

## 5.6: Ions With Variable Charges

### Learning Objectives

- Write the correct names and formulas for binary ionic compounds that have ions with variable charges.

Up until now, it has been assumed that elements form ions with fixed charges. However, many metals form ions that have variable charges. In fact, the large majority of transition metals form ions with variable charges. There is also a small block of main group metals that form ions with variable charges as well (see [Figure 5.6.1](#) below). As we will find out, there is no need to memorize the charges of metals that form ions with variable charges, as the charges may be identified by using Roman numerals. When writing the formula of the ion, the name of the metal is immediately followed by parentheses (no space) within which is a Roman numeral equal to the magnitude of charge on the ion.

For example,

- the iron(II) ion has a formula of  $\text{Fe}^{2+}$ .
- the iron(III) ion has a formula of  $\text{Fe}^{3+}$ .

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H 1.008																	2 He 4.003
2	3 Li 6.939	4 Be 9.012	transition metals that form ions with variable charges										5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31	main group elements that form ions with variable charges										13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (99)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)

Figure 5.6.1: The periodic table showing elements that form ions with variable charges.

### Exercise 5.6.1

If the formula of an ion is provided, write the name. If the name of an ion is provided, write the formula.

- $\text{Mn}^{3+}$
- copper(I)
- lead(IV)
- $\text{Cu}^{2+}$

#### Answer A

manganese(III)

#### Answer B

$\text{Cu}^+$

#### Answer C

$\text{Pb}^{4+}$

#### Answer D

copper(II)

When writing names for compounds containing metals that form ions with variable charges, the name *must include* the Roman numeral that shows the charge on the metal ion. Roman numerals are *not* included when the metal only forms ions with fixed charges. Chemical formulas themselves will never include Roman numerals as the charge on the metal ions present may be determined from the subscripts in the chemical formula.

### ✓ Example 5.6.1: Writing Chemical Formulas

Write the chemical formula for each compound.

A. iron(II) oxide

B. iron(III) oxide

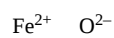
**Solution**

iron(II) oxide

iron(III) oxide

**iron(II) oxide**
**iron(III) oxide**

1. Write the chemical formula for each compound.



	iron(II) oxide	iron(III) oxide
2. Balance the charges.	$\text{Fe}^{2+} \quad \text{O}^{2-}$	$\begin{array}{c} \text{Fe}^{3+} \quad \text{O}^{2-} \\ \text{Fe}^{3+} \quad \text{O}^{2-} \\ \text{Fe}^{3+} \quad \text{O}^{2-} \end{array}$
3. Explain that ion.	2+ balances 2-	6+ balances 6-
4. Write	FeO	Fe <sub>2</sub> O <sub>3</sub>

iron(II) oxide

iron(III) oxide

e  
t  
h  
e  
f  
i  
n  
a  
l  
f  
o  
r  
m  
u  
l  
a  
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C  
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i  
p  
t  
s  
o  
f  
l  
a  
r  
e  
i  
m  
p  
l  
i  
e

iron(II) oxide

d

.

iron(III) oxide

### ✓ Example 5.6.2: Writing Chemical Names

Give the correct name for each compound.

- A. CuO  
B. Cu<sub>2</sub>O

#### Solution

	CuO	Cu <sub>2</sub> O
1. Write the name leaving room for a Roman numeral, since copper forms ions with variable charges.	copper( ) oxide	copper( ) oxide
2. Based on position on the periodic table, the oxide ion has a charge of 2 <sup>-</sup> . Note that CuO has only one copper ion, while Cu <sub>2</sub> O has two copper ions. Both have only one oxide ion.	Cu <sup>2+</sup> O <sup>2-</sup>	Cu <sup>2+</sup> Cu <sup>2+</sup> O <sup>2-</sup>
3. Determine the charge of the copper ion (Cu <sup>?</sup> ).	Cu <sup>2+</sup> must have a charge of 2+ (Cu <sup>2+</sup> ) to balance oxide's charge of 2- (O <sup>2-</sup> ).	Each Cu <sup>2+</sup> must have a charge of 1+ (Cu <sup>+</sup> ) to balance oxide's charge of 2- (O <sup>2-</sup> ).
4. The charge on the copper ion determines the Roman numeral that belongs inside the parentheses.	Cu <sup>2+</sup> means copper(II), so the name is: copper(II) oxide	Cu <sup>+</sup> means copper(I), so the name is: copper(I) oxide

### Exercise 5.6.2

If a formula is provided, write the name of the compound. If a name is provided, write the formula of the compound.

- A. titanium(IV) sulfide  
B. Co<sub>2</sub>O<sub>3</sub>  
C. PbCl<sub>2</sub>

#### Answer A

TiS<sub>2</sub>

#### Answer B

cobalt(III) oxide

#### Answer C

lead(II) chloride

## Stock System vs. Common Names

The approach for naming the ions for metals that have variable charges is called the **Stock system**, in which an ion's positive charge is indicated by a Roman numeral in parentheses after the element name. The  $\text{Na}^+$  ion is not called the sodium(I) ion because (I) is unnecessary. Sodium forms only a  $1+$  ion, so there is no ambiguity about the name *sodium ion*.

A 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 root name of the element. The *-ic* suffix represents the cation with the larger of the two charges, and the *-ous* suffix represents the cation with the smaller of the two charges. In many cases, the stem of the element name comes from the Latin name of the element. [Table 5.6.1](#) lists the elements that use the common system, along with their respective cation names. *This text uses the Stock system of nomenclature.*

Table 5.6.1: The Modern and Common System of Cation Names

Element	Root Name	Charge	Modern Name	Common Name
iron	ferr-	2+	iron(II) ion	ferrous ion
		3+	iron(III) ion	ferric ion
copper	cupr-	1+	copper(I) ion	cuprous ion
		2+	copper(II) ion	cupric ion
tin	stann-	2+	tin(II) ion	stannous ion
		4+	tin(IV) ion	stannic ion
lead	plumb-	2+	lead(II) ion	plumbous ion
		4+	lead(IV) ion	plumbic ion

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