# Covalent and Ionic Compounds: Classification, Formulas, and Nomenclature

## ORGANIZATION

- Pre-Lab: no pre-lab
- Mode: inquiry, groups of 2
- Grading: lab notebook, post-lab report
- Safety: No specific safety requirements

**GOAL:**

In this lab you will learn the rules behind naming chemical compounds, both ionic and covalent. By the end of the lab you should be able to name the compounds you will encounter in general chemistry, as well as write the chemical formula if given a name.

## I: BACKGROUND

Chemistry deals with matter, and there is a tremendous variety of matter in the universe. The behavior of matter depends on the type of elements that are present and on the structure of those elements—how they are connected to make a molecule. In this exercise, you will evaluate some representative models to develop the rules used to classify a compound, to predict the formula of a compound, and to name the compound. This exercise is just the beginning of the work needed to be done to master the rules of writing formulas and nomenclature. Your textbook has tables of the names and formulas of common cations and anions, and discusses the rules of nomenclature in detail. You will need to spend some time with this material, as the formal rules of nomenclature may not be presented in lecture, although they will certainly be used in discussions of Lewis structures and reaction chemistry.

## II: EXERCISES

### Part A: Covalent or Ionic Compound?

Many compounds, especially those discussed in general chemistry courses, are classified as either covalent compounds or ionic compounds. The classification of a compound depends on the type of chemical bond between the elements in the compound. In this part of the worksheet, you will learn to easily classify compounds into one of the two categories.

**Table 1: Classification of Compounds**

| Covalent Compounds | Ionic Compounds |
|---|---|
| $N_2O_4$ | $AlF_3$ |
| $CO_2$ | $KNO_3$ |
| $PCl_3$ | MgO |
| $CH_4$ | $Fe_2O_3$ |
| $NO_2$ | PbS |
| $O_2$ | $Na_3N$ |

In a covalent compound, valence electrons are shared between the two atoms in the bond. These can be evenly shared (covalent bond) or unevenly shared (polar covalent bond). In an ionic bond, electrons are localized to one of the atoms (giving it an overall negative charge), while the other atom has an overall positive charge. The difference in electronegativity between the two atoms in the bond can help predict whether the bond is likely to be ionic, covalent, or polar covalent, as can the type of atoms involved (metals or non-metals). A bond with two identical atoms is always pure covalent, while a covalent bond with two different atoms is likely to be polar covalent.

### Characteristics of Covalent and Ionic Compounds

Consider Table 1 when answering the following questions.

1. Are the elements in the covalent compounds metals, non-metals, or a mixture of both?
2. Are the elements in the ionic compounds metals, non-metals, or a mixture of both?
3. Compare the types of elements found (metals or non-metals) for the two classifications. What trend do you see in the type of element present and the classification?

### Classifying Compounds

4. For each covalent compound, classify the type of bond as polar or non-polar covalent.
5. What trend do you see in the classification of the compound and the type of bond formed between the elements in the compound?
6. Write a rule that will allow you to classify a compound as ionic or covalent on the basis of what you learned from exploring the model in Part A.

## Part B: Predicting the Formula of an Ionic Compound

In a chemical formula, subcripts are used to specify the numbers of a type of atom in the formula. For example, $O_2$ is interpreted as a molecule formed by two oxygen atoms, and $CH_3OH$ is

interpreted as a molecule with one carbon, four hydrogens, and one oxygen. Superscripts are used to specify the charge of an ion. $Al^{3+}$ is interpreted as being a single aluminum atom with a charge of 3+, making this the aluminum cation.

Some ions are atomic, like $Al^{3+}$ or $F^-$, but there are also polyatomic ions. A polyatomic ion is a particle made of more than one atom, which collectively carries an ionic charge. $OH^-$ (the hydroxide anion) is a particle of one oxygen and one hydrogen, and the entire entity has a negative charge; $NO_3^-$ (nitrate) has one nitrogen and three oxygen atoms with a negative charge carried by the entire particle. If the formula of a compound has a superscript, it can be assumed that the substance is an ion, while if the formula has no superscript, it can be assumed that the charge on the molecule is zero (neutral).

**Table 2: Ionic Compound Formulas and Ions**

| Formula of Ionic Compounds | Cation in Compound | Anion in Compound |
|---|---|---|
| NaCl | $Na^+$ | $Cl^-$ |
| $AlPO_4$ | $Al^{3+}$ | $PO_4^{3-}$ |
| $CuSO_4$ | $Cu^{2+}$ | $SO_4^{2-}$ |
| $Fe(NO_3)_3$ | $Fe^{3+}$ | $NO_3^-$ |
| $Mg(OH)_2$ | $Mg^{2+}$ | $OH^-$ |
| $Fe_2O_3$ | $Fe^{3+}$ | $O^{2-}$ |
| $AlF_3$ | $Al^{3+}$ | $F^-$ |

### Characteristics of Ionic Compounds

1. Looking at the first column, what is the charge of each ionic compound?
2. Based on the formula of the ionic compound, how many cations and how many anions are present in each ionic compound?
3. What is the sum of the total cation charge plus the total anion charge? Take into account the number of each ion present in the formula of the compound, as well as the sign of the charge on each ion.

### Balancing Charge in Ionic Compounds

4. Why does $AlF_3$ have more $F^-$ ions in the formula of the ionic compound than NaF?
5. Why are parentheses needed in the formulas with multiple polyatomic ions in the compound?
6. Consider a cation with a 4+ charge and an anion with a 2− charge. How many cations and how many anions would be needed for an ionic compound formed between these two ions?

7. Write a rule that will allow you to predict the numbers of cations and anions present in the formula of an ionic compound. Make a list of what you need to know to be able to write the formula of an ionic compound.

## Part C: Nomenclature for Covalent and Ionic Compounds

Nomenclature is the systematic naming of compounds so that the numbers and types of elements or ions present in the compound are communicated. Understanding the rules of nomenclature becomes increasingly important in organic chemistry, because there are millions of organic compounds which contain only C, H, and O—to communicate which compound you are talking about, you must understand how to name the compound when given a formula or structure, and how to write the formula or structure of a compound from the name. For example, dimethyl ether and ethanol both have two carbons, one oxygen, and six hydrogen atoms, but one of these molecules can be used as a freeze spray to remove warts, and one is a nervous system depressant that makes people drunk.

It is much easier to refer to ethanol as ethanol than to refer to it as the organic compound with two carbons, six hydrogens, and one oxygen that makes people drunk. We will start the exploration of nomenclature with simple covalent compounds and with ionic compounds. Nomenclature is not difficult, but it is...tedious. There is no getting around some memorization with nomenclature. The rules of nomenclature and the formulas and charges on different ions need to be known, in order to correctly name compounds from formulas or write the formulas from names.

**Table 3: Covalent Compounds and their Names**

| Covalent Compound | Name |
|---|---|
| $N_2O_4$ | dinitrogen tetroxide |
| $CO_2$ | carbon dioxide |
| $PCl_3$ | phosphorus trichloride |
| CO | carbon monoxide |
| $NO_2$ | nitrogen dioxide |
| HCl | hydrogen chloride |

### Nomenclature of Covalent Compounds

For the covalent compounds in Table 3, answer the following questions.

1. Is the first element written in the formula the more electronegative of the elements in the formula, or the less electronegative of the elements? Does this order change in the name of the compound? What *does* change in the name of the compound?

2. Describe how the number of elements in the formula is communicated in the name of the compound.

**3.** Consider the compounds in the table above with carbon and oxygen or with nitrogen and oxygen. Why is it important to communicate the numbers of each element in the name? Why would it not work, for example, to give the name of carbon oxide for a compound that consists of carbon and oxygen?

**Table 4: Ionic Compounds and their Names**

| Formula of Ionic Compounds | Cation and Name of Cation | Anion and Name of Anion | Name of Ionic Compound |
|---|---|---|---|
| NaCl | $Na^+$, sodium ion | $Cl^-$, chloride ion | sodium chloride |
| $AlPO_4$ | $Al^{3+}$, aluminum ion | $PO_4^{3-}$, phosphate ion | aluminum phosphate |
| $CuSO_4$ | $Cu^{2+}$, copper(II) ion | $SO_4^{2-}$, sulfate ion | copper(II) sulfate |
| $KNO_3$ | $K^+$, potassium ion | $NO_3^-$, nitrate ion | potassium nitrate |
| $Mg(OH)_2$ | $Mg^{2+}$, magnesium ion | $OH^-$, hydroxide ion | magnesium hydroxide |
| $Fe_2O_3$ | $Fe^{3+}$, iron(III) ion | $O^{2-}$, oxide ion | iron(III) oxide |
| $AlF_3$ | $Al^{3+}$, aluminum ion | $F^-$, fluoride ion | aluminum fluoride |

### Nomenclature of Ionic Compounds

For the ionic compounds in Table 4, answer the following questions.

**4.** Is the cation or the anion written first in the formula? Does this order change in the name?

**5.** Is the number of cations or anions in the formula communicated in the name of the compound? Why do you think it is unnecessary to do this?

**6.** The names of the cations are the same as the names of the elements for the main group metals in the table, but not for the cations of copper and iron. What is the significance of the Roman numeral in the names of the cations of copper and iron?

### Analyzing Nomenclature Rules

**7.** Write a short description of the rules for naming covalent compounds based on the compounds explored in Table 3.

**8.** If the anion of oxygen is called oxide, and the anion of chlorine is called chloride, predict the name of the anions of sulfur, bromine, and nitrogen. What would the charge be for each of these anions?

**9.** Write a short description of the rules for naming covalent compounds based on the compounds explored in Table 4.

**10.** Why is it not necessary to specify the charge of the cations of the alkali metals or the alkaline earth metals, but it *is* necessary to specify the charge of transition metal cations?

This has been a brief introduction to the systematic naming of covalent and ionic compounds. Only a small fraction of the many possible compounds have been presented here, but if you know the rules of nomenclature, and you know the formulas of the ions, you can name anything or interpret any name.

## Part D: Nomenclature of Anions—the -ides, the -ites, the -ates

**Table 5: Names of Different Ions of Sulfur, Nitrogen, and Phosphorus**

| Formula | Name | Formula | Name | Formula | Name |
|---|---|---|---|---|---|
| $S^{2-}$ | sulfide ion | $N^{3-}$ | nitride ion | $P^{3-}$ | phosphide ion |
| $SO_3^{2-}$ | sulfite ion | $NO_2^-$ | nitrite ion | $PO_3^{3-}$ | phosphite ion |
| $SO_4^{2-}$ | sulfate ion | $NO_3^-$ | nitrate ion | $PO_4^{3-}$ | phosphate ion |

### Naming Anions of Sulfur, Nitrogen, and Phosphorus

1. For the -ide anions, how is the charge on the anion related to the electron configuration of the neutral element and the position of the element in the periodic table? How does the electron configuration of the element change when it forms the specified anion?

2. In the series of anions of the same element (the sulfur-containing anions for example), what changes in the formula of the anion in going from the -ide anion to the -ite and the -ate anion?

3. What trend do you see in the number of oxygen atoms in the -ate forms of the anions to the -ite forms of the anions? What trend do you see in the charge of the -ate and the -ite anions?

4. Write a statement that describes how you could predict the charge on the anion of an element that would have the -ide ending (choride or sulfide, for example).

5. The general name for the collection of -ate and -ite anions is oxyanion. Explain why these ions are called oxyanions.

6. Write a statement that would describe how to determine the formula of the -ite anion of an element from the formula of the -ate anion of that element.

## Part E: Nomenclature of Anions—the per-ates, the -ates, the -ites, the hypo-ites

Consider Table 6 below.

**Table 6: Names of Different Ions of Chlorine and Bromine**

| Formula | Name | Formula | Name |
|---|---|---|---|
| $ClO_4^-$ | perchlorate ion | $BrO_4^-$ | perbromate ion |
| $ClO_3^-$ | chlorate ion | $BrO_3^-$ | bromate ion |
| $ClO_2^-$ | chlorite ion | $BrO_2^-$ | bromite ion |
| $ClO^-$ | hypochlorite ion | $BrO^-$ | hypobromite ion |

### Naming Anions of Chlorine and Bromine

1. Starting with chlorate and bromate, describe the change in the formula seen for perchlorate and perbromate.
2. Starting with chlorate and bromate, describe the change in the formula seen for hypochlorite and hypobromite.
3. Write a general statement that describes how to determine the formula of the per-ate anion of an element from the formula of the -ate anion of that compound.
4. Write a general statement that describes how to determine the formula of the hypo-ite anion of an element from the formula of the -ite anion of that compound.

## Part F: Nomenclature of Oxyacids—the -ic Acids and the -ous Acids

Consider Table 7 below.

**Table 7: Classification of Types of Compounds**

| Formula of Acid | Anion | Name of Acid |
|---|---|---|
| $HClO_4$ | $ClO_4^-$, perchlorate ion | perchloric acid |
| $HClO_3$ | $ClO_3^-$, chlorate ion | chloric acid |
| $HClO_2$ | $ClO_2^-$, chlorite ion | chlorous acid |
| $HClO$ | $ClO^-$, hypochlorite ion | hypochlorous acid |
| $H_2SO_4$ | $SO_4^{2-}$, sulfate ion | sulfuric acid |
| $H_2SO_3$ | $SO_3^{2-}$, sulfite ion | sulfurous acid |
| $HNO_3$ | $NO_3^-$, nitrate ion | nitric acid |
| $HNO_2$ | $NO_2^-$, nitrite ion | nitrous acid |
| $H_2CO_3$ | $CO_3^{2-}$, carbonate ion | carbonic acid |

### Naming Oxyacids

1. What is the identity of the cation for each of the acids?
2. What is the trend in the name of the acids of the -ate oxyanions?
3. What is the trend in the name of the acids of the -ite oxyanions?
4. Write a general statement that describes how to predict the formula and name of an oxyacid when given the formula and name of the oxyanion.

## Part G: Nomenclature Bingo

Your instructor will provide you with a bingo card containing a mixture of chemical formulas and names. They will call out the missing information, and you have to indicate whether you have the matching formula or name. The first student to match five in a row, column or diagonal, will call out the next set of chemicals.