td>
<td>OH$^-$</td>
</tr>
<tr>
<td>nitrate ion</td>
<td>NO$_3^-$</td>
</tr>
<tr>
<td>nitrite ion</td>
<td>NO$_2^-$</td>
</tr>
<tr>
<td>permanganate ion</td>
<td>MnO$_4^-$</td>
</tr>
<tr>
<td>phosphate ion</td>
<td>PO$_4^{3-}$</td>
</tr>
<tr>
<td>hydrogen phosphate ion</td>
<td>HPO$_4^{2-}$</td>
</tr>
<tr>
<td>dihydrogen phosphate ion</td>
<td>H$_2$PO$_4^-$</td>
</tr>
<tr>
<td>sulfate ion</td>
<td>SO$_4^{2-}$</td>
</tr>
<tr>
<td>hydrogen sulfate ion (bisulfate ion)</td>
<td>HSO$_4^-$</td>
</tr>
<tr>
<td>sulfite ion</td>
<td>SO$_3^{2-}$</td>
</tr>
</tbody>
</table>

The rule for constructing formulas for ionic compounds containing polyatomic ions is the same as for formulas containing monatomic (single-atom) ions: the positive and negative charges must balance. If more than one of a particular polyatomic ion is needed to balance the charge, the entire formula for the polyatomic ion must be enclosed in parentheses, and the numerical subscript is placed outside the parentheses. This is to show that the subscript applies to the entire polyatomic ion. An example is Ba(NO$_3$)$_2$.

Example \(\PageIndex{2}\)

Write the chemical formula for an ionic compound composed of each pair of ions.

1. the potassium ion and the sulfate ion
2. the calcium ion and the nitrate ion

**SOLUTION**

1. Potassium ions have a charge of 1+, while sulfate ions have a charge of 2−. We will need two potassium ions to balance the charge on the sulfate ion, so the proper chemical formula is K$_2$SO$_4$.
2. Calcium ions have a charge of 2+, while nitrate ions have a charge of 1−. We will need two nitrate ions to balance the charge on each calcium ion. The formula for nitrate must be enclosed in parentheses. Thus, we write Ca(NO$_3$)$_2$ as the formula for this ionic compound.
Exercise \(\PageIndex{2}\)

Write the chemical formula for an ionic compound composed of each pair of ions.

a. the magnesium ion and the carbonate ion  
b. the aluminum ion and the acetate ion

Recognizing Ionic Compounds

There are two ways to recognize ionic compounds. First, compounds between metal and nonmetal elements are usually ionic. For example, \(\text{CaBr}_2\) contains a metallic element (calcium, a group 2A metal) and a nonmetallic element (bromine, a group 7A nonmetal). Therefore, it is most likely an ionic compound. (In fact, it is ionic.) In contrast, the compound \(\text{NO}_2\) contains two elements that are both nonmetals (nitrogen, from group 5A, and oxygen, from group 6A). It is not an ionic compound; it belongs to the category of covalent compounds discussed elsewhere. Also note that this combination of nitrogen and oxygen has no electric charge specified, so it is not the nitrite ion.

Second, if you recognize the formula of a polyatomic ion in a compound, the compound is ionic. For example, if you see the formula \(\text{Ba(NO}_3)_2\), you may recognize the “\(\text{NO}_3^-\)” part as the nitrate ion, \((\text{NO}_3^\rightarrow)\). (Remember that the convention for writing formulas for ionic compounds is not to include the ionic charge.) This is a clue that the other part of the formula, \(\text{Ba}\), is actually the \(\text{Ba}^{2+}\) ion, with the \(2^+\) charge balancing the overall \(2^-\) charge from the two nitrate ions. Thus, this compound is also ionic.

Example \(\PageIndex{3}\)

Identify each compound as ionic or not ionic.

1. \(\text{Na}_2\text{O}\)  
2. \(\text{PCl}_3\)  
3. \(\text{NH}_4\text{Cl}\)  
4. \(\text{OF}_2\)

**SOLUTION**

1. Sodium is a metal, and oxygen is a nonmetal; therefore, \(\text{Na}_2\text{O}\) is expected to be ionic.
2. Both phosphorus and chlorine are nonmetals. Therefore, \(\text{PCl}_3\) is not ionic.
3. The \(\text{NH}_4\) in the formula represents the ammonium ion, \(\text{NH}_4^+\), which indicates that this compound is ionic.
4. Both oxygen and fluorine are nonmetals. Therefore, \(\text{OF}_2\) is not ionic.

Exercise \(\PageIndex{3}\)

Identify each compound as ionic or not ionic.

a. \(\text{N}_2\text{O}\)  
b. \(\text{FeCl}_3\)  
c. \((\text{NH}_4)_3\text{PO}_4\)
Looking Closer: Blood and Seawater

Science has long recognized that blood and seawater have similar compositions. After all, both liquids have ionic compounds dissolved in them. The similarity may be more than mere coincidence; many scientists think that the first forms of life on Earth arose in the oceans.

A closer look, however, shows that blood and seawater are quite different. A 0.9% solution of sodium chloride approximates the salt concentration found in blood. In contrast, seawater is principally a 3% sodium chloride solution, over three times the concentration in blood. Here is a comparison of the amounts of ions in blood and seawater:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Percent in Seawater</th>
<th>Percent in Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>2.36</td>
<td>0.322</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>1.94</td>
<td>0.366</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.13</td>
<td>0.002</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>0.09</td>
<td>—</td>
</tr>
<tr>
<td>K⁺</td>
<td>0.04</td>
<td>0.016</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>0.04</td>
<td>0.0096</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>0.002</td>
<td>0.165</td>
</tr>
<tr>
<td>HPO₄²⁻, H₂PO₄⁻</td>
<td>—</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Most ions are more abundant in seawater than they are in blood, with some important exceptions. There are far more hydrogen carbonate ions (HCO₃⁻) in blood than in seawater. This difference is significant because the hydrogen carbonate ion and some related ions have a crucial role in controlling the acid-base properties of blood. The amount of hydrogen phosphate ions—HPO₄²⁻ and H₂PO₄⁻—in seawater is very low, but they are present in higher amounts in blood, where they also affect acid-base properties. Another notable difference is that blood does not have significant amounts of the sulfate ion (SO₄²⁻), but this ion is present in seawater.

Contributors

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