3.2 Names and Formulas of Ionic Compounds

Each ionic compound has a name that identifies the two types of ions it contains. An ionic compound also has a chemical formula that shows the ratio of the ions in the compound. In an ionic compound with only two elements, the first ion is always a positive metal ion and the second ion is always a negative non-metal ion. A metal that can form an ion in more than one way is described as multivalent. The name of a ion multivalent compound includes a Roman numeral to indicate the positive ion charge. Polyatomic ions contain the atoms of more than one element. There are both positive polyatomic ions and negative polyatomic ions.

Words to Know

chemical formula
chemical name
multivalent metal
Roman numeral

Table salt, road salt, rock salt, and sea salt are all different types of salt (Figure 3.10). Table salt and road salt are pure substances. Their chemical names are sodium chloride and calcium chloride. Rock salt and sea salt are mixtures of many different compounds. Names are important to us: we name ourselves, our pets, and the places where we live. What is important in naming a chemical?

(A) Table salt (B) Road salt (C) Rock salt (D) Sea salt

Figure 3.10 Salt comes in many forms and can be made of different compounds.

3-2A What's in a Name? Find Out ACTIVITY

A chemical name refers to only one compound and indicates the elements present. In this activity, you will work with a partner to discover what information can be collected from the names of ionic compounds.

What to Do

1. Working with your partner and the periodic table on page 54, review the ionic compounds listed below.
   lithium fluoride zinc bromide
   calcium chloride aluminum sulphide
   copper oxide
2. Look at where each element in the compound is located in the periodic table. What is one pattern that you can find in how these names are written?
3. Find one more pattern by examining the name of each ionic compound listed. The pattern has to apply to each chemical name.
4. Record any further patterns you or your partner observes.
5. Share your findings with the class.

What Did You Find Out?

1. What were two patterns you found in the chemical names of ionic compounds?
2. (a) What patterns and observations did you and your partner make that were similar to others in your class?
   (b) Which patterns and observations were different?
3. Explain how these patterns could be used as rules for identifying ionic compounds.

A Compound Has Both a Name and a Formula

All ionic compounds are composed of positive ions and negative ions. You can describe ionic compounds using a name or a formula. A **chemical name** indicates the elements present in the compound.

The chemical name

The International Union of Pure and Applied Chemistry (IUPAC) is a group that represents chemists around the world and is responsible for the rules for naming compounds. These rules are used in this textbook. The chemical name of an ionic compound always has two parts, one for each type of ion in it. The chemical name of table salt is sodium chloride.

- The first part of "sodium chloride" names the positive ion, sodium, which comes from the name of the sodium atom. The positive ion is *always* a metal in a compound containing two elements.
- The second part of "sodium chloride" names the negative ion, chloride. It is derived from a chlorine atom. The negative ion is *always* a non-metal in a compound containing two elements.
- The non-metal ion's name always ends with the suffix "-ide." In this example, "chlorine" changed to "chloride." The names and symbols for the non-metal ions are shown in Table 3.1.

Table 3.2 shows some examples of elements that can combine to form ionic compounds and the name of the resulting compound. Notice that the non-metal ion's name always ends in "-ide."

Table 3.1
Names and Symbols of Non-metal Ions

Name	Symbol
fluoride	F^-
chloride	Cl^-
bromide	Br^-
iodide	I^-
oxide	O^{2-}
sulphide	S^{2-}
selenide	Se^{2-}
nitride	N^{3-}
phosphide	P^{3-}

Table 3.2 Examples of Names of Ionic Compounds

Elements Forming the Ionic Compound	Name of the Ionic Compound
calcium and nitrogen	calcium nitride
potassium and oxygen	potassium oxide
lithium and chlorine	lithium chloride
magnesium and sulphur	magnesium sulphide
silver and fluorine	silver fluoride

Did You Know?

Antoine-Laurent Lavoisier (1743–1794) is considered the founder of modern chemistry. He published his ideas for a chemical naming system in 1787. The system of names we use today came from his ideas.

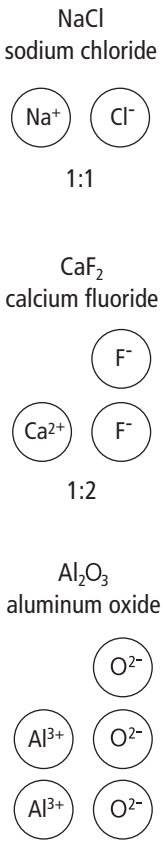


Figure 3.11 The formula and the diagram show the ratio of ions. Calcium fluoride has one Ca^{2+} ion for every two F^- ions. Aluminum oxide has two Al^{3+} and three O^{2-} ions.

The chemical formula

The **chemical formula** of an ionic compound contains symbols to identify each ion. It also shows the relative numbers of ions in the compound. These numbers are shown by a subscript set to the right of the element symbol. Figure 3.11 shows three examples.

- The metal ions in these examples are Na^+, Ca^{2+}, and Al^{3+}. Remember that these are ions, not atoms, when present in a compound. You can find their charges on the periodic table.
- The non-metal ions in these examples are Cl^-, F^-, and O^{2-}. You can also find their charges on the periodic table.

Rules for Writing the Names of Ionic Compounds

The rules for writing the name of an ionic compound from its formula are shown in Table 3.3, including two examples.

Table 3.3 Rules for Naming Ionic Compounds Containing Two Elements

Steps for Writing the Name	Examples	
	$MgBr_2$	Li_3N
1. Name the metal ion.	• The metal ion is Mg^{2+}. • The ion's name is given in the periodic table as magnesium.	• The metal ion is Li^+. • The ion's name is given in the periodic table as lithium.
2. Name the non-metal ion by ending the element name with the suffix "ide."	• The non-metal ion is Br^-. The element's name is bromine. • Changing the name to end with the suffix "-ide" gives bromide.	• The non-metal ion is N^{3-}. The element's name is nitrogen. • Changing the name to end with the suffix "-ide" gives nitride.
3. Write the name of the compound.	magnesium bromide	lithium nitride

Practice Problems

Write the names of the following compounds.

(a) AlI_3
(b) Na_2O
(c) Mg_3P_2
(d) AgI
(e) CaSe
(f) K_2S
(g) RbF
(h) Ag_3N
(i) KBr
(j) Sr_3P_2
(k) CdS
(l) Ag_2O
(m) Cs_2S
(n) CaI_2
(o) NaF

Answers provided on page 509

Rules for Writing the Formulas of Ionic Compounds

In an ionic compound, the positive charges balance the negative charges. You can use this balance to find the ratio of positive ions to negative ions. Then use the ratio to write subscripts in the formula. Table 3.4 gives the rules and two examples.

Notice that the final formula must represent the smallest whole number ratio. For example, Sn^{4+} combining with O^{2-} is written SnO_2 and not Sn_2O_4.

Word Connect

The word "subscript" comes from the prefix "sub-," which means below, and "script," meaning to write. Subscripts are used in the formulas of ionic compounds to show the relative amounts of each ion.

Table 3.4 Rules for Writing Formulas of Ionic Compounds Containing Two Elements

Steps for Writing the Formula	Examples	
	zinc nitride	aluminum chloride
1. Identify each ion and its charge.	zinc: Zn^{2+} nitride: N^{3-}	aluminum: Al^{3+} chloride: Cl^-
2. Determine the total charges needed to balance positive with negative.	Zn^{2+}: $+2$ $+2$ $+2 = +6$ N^{3-}: -3 -3 $= -6$	Al^{3+} : $= +3$ Cl^-: -1 -1 -1 $= -3$
3. Note the ratio of positive ions to negative ions.	3 Zn^{2+} ions for every 2 N^{3-} ions	1 Al^{3+} ion for every 3 Cl^- ions
4. Use subscripts to write the formula. A "1" is not shown in the subscripts.	Zn_3N_2	$AlCl_3$

Practice Problems

1. Write the formulas of the compounds containing the following ions.

(a) Li^+ with Cl^-

(b) Ca^{2+} with F^-

(c) Na^+ with S^{2-}

(d) Ca^{2+} with S^{2-}

(e) Al^{3+} with O^{2-}

(f) Al^{3+} with N^{3-}

2. Write the formulas of the following compounds.

(a) lithium fluoride

(b) silver sulphide

(c) magnesium chloride

(d) zinc oxide

(e) lithium oxide

(f) aluminum iodide

(g) barium phosphide

(h) aluminum phosphide

(i) rubidium selenide

(j) strontium nitride

(k) cesium sulphide

(l) sodium nitride

(m) zinc phosphide

(n) calcium oxide

Answers provided on page 509

Suggested Activity

Think About It 3-2B on page 93

Compounds Containing a Multivalent Metal

Many important metals are multivalent. The prefix "multi-" means many, and "valent" refers to the capacity to bond. **Multivalent metals** can form two or more different positive ions with different ion charges (Figure 3.12).

Figure 3.12 Ion charge can affect the colour of a metal ion. Solutions of vanadium ions are shown left to right: 5^+, 4^+, 3^+, and 2^+.

Table 3.5
Roman Numerals

Metal Ion Charge	Roman Numeral
1+	I
2+	II
3+	III
4+	IV
5+	V
6+	VI
7+	VII

Find iron on the periodic table. You will see that iron is multivalent. The table lists two ion charges: 3^+ and 2^+. This means that in some compounds, the iron ion is Fe^{3+}, and in other compounds the iron ion is Fe^{2+}. The table always lists the most common ion charge first. So for iron, Fe^{3+} is more common than Fe^{2+}.

To distinguish between two ions formed from multivalent metals, you need to name each ion. The name must contain the ion's charge. To do this, you need to know the Roman numerals from I to VII. (**Roman numerals** are numerals based on those used by the ancient Romans.) These correspond to ion charges from 1^+ to 7^+, as shown in Table 3.5. Here are some examples:

- Fe^{3+} or iron(III) is pronounced "iron three" and means the iron ion has an ion charge of 3+.
- Fe^{2+} or iron(II) is pronounced "iron two" and means the iron ion has an ion charge of 2+.
- Pb^{4+} or lead(IV) is pronounced "lead four" and means the lead ion has an ion charge of 4+.
- Cu^+ or copper(I) is pronounced "copper one" and means the copper ion has an ion charge of 1+.

What does a Roman numeral reveal about an ion? First, it tells you that this metal can form ions with different ion charges. Second, it tells you the charge on the metal ion. Table 3.6 gives examples of names and formulas for compounds containing a multivalent ion. Remember that the positive and negative charges on the ions must balance so that the overall charge on the compound is zero.

Table 3.6
Compounds with Multivalent Metal Ions

Name	Formula
chromium(II) fluoride	CrF_2
chromium(III) fluoride	CrF_3
lead(IV) sulphide	PbS_2
copper(I) phosphide	Cu_3P

Writing the Formula

Table 3.7 shows how to write the formula when you are given the name of a compound containing a multivalent metal.

Table 3.7 Rules for Writing Formulas of Compounds Containing a Multivalent Metal

Steps for Writing the Formula	Examples	
	iron(III) sulphide	**lead(IV) oxide**
1. Identify each ion and its charge.	iron(III): Fe^{3+} sulphide: S^{2-}	lead(IV): Pb^{4+} oxide: O^{2-}
2. Determine the total charges needed to balance positive with negative.	Fe^{3+}: $+3$ $+3$ $= +6$ S^{2-} : -2 -2 $-2 = -6$	Pb^{4+}: $= +4$ O^{2-}: -2 -2 $= -4$
3. Note the ratio of positive ions to negative ions.	2 Fe^{3+} ions for every 3 S^{2-} ions	1 Pb^{4+} ion for every 2 O^{2-} ions
4. Use subscripts to write the formula. A "1" is not shown in the subscripts.	Fe_2S_3	PbO_2

Practice Problems

1. Write the formulas of the following compounds.

(a) chromium(II) chloride
(b) chromium(III) chloride
(c) copper(I) sulphide
(d) copper(I) iodide
(e) iron(II) phosphide
(f) iron(III) phosphide
(g) manganese(II) oxide
(h) manganese(IV) oxide
(i) mercury(II) bromide
(j) tin(II) sulphide
(k) tin(II) nitride
(l) tin(IV) nitride
(m) copper(I) nitride
(n) lead(IV) chloride

Answers provided on page 509

Writing the Name

When you are writing the name of an ionic compound containing a multivalent metal, do you need a Roman numeral to indicate the ion charge. Table 3.8 shows how to determine the correct Roman numeral.

Table 3.8 Naming Ionic Compounds Containing a Multivalent Metal

Steps for Writing the Name	Examples	
	Cu_3P	MnO_2
1. Identify the metal.	copper (Cu)	manganese (Mn)
2. Verify that it can form more than one kind of ion by checking the periodic table.	Cu^{2+} and Cu^{+}	Mn^{2+}, Mn^{3+}, and Mn^{4+}
3. Determine the ratio of the ions in the formula.	Cu_3P means 3 copper ions for every 1 phosphide ion.	MnO_2 means 1 manganese ion for every 2 oxide ions.
4. Note the charge of the negative ion from the periodic table.	The charge on the phosphide P^{3-} is $3-$.	The charge on the oxide O^{2-} is $2-$.
5. The positive and negative charges must balance out. Determine what the charge needs to be on the metal ion to balance the negative ion.	Each of the 3 copper ions must have a charge of $1+$ to balance the 1 phosphide ion with a charge of $3-$. Therefore the name of the copper ion is copper(I).	The 1 manganese ion must have a charge of $4+$ to balance the 2 oxide ions that each have a charge of $2-$. Therefore, the name of the manganese ion is manganese(IV).
6. Write the name of the compound.	copper(I) phosphide	manganese(IV) oxide

Practice Problems

1. Each of these compounds contains a multivalent metal ion. That means that the name of the metal ion will contain a Roman numeral, which you will need to determine. Write the names of the following compounds.

(a) $CrBr_2$
(b) $CrBr_3$
(c) FeI_2
(d) FeI_3
(e) PbF_2
(f) PbF_4
(g) MnO
(h) PbS
(i) Fe_2O_3
(j) Hg_3P_2
(k) Hg_3N_2
(l) HgI_2
(m) MnS
(n) MnS_2
(o) Sn_3P_4

Answers provided on page 509.

Polyatomic Ions

You learned in section 3.1 that some molecules gain or lose one or more electrons and become polyatomic ions. Because a polyatomic ion carries an electric charge, it cannot exist on its own. It is always paired up with ions that carry an opposite charge. Table 3.9 shows you how to write the formulas for compounds with polyatomic ions.

Table 3.9 Steps for Writing the Formula of a Compound with Polyatomic Ions

Steps for Writing the Formula	Examples	
	iron(III) hydroxide	ammonium carbonate
1. Identify each ion and its charge.	iron(III): Fe^{3+} hydroxide: OH^-	ammonium: NH_4^+ carbonate: CO_3^{2-}
2. Determine the total charges needed to balance positive with negative.	Fe^{3+}: $= 3+$ OH^{-1}: $-1\ -1\ -1 = 3-$	NH_4^+: $+1\ +1 = 2+$ CO_3^{2-}: $= 2-$
3. Note the ratio of positive ions to negative ions.	1 Fe^{3+} ion for every 3 OH^- ions	2 NH_4^+ ions for every 1 CO_3^{2-} ion
4. Use subscripts and brackets to write the formula. Omit brackets if only one ion is needed.	$Fe(OH)_3$	$(NH_4)_2CO_3$

Practice Problems

Refer to Table 3.10 on page 92 as you do these problems.

1. Write the names of the following compounds.

(a) $NaCH_3COO$

(b) $Ca(CH_3COO)_2$

(c) $Cr(CH_3COO)_3$

(d) $Al(OH)_3$

(e) $Cr(OH)_3$

(f) $(NH_4)_3P$

(g) $(NH_4)_3PO_4$

(h) $CaSO_4$

(i) $Mg_3(PO_4)_2$

(j) $Ba_3(PO_3)_2$

2. Write the formulas of the following compounds.

(a) sodium chromate

(b) potassium permanganate

(c) lithium dichromate

(d) sodium hydroxide

(e) magnesium hydroxide

(f) ammonium nitrate

(g) tin(II) hydroxide

(h) lead(II) hydroxide

(i) aluminum nitrate

(j) manganese(IV) sulphate

Answers provided on page 509

Did You Know?

All medicines come with a list of ingredients like the one shown below. The list includes the chemical name of the medicine. The chemical name allows you to compare products that have different brand names but contain the same active (medicinal) ingredient. Non-medicinal ingredients may improve the taste, act as filler to make the dose large enough to handle, or increase shelf life.

Common Polyatomic Ions

There are many polyatomic ions. Table 3.10 lists some common ones. The names of these ions were assigned by the IUPAC. You do not have to memorize them. Simply refer to this table to find a name and formula.

Table 3.10 Common Polyatomic Ions

Name	Formula
acetate	CH_3COO^-
ammonium	NH_4^+
carbonate	CO_3^{2-}
chlorate	ClO_3^-
chlorite	ClO_2^-
chromate	CrO_4^{2-}
cyanide	CN^-
dichromate	$Cr_2O_7^{2-}$
hydrogen carbonate	HCO_3^-
hydrogen sulphate	HSO_4^-
hydrogen sulphide	HS^-
hydrogen sulphite	HSO_3^-
hydroxide	OH^-
hypochlorite	ClO^-
nitrate	NO_3^-
nitrite	NO_2^-
perchlorate	ClO_4^-
permanganate	MnO_4^-
phosphate	PO_4^{3-}
phosphite	PO_3^{3-}
sulphate	SO_4^{2-}
sulphite	SO_3^{2-}

Explore More

Ammonium (NH_4^+) and nitrate (NO_3^-) are present in fertilizers. They are both produced from ammonia (NH_3), which you may be familiar with as window cleaner. Find out about the Haber process for the production of ammonia. Begin your research at **www.bcscience9.ca**.

Reading Check

1. In Table 3.10, find the following:
   (a) the formula of an ion with a positive charge
   (b) the formulas of all four ions made of only two atoms
   (c) the name of the ion that contains nine atoms
   (d) the formula of the ion containing three elements and six atoms
   (e) the formula of the ion containing three elements and having a charge of 2−
   (f) the names and formulas of two ions containing nitrogen and oxygen
   (g) the charge on the ion containing four hydrogen atoms
2. Find all four ions in Table 3.10 that contain a chlorine atom, and write their formulas in descending order according to the number of oxygen atoms in each one.

3-2B Modelling an Ionic Compound

Think About It

In this activity, your teacher will guide you as you use different shapes to represent positive and negative ions. These shapes combine in a way that closely matches the way real ions combine. The patterns you discover here can help you write the names and formulas of ionic compounds.

Materials

- set of shapes in one colour representing various kinds of positive ions
- set of shapes in a different colour representing various kinds of negative ions
- scissors

What to Do

1. Work in pairs.
2. Your teacher will give you photocopies of sheets of shapes that you will cut out. You need to know the following points about each shape:
   - Each shape represents a single ion.
   - Positive ions look like a rectangle with a piece cut out. The cut-out part is called a hole.
   - Negative ions also look like a rectangle, but with an extra piece attached. The extra piece is called a peg.
3. An ionic compound has an orderly arrangement of alternating positive and negative ions. You will make models of several ionic compounds. For each compound, you will need one kind of positive ion and one kind of negative ion. You need to know the following points about each arrangement of your shapes.
   - Every hole must be filled with a peg, and every peg must be in a hole. Keep adding ions until this happens.
   - The positive and negative ions must alternate as much as possible throughout the compound.
4. In the beginning, your teacher will tell you which ions to use for each compound. For each compound, build the model, name the compound, and then write its formula using the following rules.

The Name

- Write the name of the positive ion, leave a blank space equal to one letter, and write the name of the negative ion.

The Formula

- Count the numbers of positive ions and negative ions in your model. Then find the smallest ratio of these two numbers (use whole numbers). For example, if your model has two positive ions and one negative ion, the ratio is 2:1. If it has six positive ions and nine negative ions, the ratio is 2:3.
- Write the symbol of the positive ion (without its charge) followed by the first number from the ratio as a subscript. Beside this, write the symbol for the negative ion (without its charge) followed by the second number in the ratio as a subscript. For example, if Al^{3+} is the symbol for the positive ion and S^{2-} is the symbol for the negative ion, the formula for this compound would be Al_2S_3.

What Did You Find Out?

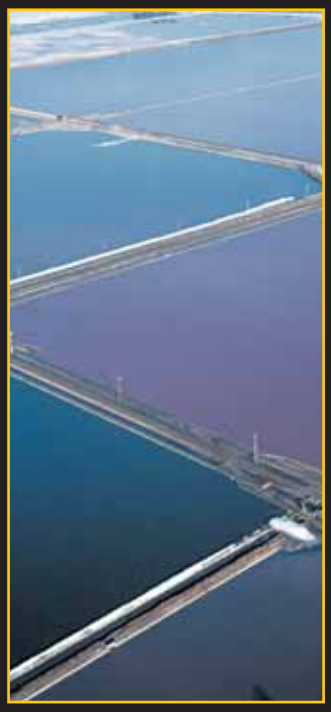
1. In what order are the ions named in an ionic compound: negative ion followed by positive ion or positive ion followed by negative ion?
2. Three possible formulas for silver sulphide are Ag_6S_3, Ag_2S, and $Ag_{12}S_6$. Only one of these formulas is correct.
   (a) Which one is correct?
   (b) Why?
3. Cadmium bromide is a poisonous compound used to engrave metal. Its formula is $CdBr_2$. How can the formula be used to find the charge on a cadmium ion if you already know that the bromide ion is Br^-?

NATIONAL GEOGRAPHIC

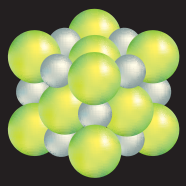
VISUALIZING SALT

The salt you use every day comes from both the land and the sea. Some salt can be mined from the ground in much the same way as coal, or salt can be obtained by the process of evaporation in crystallizing ponds.

▲ MINING SALT Underground salt deposits are found where there was once a sea. Salt mines can be located deep underground or near Earth's surface in salt domes. Salt domes form when pressure from Earth pushes buried salt deposits close to the surface, where they are easily mined.



◀ EVAPORATION PROCESS Workers fill evaporation ponds with salt water, or brine. They move the brine from pond to pond as it becomes saltier through evaporation. (Red-tinted ponds have a higher salt content.) The saltiest water is then pumped from evaporation ponds into crystallizing ponds, where the remaining water is drained off. In the five years it takes to produce a crop of salt, brine may move through as many as 23 different ponds.



Unit cell of sodium chloride (NaCl)

◀ TABLE SALT Raw sodium chloride is washed in chemicals and water to remove impurities before it appears on your dining-room table as salt. Iodine is added to table salt to ensure against iodine deficiency in the diet.

▼ SALT MOUNDS When the crystallizing ponds are drained, the result is huge piles of salt, like these on the Caribbean island of Bonaire.

Check Your Understanding

Checking Concepts

1. (a) How many parts are there in the name of an ionic compound?
   (b) What does each part describe?
2. Name each of the ions in the list below and indicate which of the following words describe it: positive ion, negative ion, multivalent metal, polyatomic ion.
   (a) Li^+
   (b) NO_3^-
   (c) Fe^{3+}
   (d) CH_3COO^-
   (e) Cr^{2+}
   (f) Cl^-
   (g) ClO_4^-
   (h) NH_4^+

3. For each polyatomic ion, list the name, the number of each kind of atom, the total number of atoms, and the electric charge on the ion.
   (a) CrO_4^{2-}
   (b) $Cr_2O_7^{2-}$
   (c) NH_4^+
   (d) CH_3COO^-
   (e) HSO_4^-
   (f) SO_4^{2-}
   (g) SO_3^{2-}
   (h) S^{2-}

Understanding Key Ideas

4. Write the name or formula of the following compounds.
   (a) sodium chloride
   (b) magnesium fluoride
   (c) aluminum bromide
   (d) potassium iodide
   (e) lithium sulphide
   (f) aluminum oxide
   (g) LiBr
   (h) NaI
   (i) K_2S
   (j) MgF_2
   (k) Al_2O_3
   (l) Ca_3N_2

5. Write the name or formula of the following compounds.
   (a) iron(III) bromide
   (b) iron(II) bromide
   (c) nickel(II) fluoride
   (d) nickel(II) sulphide
   (e) tin(IV) nitride
   (f) manganese(II) phosphide
   (g) CrF_2
   (h) CuI
   (i) MnS
   (j) PbO_2
   (k) SnS_2
   (l) Cr_3N_2

6. Write the name or formula of the following compounds.
   (a) $Mg(OH)_2$
   (b) K_2SO_4
   (c) $Al(HCO_3)_3$
   (d) Cu_2CO_3
   (e) $Fe(MnO_4)_2$
   (f) $(NH_4)_2SO_4$
   (g) sodium sulphate
   (h) calcium phosphate
   (i) aluminum nitrate
   (j) ammonium hydrogen sulphate
   (k) lead(IV) chlorate
   (l) iron(III) carbonate

Pause and Reflect

All ionic compounds have a chemical name and a chemical formula in accordance with rules of the IUPAC. It may be tempting to think that the formula is simply a shorter way of writing the chemical name. However, the two do not give exactly the same information about a compound. What information does the formula give about a compound that is not present in the name?