CHAPTER 6. INORGANIC COMPOUND NOMENCLATURE

Enhanced Introductory College Chemistry

by Gregory Anderson; Caryn Fahey; Jackie MacDonald; Adrienne Richards; Samantha Sullivan Sauer; J.R. van Haarlem; and David Wegman;

Chapter Contents

Please visit the web version of Enhanced Introductory College Chemistry (https://ecampusontario.pressbooks.pub/enhancedchemistry/) to access the complete book, interactive activities and ancillary resources.

In this chapter, you will learn about

- Elements and their associated ions (cations and anions)

- Nomenclature
- Writing chemical formulas
- Naming binary ionic compounds
- Naming molecular compounds
- Naming acids

To better support your learning, you should be familiar with the following concepts before starting this chapter:

- Elements and ions
- Groups in the periodic table (metals and nonmetals)
- Formation of compounds

In this chapter, we will be learning about chemical nomenclature.

Chemical nomenclature is far too big a topic to treat comprehensively, and it would be a useless diversion to attempt to do so in a beginning course; most chemistry students pick up chemical names and the rules governing them as they go along. But we can hardly talk about chemistry without mentioning *some* chemical substances, all of which do have names— and often, more than one!

There are more than 100 million named chemical substances. Who thinks up the names for all these chemicals? Are we in danger of running out of new names? The answer to the last question is "no", for the simple reason that the vast majority of the names are not "thought up"; there are elaborate rules for assigning names to chemical substances on the basis of their structures. These are called *systematic names*; they may be a bit ponderous, but they uniquely identify a given substance. The rules for these names are defined by an international body. But in order to make indexing and identification easier, every known chemical substance has its own numeric "personal ID", known as a CAS registry number. For example, caffeine is uniquely identified by the registry number 58-08-2. About 15,000 new numbers are issued every day.

Common and Systematic Names

Many chemicals are so much a part of our life that we know them by their familiar names, just like our other friends. A given substance may have several common or *trivial names*; ordinary cane sugar, for example, is more formally known as "sucrose", but asking for it at the dinner table by that name will likely be a conversation-stopper, and I won't even venture to predict the outcome if you try using its systematic name in the same context:

"please pass the α-D-glucopyranosyl-(1,2)- β-D-fructofuranoside!"

But "sucrose" would be quite appropriate if you need to distinguish this particular sugar from the hundreds of other named sugars. The only place you would come across a systematic name like the rather unwieldy one mentioned here is when referring (in print or in a computer data base) to a sugar that has no common name.

Chemical substances have been a part the fabric of civilization and culture for thousands of years, and present-day chemistry retains a lot of this ancient baggage in the form of terms whose hidden cultural and historic connections add colour and interest to the subject. Many common chemical names have reached us only after remarkably long journeys through time and place, as the following two examples illustrate.

Ammonia

Most people can associate the name ammonia (NH_3) with a gas having a pungent odour; the systematic name "nitrogen trihydride" (which is rarely used) will tell you its formula. What it will not tell you is that smoke from burning camel dung (the staple fuel of North Africa) condenses on cool surfaces to form a crystalline deposit. The ancient Romans first noticed this on the walls and ceiling of the temple that the Egyptians had built to the Sun-god Amun in Thebes, and they named the material sal ammoniac, meaning "salt of Amun". In 1774, Joseph Priestly (the discoverer of oxygen) found that heating sal ammoniac produced a gas with a pungent odour, which a T. Bergman named "ammonia" eight years later.

Alcohol

Alcohol entered the English language in the 17th Century with the meaning of a "sublimated" substance, then became the "pure spirit" of anything, and only became associated with "spirit of wine" in 1753. Finally, in 1852, it become a part of chemical nomenclature that denoted a common class of organic compound. But it's still common practice to refer to the specific substance CH_3CH_2OH as "alcohol" rather then its systematic name *ethanol*.

Arabic alchemy has given us a number of chemical terms; for example, alcohol is believed to derive from Arabic or al-ghawl whose original meaning was a metallic powder used to darken women's eyelids (kohl).

Popular Names

The general practice among chemists is to use the more common chemical names whenever it is practical to do so, especially in spoken or informal written communication. For many of the very simplest compounds (including most of those you will encounter in a first-year course), the systematic and common names are the same, but where there is a difference and if the context permits it, the common name is usually preferred.

Many of the "common" names we refer to are known and used mainly by the scientific community. Chemical substances that are employed in the home, the arts, or in industry have acquired traditional or "popular" names that are still in wide use. Many, like sal ammoniac mentioned above, have fascinating stories to tell. Table 6a provides a list of popular names, their associated chemical names and their chemical formula.

Table 6a A list of popular names, their associated chemical name and formula.

popular name	chemical name	Formula
borax	sodium tetraborate decahydrate	$B_4O_7{\cdot}10H_2O$
calomel	mercury(I) chloride	Hg_2Cl_2
milk of magnesia	magnesium hydroxide	$Mg(OH)_2$
muriatic acid	hydrochloric acid	$HCl\textit{(aq)}$
oil of vitriol	sulfuric acid	H_2SO_4
saltpeter	sodium nitrate	$NaNO_3$
slaked lime	calcium hydroxide	$Ca(OH)_2$

Minerals are solid materials that occur in the earth which are classified and named according to their compositions (which often vary over a continuous range) and the arrangement of the atoms in their crystal lattices. There are about 4000 named minerals. Many are named after places, people, or properties, and most frequently end with -ite.

Proprietary Names

Chemistry is a major industry, so it is not surprising that many substances are sold under trademarked names. This is especially common in the pharmaceutical industry, which uses computers to churn out names that they hope will distinguish a new product from those of its competitors. Perhaps the most famous of these is Aspirin, whose name was coined by the German company Bayer in 1899. This trade name was seized by the U.S. government following World War I, and is no longer a protected trademark in that country.

Attribution & References

Except where otherwise noted, this section is adapted by Adrienne Richards and Samantha Sullivan Sauer from "4.5 Introduction to Chemical Nomenclature (https://chem.libretexts.org/Bookshelves/

General_Chemistry/Book%3A_Chem1_(Lower)/04%3A_The_Basics_of_Chemistry/
4.05%3A_Introduction_to_Chemical_Nomenclature)" in*Book: Chem1 (Lower)* (*LibreTexts Chemistry*) by Stephen Lower, Licensed under CC BY 3.0.

6.1 ELEMENTS AND THEIR IONS

Learning Objectives

By the end of this section, you will be able to:

- Define ions
- Identify ions on the periodic table

Ions

As a recap from Chapter 3, during the formation of some compounds, atoms gain or lose electrons, and form electrically charged particles called ions (Figure 6.1a).

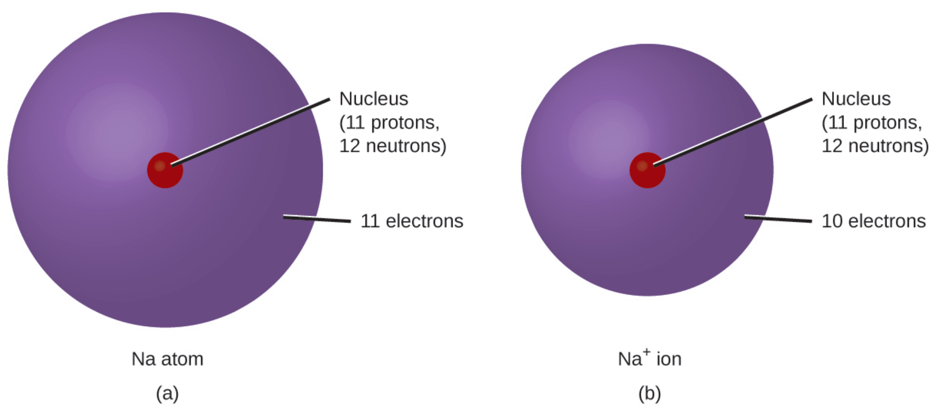

Figure 6.1a (a) A sodium atom (Na) has equal numbers of protons and electrons (11) and is uncharged. (b) A sodium cation (Na^+) has lost an electron, so it has one more proton (11) than electrons (10), giving it an overall positive charge, signified by a superscripted plus sign (credit: *Chemistry (OpenStax)*, CC BY 4.0).

You can use the periodic table to predict whether an atom will form an anion or a cation, and you can often predict the charge of the resulting ion. Atoms of many main-group metals lose enough electrons to leave them with the same number of electrons as an atom of the preceding noble gas. To illustrate, an atom of an alkali metal (group 1) loses one electron and forms a cation with a 1+ charge; an alkaline earth metal (group 2) loses two electrons and forms a cation with a 2+ charge, and so on. For example, a neutral calcium atom, with 20 protons and 20 electrons, readily loses two electrons. This results in a cation with 20 protons, 18 electrons, and a 2+ charge. It has the same number of electrons as atoms of the preceding noble gas, argon, and is symbolized Ca^{2+}. The name of a metal ion is the same as the name of the metal atom from which it forms, so Ca^{2+} is called a calcium ion.

When atoms of nonmetal elements form ions, they generally gain enough electrons to give them the same number of electrons as an atom of the next noble gas in the periodic table. Atoms of group 17 gain one electron and form anions with a 1− charge; atoms of group 16 gain two electrons and form ions with a 2− charge, and so on. For example, the neutral bromine atom, with 35 protons and 35 electrons, can gain one electron to provide it with 36 electrons. This results in an anion with 35 protons, 36 electrons, and a 1− charge. It has the same number of electrons as atoms of the next noble gas, krypton, and is symbolized Br^{-}. (A discussion of the theory supporting the favored status of noble gas electron numbers reflected in these predictive rules for ion formation is provided in a later chapter.)

Note the usefulness of the periodic table in predicting likely ion formation and charge (Figure 6.1b). Moving from the far left to the right on the periodic table, main-group elements tend to form cations with a charge equal to the group number. That is, group 1 elements form 1+ ions; group 2 elements form 2+ ions, and so on. Moving from the far right to the left on the periodic table, elements often form anions with a negative charge equal to the number of groups moved left from the noble gases. For example, group 17 elements (one group left of the noble gases) form 1− ions; group 16 elements (two groups left) form 2− ions, and so on. This trend can be used as a guide in many cases, but its predictive value decreases when moving toward the center of the periodic table. In fact, transition metals and some other metals often exhibit variable charges that are not predictable by their location in the table. For example, copper can form ions with a 1+ or 2+ charge, and iron can form ions with a 2+ or 3+ charge.

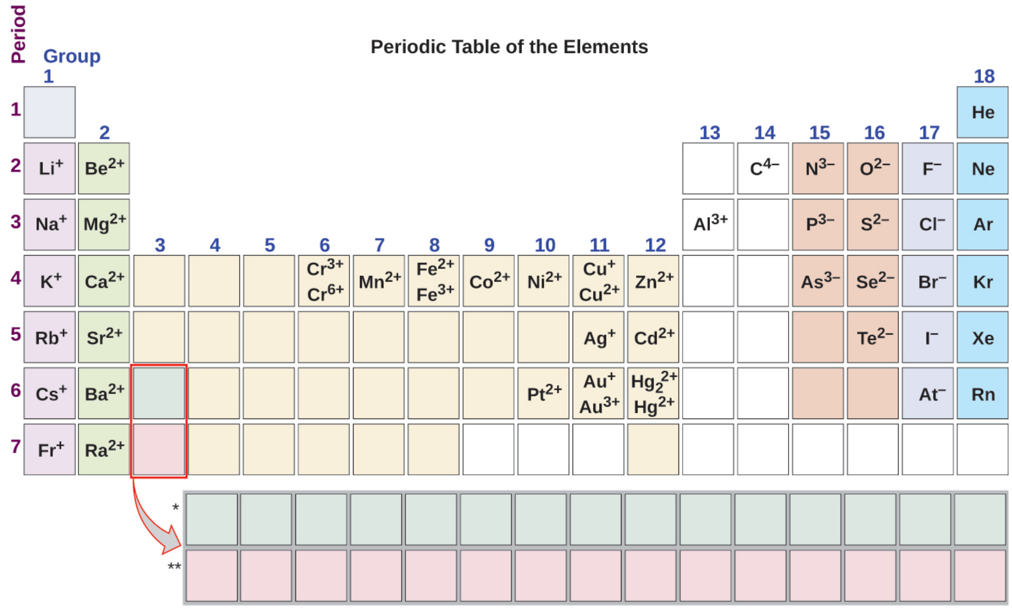

Figure 6.1b Some elements exhibit a regular pattern of ionic charge when they form ions. Review the Periodic Table of the Elements in other formats in Appendix A (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Example 6.1a

Composition of Ions

An ion found in some compounds used as antiperspirants contains 13 protons and 10 electrons. What is its symbol?

Solution

Because the number of protons remains unchanged when an atom forms an ion, the atomic number of the element must be 13. Knowing this lets us use the periodic table to identify the element as Al (aluminum). The Al atom has lost three electrons and thus has three more positive charges (13) than it has electrons (10). This is the aluminum cation, Al^{3+}.

Exercise 6.1a

Give the symbol and name for the ion with 34 protons and 36 electrons.

Check Your Answer[1]

The ions that we have discussed so far are called **monatomic ions**, that is, they are ions formed from only one atom.

Links to Interactive Learning Tools

Explore Ion and Formula Writing (https://h5pstudio.ecampusontario.ca/content/9190) from eCampusOntario H5P Studio. (https://h5pstudio.ecampusontario.ca/)

Attribution & References

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Notes

1. Se^{2-}, the selenide ion

6.2 WRITING FORMULAS OF IONIC COMPOUNDS

Learning Objectives

By the end of this section, you will be able to:

- Define ionic compounds
- Predict the type of compound formed from elements based on their location within the periodic table
- Determine formulas for simple ionic compounds

Ionic Compounds

When an element composed of atoms that readily lose electrons (a metal) reacts with an element composed of atoms that readily gain electrons (a nonmetal), a transfer of electrons usually occurs, producing ions. The compound formed by this transfer is stabilized by the electrostatic attractions (ionic bonds) between the ions of opposite charge present in the compound. For example, when each sodium atom in a sample of sodium metal (group 1) gives up one electron to form a sodium cation, Na^+, and each chlorine atom in a sample of chlorine gas (group 17) accepts one electron to form a chloride anion, Cl^-, the resulting compound, NaCl, is composed of sodium ions and chloride ions in the ratio of one Na^+ ion for each Cl^- ion. Similarly, each calcium atom (group 2) can give up two electrons and transfer one to each of two chlorine atoms to form $CaCl_2$, which is composed of Ca^{2+} and Cl^- ions in the ratio of one Ca^{2+} ion to two Cl^- ions.

A compound that contains ions and is held together by ionic bonds is called an **ionic compound**. The periodic table can help us recognize many of the compounds that are ionic: When a metal is combined with one or more nonmetals, the compound is usually ionic. This guideline works well for predicting ionic compound formation for most of the compounds typically encountered in an introductory chemistry course. However, it is not always true (for example, aluminum chloride, $AlCl_3$, is not ionic).

You can often recognize ionic compounds because of their properties. Ionic compounds are solids that typically melt at high temperatures and boil at even higher temperatures. For example, sodium chloride melts at 801 °C and boils at 1413 °C. (As a comparison, the molecular compound water melts at 0 °C and boils at 100 °C.) In solid form, an ionic compound is not electrically conductive because its ions are unable to flow ("electricity" is the flow of charged particles). When molten, however, it can conduct electricity because its ions are able to move freely through the liquid (Figure 6.2a).

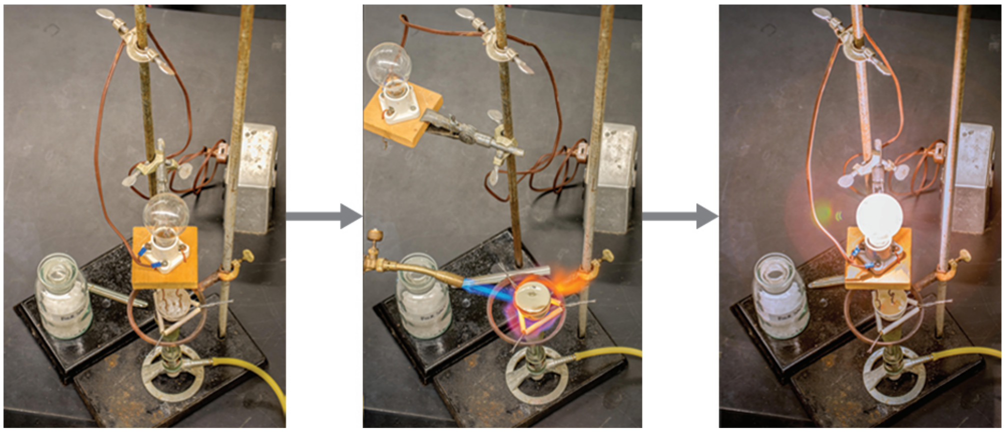

Figure 6.2a Sodium chloride melts at 801 °C and conducts electricity when molten. (credit: modification of work by Mark Blaser and Matt Evans in *Chemistry (OpenStax)*, CC BY 4.0).

Watch Conductivity Molten Salt Video (51 seconds) (https://www.youtube.com/watch?v=ePzEVPDyJV8)

In every ionic compound, the total number of positive charges of the cations equals the total number of negative charges of the anions. Thus, ionic compounds are electrically neutral overall, even though they contain positive and negative ions. We can use this observation to help us write the formula of an ionic compound. The formula of an ionic compound must have a ratio of ions such that the numbers of positive and negative charges are equal.

Example 6.2a

Formation of Ions

Magnesium and nitrogen react to form an ionic compound. Predict which forms an anion, which forms a cation, and the charges of each ion. Write the symbol for each ion and name them.

Solution

Magnesium's position in the periodic table (group 2) tells us that it is a metal. Metals form positive ions (cations). A magnesium atom must lose two electrons to have the same number electrons as an atom of the previous noble gas, neon. Thus, a magnesium atom will form a cation with two fewer electrons than protons and a charge of 2+. The symbol for the ion is Mg^{2+}, and it is called a magnesium ion.

Nitrogen's position in the periodic table (group 15) reveals that it is a nonmetal. Nonmetals form negative ions (anions). A nitrogen atom must gain three electrons to have the same number of electrons as an atom of the following noble gas, neon. Thus, a nitrogen atom will form an anion with three more electrons than protons and a charge of 3−. The symbol for the ion is N^{3-}, and it is called a nitride ion.

Exercise 6.2a

Aluminum and carbon react to form an ionic compound. Predict which forms an anion, which forms a cation, and the charges of each ion. Write the symbol for each ion and name them.

Check Your Answer[1]

The ions that we have discussed so far are called **monatomic ions**, that is, they are ions formed from only one atom. We also find many **polyatomic ions**. These ions, which act as discrete units, are electrically charged molecules (a group of bonded atoms with an overall charge). Some of the more important polyatomic ions are listed in Table 6.2a. **Oxyanions** are polyatomic ions that contain one or more oxygen atoms.

Table 6.2a Common Polyatomic Ions

Name	Formula	Related Acid	Formula
ammonium	$NH_4{}^+$		
hydronium	H_3O^+		
oxide	$O_2{}^-$		
peroxide	$O_2{}^{2-}$		
hydroxide	OH^-		
acetate	CH_3COO^-	acetic acid	CH_3COOH
cyanide	CN^-	hydrocyanic acid	HCN
azide	$N_3{}^-$	hydrazoic acid	HN_3
carbonate	$CO_3{}^{2-}$	carbonic acid	H_2CO_3
bicarbonate	$HCO_3{}^-$		
nitrate	$NO_3{}^-$	nitric acid	HNO_3
nitrite	$NO_2{}^-$	nitrous acid	HNO_2
sulfate	$SO_4{}^{2-}$	sulfuric acid	H_2SO_4
hydrogen sulfate	$HSO_4{}^-$		
sulfite	$SO_3{}^{2-}$	sulfurous acid	H_2SO_3
hydrogen sulfite	$HSO_3{}^-$		
phosphate	$PO_4{}^{3-}$	phosphoric acid	H_3PO_4
hydrogen phosphate	$HPO_4{}^{2-}$		
dihydrogen phosphate	$H_2PO_4{}^-$		
perchlorate	$ClO_4{}^-$	perchloric acid	$HClO_4$
chlorate	$ClO_3{}^-$	chloric acid	$HClO_3$
chlorite	$ClO_2{}^-$	chlorous acid	$HClO_2$

Name	Formula	Related Acid	Formula
hypochlorite	ClO^{-}	hypochlorous acid	$HClO$
chromate	$CrO_4{}^{2-}$	chromic acid	H_2CrO_4
dichromate	$Cr_2O_7{}^{2-}$	dichromic acid	$H_2Cr_2O_7$
permanganate	$MnO_4{}^{-}$	permanganic acid	$HMnO_4$

Note that there is a system for naming some polyatomic ions; *-ate* and *-ite* are suffixes designating polyatomic ions containing more or fewer oxygen atoms. *Per-* (short for "hyper") and *hypo-* (meaning "under") are prefixes meaning more oxygen atoms than *-ate* and fewer oxygen atoms than *-ite*, respectively. For example, perchlorate is $ClO_4{}^{-}$, chlorate is $ClO_3{}^{-}$, chlorite is $ClO_2{}^{-}$ and hypochlorite is ClO^{-}. Unfortunately, the number of oxygen atoms corresponding to a given suffix or prefix is not consistent; for example, nitrate is $NO_3{}^{-}$ while sulfate is $SO_4{}^{2-}$. This will be covered in more detail in the next module on nomenclature.

As you encounter monoatomic and polyatomic ions in different compounds and solutions, it is important to think about the differences in these ions. As was mentioned previously, monoatomic ions are simple in that these are formed when a single atom loses or gains a number of electrons. For example, a magnesium ion (Mg^{2+}) is formed when a magnesium atom loses two electrons. The atom that the ion is formed from as well as the charge of the ion is both represented in the formula.

Polyatomic ions are different in how we think about their formation and how we represent them. Polyatomic ions are still charged particles so we must represent the charge in the formula, but as the name implies these ions are formed from more than one atom. Let's consider a sulfate ($SO_4{}^{2-}$) ion as our example as illustrated in Figure 6.2b. Using what we've learned in previous sections, we can see that there is one sulfur atom and four oxygen atoms and that there is a charge of -2. The sulfur atom is bonded to the oxygen atoms with covalent bonds. All five of those atoms bonded together make up the polyatomic ion.

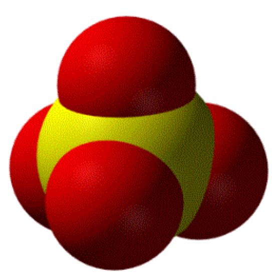

Figure 6.2b A space-filling image of a sulfate ion, where the S is represented by a yellow sphere and the oxygens are represented by red spheres. (credit: work by Benjah-bmm27, PD)

The 5-atom unit (1 x S, 4 x O) has an overall charge of -2. (It is incorrect to think that the oxygen has a -2 charge OR the sulfur has a -2 charge) In general, the atoms of a polyatomic ions (and the associated overall charge) stay together whether you are writing the ion by itself or as a part of a formula. This idea of keeping all of the atoms in a polyatomic together will be important when you learn about the dissociation of ionic compounds.

The nature of the attractive forces that hold atoms or ions together within a compound is the basis for classifying chemical bonding. When electrons are transferred and ions form, **ionic bonds** result. Ionic bonds are electrostatic forces of attraction, that is, the attractive forces experienced between objects of opposite electrical charge (in this case, cations and anions). When electrons are "shared" and molecules form, **covalent bonds** result. Covalent bonds are the attractive forces between the positively charged nuclei of the bonded atoms and one or more pairs of electrons that are located between the atoms. Compounds are classified as ionic or molecular (covalent) on the basis of the bonds present in them.

Example 6.2b

Predicting the Formula of an Ionic Compound

The gemstone sapphire (Figure 6.2c) is mostly a compound of aluminum and oxygen that contains aluminum cations, Al^{3+}, and oxygen anions, O^{2-}. What is the formula of this compound?

Figure 6.2c Although pure aluminum oxide is colourless, trace amounts of iron and titanium give blue sapphire its characteristic colour. (credit: modification of work by Stanislav Doronenko, CC BY 3.0)

Solution

Because the ionic compound must be electrically neutral, it must have the same number of positive and negative charges. Two aluminum ions, each with a charge of 3+, would give us six positive charges, and three oxide ions, each with a charge of 2−, would give us six negative charges. The formula would be Al_2O_3.

Exercise 6.2b

Predict the formula of the ionic compound formed between the sodium cation, Na^+, and the sulfide anion, S^{2-}.

Check Your Answer[2]

Many ionic compounds contain polyatomic ions (Table 6.2a) as the cation, the anion, or both. As with simple ionic compounds, these compounds must also be electrically neutral, so their formulas can be predicted by treating the polyatomic ions as discrete units. We use parentheses in a formula to indicate a group of atoms that behave as a unit. For example, the formula for calcium phosphate, one of the minerals in our bones, is $Ca_3(PO_4)_2$. This formula indicates that there are three calcium ions (Ca^{2+}) for every two phosphate (PO_4^{3-}) groups. The PO_4^{3-} groups are discrete units, each consisting of one phosphorus atom and four oxygen atoms, and having an overall charge of 3−. The compound is electrically neutral, and its formula shows a total count of three Ca, two P, and eight O atoms.

Example 6.2c

Predicting the Formula of a Compound with a Polyatomic Anion

Baking powder contains calcium dihydrogen phosphate, an ionic compound composed of the ions Ca^{2+} and $H_2PO_4^-$. What is the formula of this compound?

Solution

The positive and negative charges must balance, and this ionic compound must be electrically neutral. Thus, we must have two negative charges to balance the 2+ charge of the calcium ion. This requires a ratio of one Ca^{2+} ion to two $H_2PO_4^-$ ions. We designate this by enclosing the formula for the dihydrogen phosphate ion in parentheses and adding a subscript 2. The formula is $Ca(H_2PO_4)_2$.

Exercise 6.2c

Predict the formula of the ionic compound formed between the lithium ion and the peroxide ion, O_2^{2-} (Hint: Use the periodic table to predict the sign and the charge on the lithium ion.)

Check Your Answer[3]

Because an ionic compound is not made up of single, discrete molecules, it may not be properly symbolized using a **molecular formula**. Instead, ionic compounds must be symbolized by a formula indicating the *relative numbers* of its constituent ions. For compounds containing only monatomic ions (such as NaCl) and for many compounds containing polyatomic ions (such as $CaSO_4$), these formulas are just the **empirical formulas** introduced earlier in the book. However, the formulas for some ionic compounds containing polyatomic ions are not empirical formulas. For example, the ionic compound sodium oxalate is comprised of Na^+ and $C_2O_4^{2-}$ ions combined in a 2:1 ratio, and its formula is written as $Na_2C_2O_4$. The subscripts in this formula are not the smallest-possible whole numbers, as each can be divided by 2 to yield the empirical formula, $NaCO_2$. This is not the accepted formula for sodium oxalate, however, as it does not accurately represent the compound's polyatomic anion, $C_2O_4^{2-}$.

Attribution & References

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Notes

1. Al will form a cation with a charge of 3+: Al^{3+}, an aluminum ion. Carbon will form an anion with a charge of 4−: C^{4-}, a carbide ion.
2. Na_2S
3. Li_2O_2

6.3 NAMING BINARY COMPOUNDS

Learning Objectives

By the end of this section, you will be able to:

- Generate a proper name for an ionic compound.
- Generate a proper name for a molecular compound

Nomenclature

Nomenclature, a collection of rules for naming things, is important in science and in many other situations. This module describes an approach that is used to name simple ionic and molecular compounds, such as NaCl, $CaCO_3$, and N_2O_4. The simplest of these are **binary compounds**, those containing only two elements, but we will also consider how to name ionic compounds containing polyatomic ions, and one specific, very important class of compounds known as **acids** (subsequent chapters in this text will focus on these compounds in great detail). We will limit our attention here to inorganic compounds, compounds that are composed principally of elements other than carbon, and will follow the nomenclature guidelines proposed by IUPAC. The rules for organic compounds, in which carbon is the principal element, will be introduced in a later chapter on organic chemistry.

Naming Binary Ionic Compounds

Naming ionic compounds is simple: combine the name of the cation and the name of the anion, in both cases omitting the word *ion*. *Do not use numerical prefixes if there is more than one ion necessary to balance the charges.* NaCl is sodium chloride, a combination of the name of the cation (sodium) and the anion (chloride). MgO is magnesium oxide. $MgCl_2$ is magnesium chloride—*not* magnesium dichloride.

In naming ionic compounds whose cations can have more than one possible charge, we must also include the charge, in parentheses and in roman numerals, as part of the name. Hence FeS is iron(II) sulfide, while

Fe_2S_3 is iron(III) sulfide. Again, no numerical prefixes appear in the name. The number of ions in the formula is dictated by the need to balance the positive and negative charges.

Example 6.3a

Problems

Name each ionic compound.

1. $CaCl_2$
2. AlF_3

Solutions

1. Using the names of the ions, this ionic compound is named calcium chloride. *It is not calcium(II) chloride* because calcium forms only one cation when it forms an ion, and it has a characteristic charge of 2+.
2. The name of this ionic compound is aluminum fluoride.

Exercise 6.3a

Name each ionic compound.

1. Sc_2O_3
2. AgCl

Check Your Answer[1]

Compounds Containing a Metal Ion with a Variable Charge

Most transition metals can form two or more cations with different charges.

There are two ways to make this distinction. In the simpler, more modern approach, called the **Stock**

system, an ion's positive charge is indicated by a roman numeral in parentheses after the element name, followed by the word *ion*. Thus Fe^{2+} is called the iron(II) ion, while Fe^{3+} is called the iron(III) ion. This system is used only for elements that form more than one common positive ion. We do not call the Na^{+} ion the sodium(I) ion because (I) is unnecessary. Sodium forms only a 1+ ion, so there is no ambiguity about the name *sodium ion*.

Table 6.3a The Modern and Common System of Cation Names

Element	Stem	Charge	Modern Name	Common Name
iron	ferr-	2+	iron(II) ion	ferrous ion
iron	ferr-	3+	iron(III) ion	ferric ion
copper	cupr-	1+	copper(I) ion	cuprous ion
copper	cupr-	2+	copper(II) ion	cupric ion
tin	stann-	2+	tin(II) ion	stannous ion
tin	stann-	4+	tin(IV) ion	stannic ion
lead	plumb-	2+	lead(II) ion	plumbous ion
lead	plumb-	4+	lead(IV) ion	plumbic ion
chromium	chrom-	2+	chromium(II) ion	chromous ion
chromium	chrom-	3+	chromium(III) ion	chromic ion
gold	aur-	1+	gold(I) ion	aurous ion
gold	aur-	3+	gold(III) ion	auric ion

The second system, called the common system, is not conventional but is still prevalent and used in the health sciences. This system recognizes that many metals have two common cations. The common system uses two suffixes (-*ic* and –*ous*) that are appended to the stem of the element name. The -*ic* suffix represents the greater of the two cation charges, and the -*ous* suffix represents the lower one. In many cases, the stem of the element name comes from the Latin name of the element.

Source: "3.4 Ionic Nomenclature" In *The Basics of General, Organic, and Biological Chemistry* by Saylor Academy, licensed under CC BY-NC-SA 3.0.

Compounds of these metals with nonmetals are named with the same method as compounds in the first category, except the charge of the metal ion is specified by a Roman numeral in parentheses after the name of the metal. The charge of the metal ion is determined from the formula of the compound and the charge of the anion. For example, consider binary ionic compounds of iron and chlorine. Iron typically exhibits a charge of either 2+ or 3+, and the two corresponding compound formulas are $FeCl_2$ and $FeCl_3$. The simplest name, “iron chloride,” will, in this case, be ambiguous, as it does not distinguish between these two compounds. In cases like this, the charge of the metal ion is included as a Roman numeral in parentheses immediately following the metal name. These two compounds are then unambiguously named iron(II) chloride and iron(III) chloride, respectively. Other examples are provided in Table 6.3b.

Table 6.3b Names of Some Transition Metal Ionic Compounds

Transition Metal Ionic Compound	Name
$FeCl_3$	iron(III) chloride
Hg_2O	mercury(I) oxide
HgO	mercury(II) oxide
$Cu_3(PO_4)_2$	copper(II) phosphate

Table source: *General Chemistry 1 & 2* , a derivative of *Chemistry (Open Stax),* CC BY 4.0

Out-of-date nomenclature used the suffixes *–ic* and *–ous* to designate metals with higher and lower charges, respectively: Iron(III) chloride, $FeCl_3$, was previously called ferric chloride, and iron(II) chloride, $FeCl_2$, was known as ferrous chloride. Though this naming convention has been largely abandoned by the scientific community, it remains in use by some segments of industry. For example, you may see the words *stannous fluoride* on a tube of toothpaste. This represents the formula SnF_2, which is more properly named tin(II) fluoride. The other fluoride of tin is SnF_4, which was previously called stannic fluoride but is now named tin(IV) fluoride.

Example 6.3b

Naming Ionic Compounds

Name the following ionic compounds, which contain a metal that can have more than one ionic charge:

a. Fe_2S_3
b. CuSe
c. GaN
d. $CrCl_3$
e. $Ti_2(SO_4)_3$

Solution

The anions in these compounds have a fixed negative charge (S^{2-}, Se^{2-} , N^{3-}, Cl^{-}, and SO_4^{2-}), and the compounds must be neutral. Because the total number of positive charges in each compound must equal the total number of negative charges, the positive ions must be Fe^{3+}, Cu^{2+}, Ga^{3+}, Cr^{3+}, and Ti^{3+}. These charges are used in the names of the metal ions:

a. iron(III) sulfide
b. copper(II) selenide
c. gallium(III) nitride
d. chromium(III) chloride
e. titanium(III) sulfate

Exercise 6.3b

Write the formulas of the following ionic compounds:

a. chromium(III) phosphide
b. mercury(II) sulfide
c. manganese(II) phosphate
d. copper(I) oxide
e. chromium(VI) fluoride

Check Your Answer[2]

Erin Brockovich and Chromium Contamination

In the early 1990s, legal file clerk Erin Brockovich discovered a high rate of serious illnesses in the small town of Hinckley, California. Her investigation eventually linked the illnesses to groundwater contaminated by Cr(VI) used by Pacific Gas & Electric (PG&E) to fight corrosion in a nearby natural gas pipeline. As dramatized in the film *Erin Brokovich* (for which Julia Roberts won an Oscar), Erin and lawyer Edward Masry sued PG&E for contaminating the water near Hinckley in 1993. The settlement they won in 1996—$333 million—was the largest amount ever awarded for a direct-action lawsuit in the US at that time.

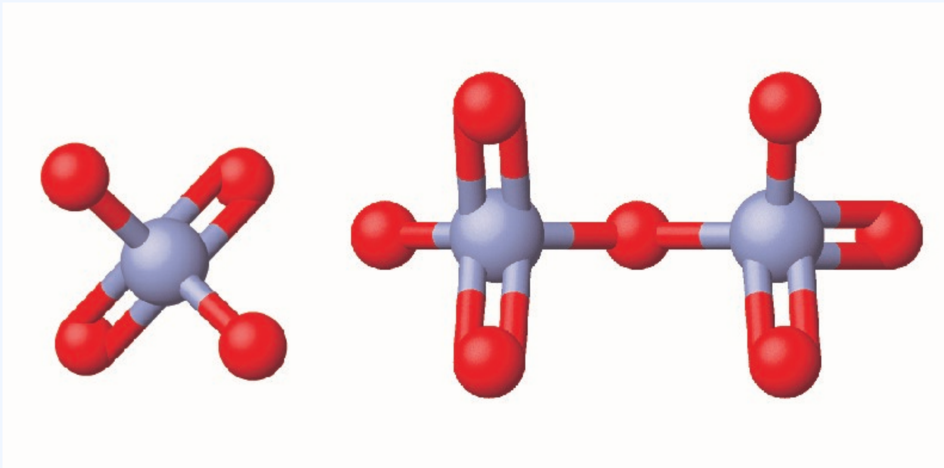

Figure 6.3a The Cr(VI) ion is often present in water as the polyatomic ions chromate, CrO_4^{2-} (left), and dichromate, $Cr_2O_7^{2-}$ (right). (credit: *Chemistry (Open Stax),* CC BY 4.0).

Chromium compounds are widely used in industry, such as for chrome plating, in dye-making, as preservatives, and to prevent corrosion in cooling tower water, as occurred near Hinckley. In the environment, chromium exists primarily in either the Cr(III) or Cr(VI) forms. Cr(III), an ingredient of many vitamin and nutritional supplements, forms compounds that are not very soluble in water, and it has low toxicity. But Cr(VI) is much more toxic and forms compounds that are reasonably soluble in water. Exposure to small amounts of Cr(VI) can lead to damage of the respiratory, gastrointestinal, and immune systems, as well as the kidneys, liver, blood, and skin.

Despite cleanup efforts, Cr(VI) groundwater contamination remains a problem in Hinckley and other locations across the globe. A 2010 study by the Environmental Working Group found that of 35 US cities tested, 31 had higher levels of Cr(VI) in their tap water than the public health goal of 0.02 parts per billion set by the California Environmental Protection Agency.

Naming Molecular Compounds

How do you know whether a formula—and by extension, a name—is for a molecular compound or for an ionic compound? Molecular compounds form between nonmetals and nonmetals, while ionic compounds form between metals and nonmetals.

There are many substances that exist as two or more atoms connected together so strongly that they behave as a single particle. These multiatom combinations are called molecules. A molecule is the smallest part of a substance that has the physical and chemical properties of that substance. In some respects, a molecule is similar to an atom. A molecule, however, is composed of more than one atom.

Some elements exist naturally as molecules. For example, hydrogen and oxygen exist as two-atom molecules. Other elements also exist naturally as diatomic molecules (Table 6.3c). As with any molecule, these elements are labeled with a molecular formula, a formal listing of what and how many atoms are in a molecule. (Sometimes only the word *formula* is used, and its meaning is inferred from the context.) For example, the molecular formula for elemental hydrogen is H_2, with H being the symbol for hydrogen and the subscript 2 implying that there are two atoms of this element in the molecule. Other diatomic elements have similar formulas: O_2, N_2, and so forth. Other elements exist as molecules—for example, sulfur normally exists as an eight-atom molecule, S_8, while phosphorus exists as a four-atom molecule, P_4 (see Figure 6.3b "Molecular Art of S"). Otherwise, we will assume that elements exist as individual atoms, rather than molecules. It is assumed that there is only one atom in a formula if there is no numerical subscript on the right side of an element's symbol.

Table 6.3c Elements that Exist as Diatomic Molecules

Name	Symbol
hydrogen	H_2
oxygen	O_2
nitrogen	N_2
fluorine	F_2
chlorine	Cl_2
bromine	Br_2
iodine	I_2

Table source: "Molecules and Chemical Nomenclature (https://opentextbc.ca/introductorychemistry/chapter/molecules-and-chemical-nomenclature/#diatomic)" In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, CC BY-NC-SA 4.0.

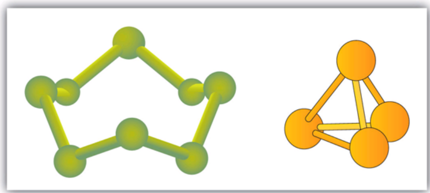

Figure 6.3b "Molecular Art of S_8 and P_4 Molecules." If each green ball represents a sulfur atom, then the diagram on the left represents an S_8 molecule. The molecule on the right shows that one form of elemental phosphorus exists, as a four-atom molecule. (credit: Molecular Art of S_8 and P_4 Molecules by David W. Ball, CC BY-NC-SA 4.0)

Figure 6.3b "Molecular Art of S" shows two examples of how we will be representing molecules in this text. An atom is represented by a small ball or sphere, which generally indicates where the nucleus is in the molecule. A cylindrical line connecting the balls represents the connection between the atoms that make this collection of atoms a molecule. This connection is called a chemical bond.

Many compounds exist as molecules. In particular, when nonmetals connect with other nonmetals, the compound typically exists as molecules.

By following the rules of nomenclature, each and every compound has its own unique name, and each name refers to one and only one compound. Here, we will start with relatively simple molecules that have only two elements in them, the so-called *binary compounds*:

Step 1: Identify the elements in the molecule from its formula.

Step 2: Begin the name with the element name of the first element. If there is more than one atom of this element in the molecular formula, use a numerical prefix to indicate the number of atoms, as listed in Table 6.3c "Numerical Prefixes Used in Naming Molecular Compounds". *Do not use the prefix* mono- *if there is only one atom of the first element.*

Table 6.3d Numerical Prefixes Used in Naming Molecular Compounds

Number of Atoms of Element	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Step 3: Name the second element by using three pieces:

- a numerical prefix indicating the number of atoms of the second element, plus
- the stem of the element name (e.g., *ox* for oxygen, *chlor* for chlorine, etc.), plus
- the suffix –*ide*.

Step 4: Combine the two words, leaving a space between them.

The flowchart provides a summary for naming binary compounds (Figure 6.3c).

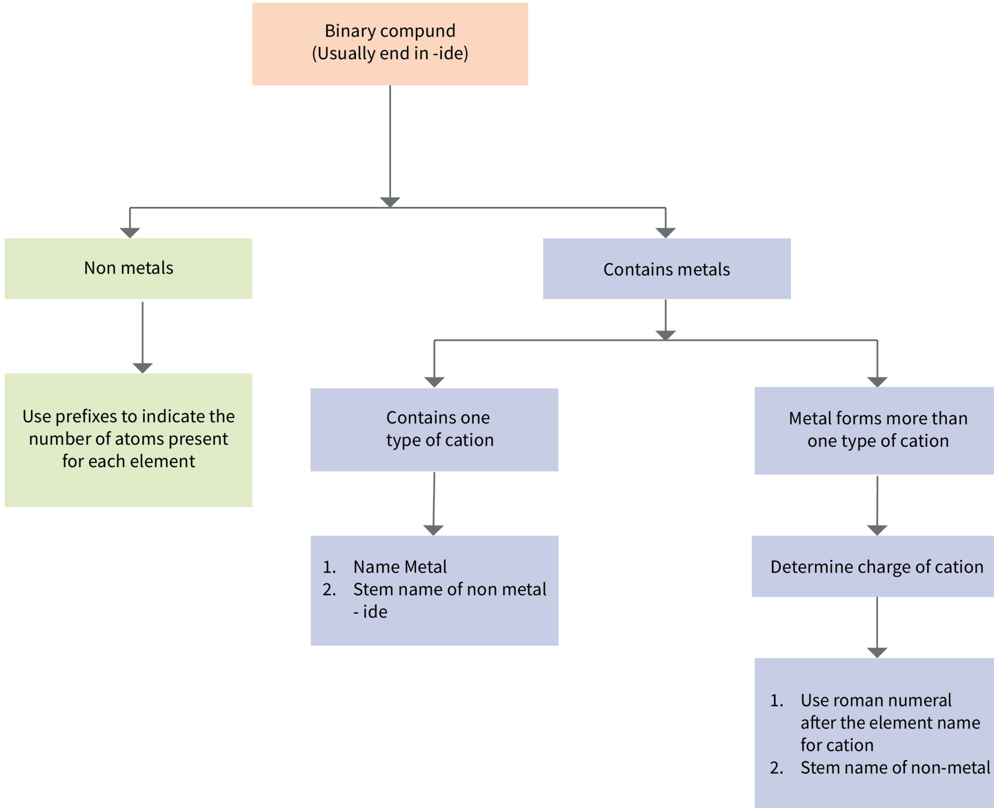

Figure 6.3c Flowchart for naming binary compounds. (credit: *Chemistry (Open Stax)*, CC BY 4.0. / Adapted into a flow chart by Revathi Mahadevan)

Let us see how these steps work for a molecule whose molecular formula is SO_2, which has one sulfur atom and two oxygen atoms—this completes step 1. According to step 2, we start with the name of the first element—sulfur. Remember, we don't use the *mono-* prefix for the first element. Now for step 3, we combine the numerical prefix *di-* (see Table 6.3c "Numerical Prefixes Used in Naming Molecular Compounds") with the stem *ox-* and the suffix *-ide*, to make *dioxide*. Bringing these two words together, we have the unique name for this compound—sulfur dioxide.

Why all this trouble? There is another common compound consisting of sulfur and oxygen whose molecular formula is SO_3, so the compounds need to be distinguished. SO_3 has three oxygen atoms in it, so it is a different compound with different chemical and physical properties. The system of chemical nomenclature is designed to *give this compound its own unique name*. Its name, if you go through all the steps, is sulfur trioxide. Different compounds have different names.

In some cases, when a prefix ends in *a* or *o* and the element name begins with *o* we drop the *a* or *o* on the prefix. So we see *monoxide* or *pentoxide* rather than *monooxide* or *pentaoxide* in molecule names.

One great thing about this system is that it works both ways. From the name of a compound, you should be able to determine its molecular formula. Simply list the element symbols, with a numerical subscript if there is more than one atom of that element, in the order of the name (we do not use a subscript 1 if there is only one atom of the element present; 1 is implied). From the name *nitrogen trichloride*, you should be able to get NCl_3 as the formula for this molecule. From the name *diphosphorus pentoxide*, you should be able to get the formula P_2O_5 (note the numerical prefix on the first element, indicating there is more than one atom of phosphorus in the formula).

Example 6.3c

Problems

Name each molecule.

1. PF_3
2. CO
3. Se_2Br_2

Solutions

1. A molecule with a single phosphorus atom and three fluorine atoms is called phosphorus trifluoride.
2. A compound with one carbon atom and one oxygen atom is properly called carbon monoxide, not carbon monooxide.
3. There are two atoms of each element, selenium and bromine. According to the rules, the proper name here is *diselenium dibromide.*

Exercise 6.3c

Name each molecule.

1. SF_4
2. P_2S_5

Check Your Answer[3]

Example 6.3d

Problems

Give the formula for each molecule.

1. carbon tetrachloride
2. silicon dioxide
3. trisilicon tetranitride

Solutions

1. The name carbon tetrachloride implies one carbon atom and four chlorine atoms, so the formula is CCl_4.
2. The name silicon dioxide implies one silicon atom and two oxygen atoms, so the formula is SiO_2.
3. We have a name that has numerical prefixes on both elements. Tri- means three, and tetra- means four, so the formula of this compound is Si_3N_4.

Exercise 6.3d

Give the formula for each molecule.

1. disulfur difluoride
2. iodine pentabromide

Check Your Answer[4]

Some simple molecules have common names that we use as part of the formal system of chemical nomenclature. For example, H_2O is given the name *water*, not *dihydrogen monoxide*. NH_3 is called *ammonia*, while CH_4 is called *methane*. We will occasionally see other molecules that have common names; we will point them out as they occur.

Links to Interactive Learning Tools

Practice Names to Formulas 1 (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Names-to-Formulas-1) by the Physics Classroom (https://www.physicsclassroom.com/).

Explore Ion and Formula Writing (https://h5pstudio.ecampusontario.ca/content/9190) from eCampusOntario H5P Studio. (https://h5pstudio.ecampusontario.ca/)

Explore Naming Compounds Flow Chart (https://h5pstudio.ecampusontario.ca/content/35085) from eCampusOntario H5P Studio (https://h5pstudio.ecampusontario.ca/).

Attribution & References

- “Naming Molecular Compounds” section is adapted from Chapter 3: Ions and Ionic Compounds & Molecules and Chemical Nomenclature (https://opentextbc.ca/introductorychemistry/part/chapter-3-atoms-molecules-and-ions/) In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0.

Notes

1. 1. scandium oxide 2. silver chloride
2. (a) CrP; (b) HgS; (c) $Mn_3(PO_4)_2$; (d) Cu_2O; (e) CrF_6
3. 1. sulfur tetrafluoride; 2. diphosphorus pentasulfide
4. 1. S_2F_2; 2. IBr_5

6.4 NAMING COMPOUNDS CONTAINING POLYATOMIC IONS

Learning Objectives

By the end of this section, you will be able to:

- Generate a proper name for an ionic compound containing polyatomic ions.

Naming Compounds with Polyatomic ions

There also exists a group of ions that contain more than one atom. These are called polyatomic ions. Table 6.4a "Common Polyatomic Ions" lists the formulas, charges, and names of some common polyatomic ions. Only one of them, the ammonium ion, is a cation; the rest are anions. Most of them also contain oxygen atoms, so sometimes they are referred to as *oxyanions*. Some of them, such as nitrate and nitrite, and sulfate and sulfite, have very similar formulas and names, so care must be taken to get the formulas and names correct. Note that the -ite polyatomic ion has one less oxygen atom in its formula than the -ate ion but with the same ionic charge. For an accessible version of Table 6.4a, refer to Appendix E.

Table 6.4a Common Polyatomic Ions

Symbol	Name	Symbol	Name	Symbol	Name
CrO_4^{2-}	Chromate	BO_3^{3-}	Borate	SO_4^{2-}	Sulfate
CrO_7^{2-}	Dichromate	AsO_4^{3-}	Arsenate	SO_3^{2-}	Sulfite
CN^{-}	Cyanide	BrO^{-}	Hypobromite	HSO_4^{-}	Hydrogen sulfate (bisulfate)
SCN^{-}	Thiocyanide	BrO_3^{-}	Bromate	HSO_3^{-}	Hydrogen sulfite (bisulfate)
NO_3^{-}	Nitrate	CIO^{-}	Hypochlorite	PO_4^{3-}	Phosphate
NO_2^{-}	Nitrite	CIO_2^{-}	Chlorite	PO_3^{3-}	Phosphite
MnO_4^{-}	Permanganate	CIO_3^{-}	Chlorate	HPO_4^{2-}	Hydrogen phosphate
OH^{-}	Hydroxide	CIO_4^{-}	Perchlorate	$H_2PO_4^{2-}$	Dihydrogen phosphate
O_2^{2-}	Peroxide	IO_4^{-}	Periodate	CO_3^{2-}	Carbonate
NH_2^{-}	Amide	IO_3^{-}	Iodate	HCO_3^{-}	Hydrogen carbonate
$C_2H_3O_2^{-}$	Acetate	IO^{-}	Hypoiodite	$HC_2O_4^{-}$	Hydrogen oxalate
$C_2O_4^{2-}$	Oxalate	NH_4^{+}	Ammonium		

The naming of ionic compounds that contain polyatomic ions follows the same rules as the naming for other ionic compounds: simply combine the name of the cation and the name of the anion. Do not use numerical prefixes in the name if there is more than one polyatomic ion; the only exception to this is if the name of the ion itself contains a numerical prefix, such as dichromate or triiodide.

Writing the formulas of ionic compounds has one important difference. If more than one polyatomic ion is needed to balance the overall charge in the formula, enclose the formula of the polyatomic ion in parentheses and write the proper numerical subscript to the right and *outside* the parentheses. Thus, the formula between calcium ions, Ca^{2+}, and nitrate ions, NO_3^{-}, is properly written $Ca(NO_3)_2$, not $CaNO_{32}$ or CaN_2O_6. Use parentheses where required. The name of this ionic compound is simply calcium nitrate.

Example 6.4a

Problems

Write the proper formula and give the proper name for each ionic compound formed between the two listed ions.

1. NH^{4+} and S^{2-}
2. Al^{3+} and PO_4^{3-}
3. Fe^{2+} and PO_4^{3-}

Solutions

1. Because the ammonium ion has a 1+ charge and the sulfide ion has a 2− charge, we need two ammonium ions to balance the charge on a single sulfide ion. Enclosing the formula for the ammonium ion in parentheses, we have $(NH_4)_2S$. The compound's name is ammonium sulfide.
2. Because the ions have the same magnitude of charge, we need only one of each to balance the charges. The formula is $AlPO_4$, and the name of the compound is aluminum phosphate.
3. Neither charge is an exact multiple of the other, so we have to go to the least common multiple of 6. To get 6+, we need three iron(II) ions, and to get 6−, we need two phosphate ions. The proper formula is $Fe_3(PO_4)_2$, and the compound's name is iron(II) phosphate.

Exercise 6.4a

Write the proper formula and give the proper name for each ionic compound formed between the two listed ions.

1. NH_4^+ and PO_4^{3-}
2. Co^{3+} and NO_2^-

Check Your Answer[1]

Food and Drink App: Sodium in Your Food

The element sodium, at least in its ionic form as Na^+, is a necessary nutrient for humans to live. In fact, the human body is approximately 0.15% sodium, with the average person having one-twentieth to one-tenth of a kilogram in their body at any given time, mostly in fluids outside cells and in other bodily fluids.

Sodium is also present in our diet. The common table salt we use on our foods is an ionic sodium compound. Many processed foods also contain significant amounts of sodium added to them as a variety of ionic compounds. Why are sodium compounds used so much? Usually sodium compounds are inexpensive, but, more importantly, most ionic sodium compounds dissolve easily. This allows processed food manufacturers to add sodium-containing substances to food mixtures and know that the compound will dissolve and distribute evenly throughout the food. Simple ionic compounds such as sodium nitrite ($NaNO_2$) are added to cured meats, such as bacon and deli-style meats, while a compound called sodium benzoate is added to many packaged foods as a preservative. Table 6.4b "Some Sodium Compounds Added to Food" is a partial list of some sodium additives used in food. Some of them you may recognize after reading this chapter. Others you may not recognize, but they are all ionic sodium compounds with some negatively charged ion also present.

Table 6.4b Some Sodium Compounds Added to Food

Sodium Compound	**Use in Food**
Sodium acetate	preservative, acidity regulator
Sodium adipate	food acid
Sodium alginate	thickener, vegetable gum, stabilizer, gelling agent, emulsifier
Sodium aluminum phosphate	acidity regulator, emulsifier
Sodium aluminosilicate	anticaking agent
Sodium ascorbate	antioxidant
Sodium benzoate	preservative
Sodium bicarbonate	mineral salt
Sodium bisulfite	preservative, antioxidant
Sodium carbonate	mineral salt
Sodium carboxymethylcellulose	emulsifier
Sodium citrates	food acid
Sodium dehydroacetate	preservative
Sodium erythorbate	antioxidant
Sodium erythorbin	antioxidant
Sodium ethyl para-hydroxybenzoate	preservative
Sodium ferrocyanide	anticaking agent
Sodium formate	preservative
Sodium fumarate	food acid
Sodium gluconate	stabilizer
Sodium hydrogen acetate	preservative, acidity regulator
Sodium hydroxide	mineral salt
Sodium lactate	food acid
Sodium malate	food acid
Sodium metabisulfite	preservative, antioxidant, bleaching agent
Sodium methyl para-hydroxybenzoate	preservative
Sodium nitrate	preservative, color fixative
Sodium nitrite	preservative, color fixative
Sodium orthophenyl phenol	preservative
Sodium propionate	preservative

Sodium Compound	Use in Food
Sodium propyl para-hydroxybenzoate	preservative
Sodium sorbate	preservative
Sodium stearoyl lactylate	emulsifier
Sodium succinates	acidity regulator, flavour enhancer
Sodium salts of fatty acids	emulsifier, stabilizer, anticaking agent
Sodium sulfite	mineral salt, preservative, antioxidant
Sodium sulfite	preservative, antioxidant
Sodium tartrate	food acid
Sodium tetraborate	preservative

The use of so many sodium compounds in prepared and processed foods has alarmed some physicians and nutritionists. They argue that the average person consumes too much sodium from his or her diet. The average person needs only about 500 mg of sodium every day; most people consume more than this—up to 10 times as much. Some studies have implicated increased sodium intake with high blood pressure; newer studies suggest that the link is questionable. However, there has been a push to reduce the amount of sodium most people ingest every day: avoid processed and manufactured foods, read labels on packaged foods (which include an indication of the sodium content), don't oversalt foods, and use other herbs and spices besides salt in cooking.

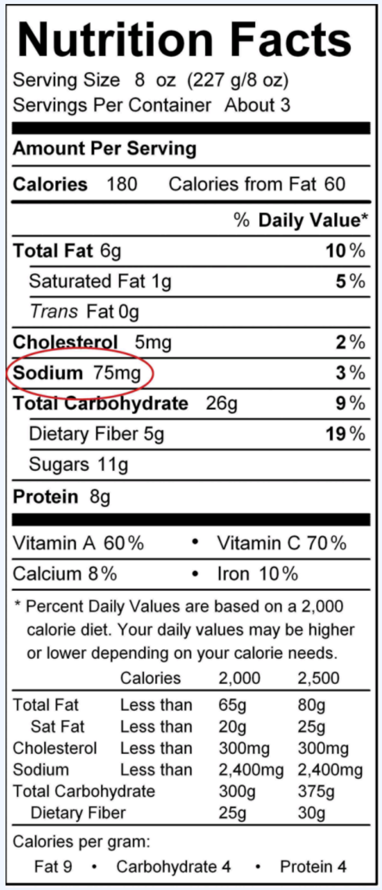

Figure 6.4a "Nutrition Facts." Food labels include the amount of sodium per serving. This particular label shows that there are 75 mg of sodium in one serving of this particular food item (credit: *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, CC BY-NC-SA 4.0).

Indigenous Perspective: Soapstone

Explore two ionic compounds used by Inuit. These include stone such as soapstone (also known as talc carbonate) and composite materials such as bone which contains 70% hydroxyapatite, $Ca_5(PO_4)_3$ (OH).

The information can be found within the article Making Chemistry Relevant to Indigenous People [New Tab] (https://uwaterloo.ca/chem13-news-magazine/february-2016/feature/making-chemistry-relevant-indigenous-peoples) from the University of Waterloo.

Figure 6.4b Soapstone (Speckstein) (credit: work by Ra'ike, CC BY-SA 3.0)

Source: Rayner-Canham, G., Taylor, R., & Lee, Y.R. (2016, February). Making chemistry relevant to Indigenous peoples. *Chem 13 News Magazine*. https://uwaterloo.ca/chem13-news-magazine/february-2016/feature/making-chemistry-relevant-indigenous-peoples

Links to Interactive Learning Tools

Practice Names to Formulas 2 (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Names-to-Formulas-2) by the Physics Classroom (https://www.physicsclassroom.com/).

Explore Naming Compounds Flow Chart (https://h5pstudio.ecampusontario.ca/content/35085) from eCampusOntario H5P Studio (https://h5pstudio.ecampusontario.ca/).

Attribution & References

Except where otherwise noted, this page is adapted by Adrienne Richards from "Chapter 3: Ions and Ionic Compounds & Molecules and Chemical Nomenclature" (https://opentextbc.ca/introductorychemistry/part/chapter-3-atoms-molecules-and-ions/) In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0.

Notes

1.
    1. $(NH_4)_3PO_4$, ammonium phosphate
    2. $Co(NO_2)_3$, cobalt(III) nitrite

6.5 NAMING ACIDS

Learning Objectives

By the end of this section, you will be able to:

- Define acid.
- Name a binary acid and an oxyacid.

There is one other group of compounds that is important to us—acids—and these compounds have interesting chemical properties. Initially, we will define an **acid** as an ionic compound of the H^+ cation dissolved in water. To indicate that something is dissolved in water, we will use the phase label (aq) next to a chemical formula (where aq stands for "aqueous," a word that describes something dissolved in water). If the formula does not have this label, then the compound is treated as a molecular compound rather than an acid.

Binary Acids

Some compounds containing hydrogen are members of an important class of substances known as acids. The chemistry of these compounds is explored in more detail in later chapters of this text, but for now, it will suffice to note that many acids release hydrogen ions, H^+, when dissolved in water. To denote this distinct chemical property, a mixture of water with acid is given a name derived from the compound's name. To indicate that something is dissolved in water, we will use the phrase label (aq) next to a chemical formula (where aq stands for "aqueous," a word that describes something dissolved in water). If the formula does not have this label, then the compound is treated as a molecular compound rather than an acid. If the compound is a **binary acid** (comprised of hydrogen and one other nonmetallic element):

1. The word "hydrogen" is changed to the prefix *hydro-*
2. The other nonmetallic element name is modified by adding the suffix *–ic*
3. The word "acid" is added as a second word

A flowchart summarizes naming acids (Figure 6.5a).

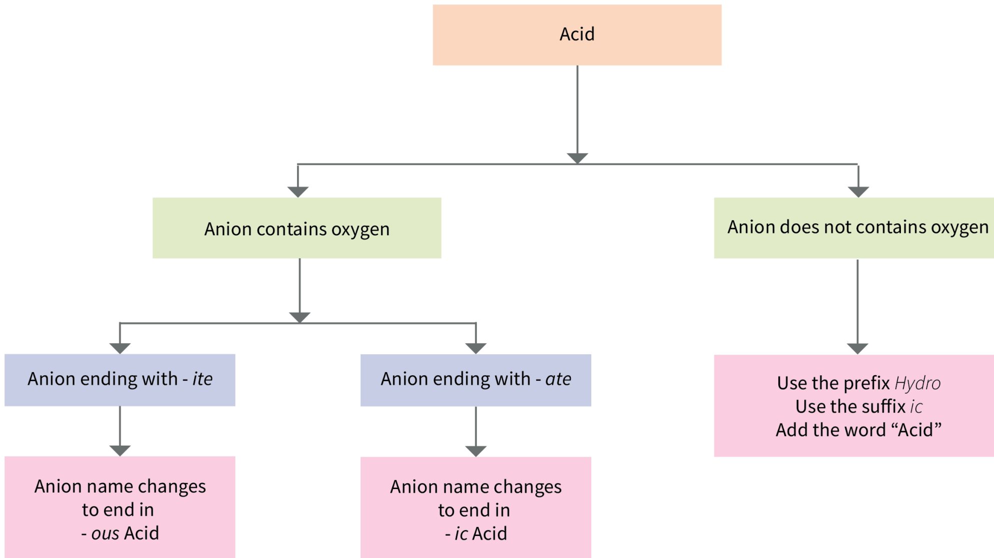

Figure 6.5a Flowchart for naming acids. (credit: *Chemistry (Open Stax)* CC BY 4.0. / Adapted into a flow chart by Revathi Mahadevan.)

For example, when the gas HCl (hydrogen chloride) is dissolved in water, the solution is called *hydrochloric acid*. Several other examples of this nomenclature are shown in Table 6.5a.

Table 6.5a Names of Some Simple Acids

Name of Gas	Name of Acid
HF(*g*), hydrogen fluoride	HF(*aq*), hydrofluoric acid
HCl(*g*), hydrogen chloride	HCl(*aq*), hydrochloric acid
HBr(*g*), hydrogen bromide	HBr(*aq*), hydrobromic acid
HI(*g*), hydrogen iodide	HI(*aq*), hydroiodic acid
H_2S(*g*), hydrogen sulfide	H_2S(*aq*), hydrosulfuric acid

Oxyacids

Many compounds containing three or more elements (such as organic compounds or coordination compounds) are subject to specialized nomenclature rules that you will learn later. However, we will briefly discuss the important compounds known as **oxyacids**, compounds that contain hydrogen, oxygen, and at least one other element, and are bonded in such a way as to impart acidic properties to the compound (you will learn the details of this in a later chapter). Typical oxyacids consist of hydrogen combined with a polyatomic, oxygen-containing ion. To name oxyacids:

1. Omit "hydrogen"
2. Start with the root name of the anion
3. Replace –*ate* with –*ic*, or –*ite* with –*ous*
4. Add "acid"

For example, consider H_2CO_3 (which you might be tempted to call "hydrogen carbonate"). To name this correctly, "hydrogen" is omitted; the –*ate* of carbonate is replaced with –*ic*; and acid is added—so its name is carbonic acid. Other examples are given in Table 6.5b. There are some exceptions to the general naming method (e.g., H_2SO_4 is called sulfuric acid, not sulfic acid, and H_2SO_3 is sulfurous, not sulfous, acid).

Table 6.5b Names of Common Oxyacids

Formula	Anion Name	Acid Name
$HC_2H_3O_2$	acetate	acetic acid
HNO_3	nitrate	nitric acid
HNO_2	nitrite	nitrous acid
$HClO_4$	perchlorate	perchloric acid
H_2CO_3	carbonate	carbonic acid
H_2SO_4	sulfate	sulfuric acid
H_2SO_3	sulfite	sulfurous acid
H_3PO_4	phosphate	phosphoric acid

Example 6.5a

Problems

Name each acid without consulting Table 6.6b.

1. HBr
2. H_2SO_4

Solutions

1. As a binary acid, the acid's name is *hydro-* + stem name + *-ic* acid. Because this acid contains a bromine atom, the name is hydrobromic acid.
2. Because this acid is derived from the sulfate ion, the name of the acid is the stem of the anion name + *-ic* acid. The name of this acid is sulfuric acid.

Exercise 6.5a

Name each acid.

1. HF
2. HNO_2

Check Your Answer[1]

All acids have some similar properties. For example, acids have a sour taste; in fact, the sour taste of some of our foods, such as citrus fruits and vinegar, is caused by the presence of acids in food. Many acids react with some metallic elements to form metal ions and elemental hydrogen. Acids make certain plant pigments change colours; indeed, the ripening of some fruits and vegetables is caused by the formation or destruction of excess acid in the plant. In a later chapter, we will explore the chemical behaviour of acids.

Acids are very prevalent in the world around us. We have already mentioned that citrus fruits contain acid; among other compounds, they contain citric acid, $H_3C_6H_5O_7(aq)$. Oxalic acid, $H_2C_2O_4(aq)$, is found in spinach and other green leafy vegetables. Hydrochloric acid not only is found in the stomach (stomach acid) but also can be bought in hardware stores as a cleaner for concrete and masonry. Phosphoric acid is an ingredient in some soft drinks.

Links to Interactive Learning Tools

Explore Naming Compounds Flow Chart (https://h5pstudio.ecampusontario.ca/content/35085) from eCampusOntario H5P Studio (https://h5pstudio.ecampusontario.ca/).

Attribution & References

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- "2.7 Chemical Nomenclature (https://openstax.org/books/chemistry-2e/pages/2-7-chemical-nomenclature)" In *Chemistry 2e (OpenStax)* by Paul Flowers, Klaus Theopold, Richard Langley, & William R. Robinson, licensed under CC BY 4.0.
- "4.3 Chemical Nomenclature (https://boisestate.pressbooks.pub/chemistry/chapter/4-3-chemical-nomenclature/)" In *General Chemistry 1 & 2* by Rice University, a derivative of *Chemistry (Open Stax)* by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson and is licensed under CC BY 4.0. Access for free at *Chemistry (OpenStax) (https://openstax.org/books/chemistry/pages/1-introduction)*
- "Chapter 3: Ions and Ionic Compounds & Molecules and Molecular Compounds – Acids (https://opentextbc.ca/introductorychemistry/chapter/acids/)" In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY NC SA 4.0. Access for free at *Chemistry 2e (OpenStax)* (https://openstax.org/details/books/chemistry-2e?Book%20details).

Adaptations include combining section 2.7, 4.3 and Chapter 3.

Notes

1.
    1. hydrofluoric acid
    2. nitrous acid

CHAPTER 6 - SUMMARY

6.1 Elements and Their Ions

Compounds that contain ions are called ionic compounds. Ionic compounds generally form from metals and nonmetals. Compounds that do not contain ions, but instead consist of atoms bonded tightly together in molecules (uncharged groups of atoms that behave as a single unit), are called covalent compounds. Covalent compounds usually form from two nonmetals.

6.2 Writing Formulas of Ionic Compounds

Ionic compounds must be symbolized by a formula indicating the *relative numbers* of its constituent ions. These compounds must be electrically neutral. For instance, NaCl would be electrically neutral since it has a single Na+ ion and a single Cl- ion.

6.3 Naming Binary Compounds

Chemists use nomenclature rules to clearly name compounds. Ionic and molecular compounds are named using somewhat-different methods. Binary ionic compounds typically consist of a metal and a nonmetal. The name of the metal is written first, followed by the name of the nonmetal with its ending changed to –*ide*. For example, K_2O is called potassium oxide. If the metal can form ions with different charges, a Roman numeral in parentheses follows the name of the metal to specify its charge. Thus, $FeCl_2$ is iron(II) chloride and $FeCl_3$ is iron(III) chloride.

Molecular compounds can form compounds with different ratios of their elements, so prefixes are used to specify the numbers of atoms of each element in a molecule of the compound. Examples include SF_6, sulfur hexafluoride, and N_2O_4, dinitrogen tetroxide.

6.4 Naming Compounds Containing Polyatomic Ions

Some compounds contain polyatomic ions. For compounds with polyatomic ions, name the metal first, followed by the name of the polyatomic ion.

6.5 Naming Acids

Acids are an important class of compounds containing hydrogen and having special nomenclature rules. Binary acids are named using the prefix *hydro-*, changing the *–ide* suffix to *–ic*, and adding “acid;” HCl is hydrochloric acid. Oxyacids are named by changing the ending of the anion to *–ic*, and adding “acid;” H_2CO_3 is carbonic acid.

Attribution & References

CHAPTER 6 - REVIEW

6.1 Elements and Their Ions

1. Using the periodic table, predict whether the following chlorides are ionic or covalent: KCl, NCl_3, ICl, $MgCl_2$, PCl_5, and CCl_4. **Check Answer:** [1]
2. Using the periodic table, predict whether the following chlorides are ionic or covalent: $SiCl_4$, PCl_3, $CaCl_2$, CsCl, $CuCl_2$, and $CrCl_3$.
3. For each of the following compounds, state whether it is ionic or covalent. If it is ionic, write the symbols for the ions involved:
   a. NF_3
   b. BaO,
   c. $(NH_4)_2CO_3$
   d. $Sr(H_2PO_4)_2$
   e. IBr
   f. Na_2O
   Check Answer: [2]
4. For each of the following compounds, state whether it is ionic or covalent, and if it is ionic, write the symbols for the ions involved:
   a. $KClO_4$
   b. $MgC_2H_3O_2$
   c. H_2S
   d. Ag_2S
   e. N_2Cl_4
   f. $Co(NO_3)_2$

6.2 Writing Formulas of Ionic Compounds; 6.3 Naming Binary Compounds; and 6.4 Naming Compounds Containing Polyatomic Ions

1. For each of the following pairs of ions, write the symbol for the formula of the compound they will form:
   a. Ca^{2+}, S^{2-}

b. NH_4^+, SO_4^{2-}
c. Al^{3+}, Br^-
d. Na^+, HPO_4^{2-}
e. Mg^{2+}, PO_4^{3-}

Check Answer: [3]

2. For each of the following pairs of ions, write the symbol for the formula of the compound they will form:
   a. K^+, O^{2-}
   b. NH_4+, PO_4^{3-}
   c. Al^{3+}, O^{2-}
   d. Na^+, CO_3^{2-}
   e. Ba^{2+}, PO_4^{3-}
3. Name the following compounds:
   a. CsCl
   b. BaO
   c. K_2S
   d. $BeCl_2$
   e. HBr
   f. AlF_3

   Check Answer: [4]
4. Name the following compounds:
   a. NaF
   b. Rb_2O
   c. BCl_3
   d. H_2Se
   e. P_4O_6
   f. ICl_3
5. Write the formulas of the following compounds:
   a. rubidium bromide
   b. magnesium selenide
   c. sodium oxide
   d. calcium chloride
   e. hydrogen fluoride
   f. gallium phosphide
   g. aluminum bromide
   h. ammonium sulfate

   Check Answer: [5]

6. Write the formulas of the following compounds:
   a. lithium carbonate
   b. sodium perchlorate
   c. barium hydroxide
   d. ammonium carbonate
   e. sulfuric acid
   f. calcium acetate
   g. magnesium phosphate
   h. sodium sulfite
7. Write the formulas of the following compounds:
   a. chlorine dioxide
   b. dinitrogen tetraoxide
   c. potassium phosphide
   d. silver(I) sulfide
   e. aluminum nitride
   f. silicon dioxide

   Check Answer: [6]
8. Write the formulas of the following compounds:
   a. barium chloride
   b. magnesium nitride
   c. sulfur dioxide
   d. nitrogen trichloride
   e. dinitrogen trioxide
   f. tin(IV) chloride
9. Each of the following compounds contains a metal that can exhibit more than one ionic charge. Name these compounds:
   a. Cr_2O_3
   b. $FeCl_2$
   c. CrO_3
   d. $TiCl_4$
   e. CoO
   f. MoS_2

   Check Answer: [7]
10. Each of the following compounds contains a metal that can exhibit more than one ionic charge. Name these compounds:
    a. $NiCO_3$
    b. MoO_3

   c. $Co(NO_3)_2$
   d. V_2O_5
   e. MnO_2
   f. Fe_2O_3
11. The following ionic compounds are found in common household products. Write the formulas for each compound:
   a. potassium phosphate
   b. copper(II) sulfate
   c. calcium chloride
   d. titanium dioxide
   e. ammonium nitrate
   f. sodium bisulfate (the common name for sodium hydrogen sulfate)
   Check Answer: [8]
12. The following ionic compounds are found in common household products. Name each of the compounds:
   a. $Ca(H_2PO_4)_2$
   b. $FeSO_4$
   c. $CaCO_3$
   d. MgO
   e. $NaNO_2$
   f. KI
13. What are the IUPAC names of the following compounds?
   a. manganese dioxide
   b. mercurous chloride (Hg_2Cl_2)
   c. ferric nitrate [$Fe(NO_3)_3$]
   d. titanium tetrachloride
   e. cupric bromide ($CuBr_2$)
   Check Answer: [9]

6.5 Naming Acids

1. Give the formula for each acid.
   a. perchloric acid
   b. hydriodic acid
   Check Answer: [10]
2. Give the formula for each acid.
   a. hydrosulfuric acid

   b. phosphorous acid
3. Name each acid.
   a. HF(aq)
   b. HNO_3(aq)
   c. $H_2C_2O_4$(aq)
   Check Answer: [11]
4. Name each acid.
   a. H_2SO_4(aq)
   b. H_3PO_4(aq)
   c. HCl(aq)
5. Name an acid found in food.
   Check Answer: [12]
6. Name some properties that acids have in common.

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- Chapter 3: Ions and Ionic Compounds & Molecules and Molecular Compounds – Acids In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0.
  Adaptations include extracting the exercises relevant to this chapter from 2.6, 2.7 and Chapter 3.

Notes

1. Ionic: KCl, $MgCl_2$; Covalent: NCl_3, ICl, PCl_5, CCl_4
2. (a) covalent; (b) ionic, Ba^{2+}, O^{2-}; (c) ionic, NH_4^+,CO_3^{2-}; (d) ionic, Sr^{2+}, $H_2PO_4^-$; (e) covalent; (f) ionic, Na^+, O^{2-}
3. (a) CaS; (b) $(NH_4)_2SO_4$; (c) $AlBr_3$; (d) Na_2HPO_4; (e) $Mg_3 (PO_4)_2$
4. (a) cesium chloride; (b) barium oxide; (c) potassium sulfide; (d) beryllium chloride; (e) hydrogen bromide; (f) aluminum fluoride
5. (a) RbBr; (b) MgSe; (c) Na_2O; (d) $CaCl_2$; (e) HF; (f) GaP; (g) $AlBr_3$; (h) $(NH_4)_2SO_4$
6. (a) ClO_2; (b) N_2O_4; (c) K_3P; (d) Ag_2S; (e) AlN; (f) SiO_2
7. (a) chromium(III) oxide; (b) iron(II) chloride; (c) chromium(VI) oxide; (d) titanium(IV) chloride; (e) cobalt(II) oxide; (f) molybdenum(IV) sulfide
8. (a) K_3PO_4; (b) $CuSO_4$; (c) $CaCl_2$; (d) TiO_2; (e) NH_4NO_3; (f) $NaHSO_4$

9. (a) manganese(IV) oxide; (b) mercury(I) chloride; (c) iron(III) nitrate; (d) titanium(IV) chloride; (e) copper(II) bromide
10. (a) $HClO_4(aq)$; (b) $HI(aq)$
11. (a) hydrofluoric acid; (b) nitric acid; (c) oxalic acid
12. Oxalic acid (answers will vary)