Chapter 6
Ionic Compounds

Have your i-clickers ready
Silence cell phones and pagers.
Octet Rule

An octet
- Contains 8 valence electrons.
- Is associated with the stability of the noble gases.
- Exception is He that is stable with 2 valence electrons (duet).

<table>
<thead>
<tr>
<th>Element</th>
<th>Valence Electrons</th>
<th>Octet Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ne</td>
<td>2, 8</td>
<td>8</td>
</tr>
<tr>
<td>Ar</td>
<td>2, 8, 8</td>
<td>8</td>
</tr>
<tr>
<td>Kr</td>
<td>2, 8, 18, 8</td>
<td>8</td>
</tr>
</tbody>
</table>
Review: Valence Electrons

The valence electrons

• Are the electrons in the s and p sublevels in the highest energy level.
• Are related to the Group number of the element.
• Determine the chemical properties of the elements.
• Elements with similar properties have the same number of valence electrons!
Forming Octets

Atoms acquire octets

• By losing, gaining, or sharing valence electrons.

• To form compounds.

• To become more stable.
Atomic Size

Atomic radius

• Is the distance from the nucleus to the valence electrons.
Sizes of Metal Atoms and Ions

A positive ion

• Has lost its valence electrons.
• Is smaller (about half the size) than its corresponding metal atom.
Size of Sodium Ion

The sodium ion Na⁺

- Forms when the Na atom loses one electron from the 3rd energy level, its valence electron.
- Is smaller than a Na atom.
Sizes of Nonmetal Atoms and Ions

A negative ion

- Has a complete octet.
- Increases the number of valence electrons.
- Is larger (about twice the size) than its corresponding metal atom.
Size of Fluoride Ion

The fluoride ion $\text{F}^-$
- Forms when a valence electron is added.
- Has increased repulsions due to the added valence electron.
- Is larger than $\text{F}$ atom
Ionic and Covalent Bonds

Ionic bonds involve
• Loss of electrons by a metal.
• Gain of electrons by a nonmetal.

Covalent bonds involve
• A sharing of electrons.
Metals Form Positive Ions

Metals form

- Octets by *losing* all of their valence electrons.
- Positive ions with the electron configuration of the nearest noble gas.
- *Positive ions* with fewer electrons than protons.

Group 1A(1) metals \[\rightarrow\] ion $^{\text{1}+}$
Group 2A(2) metals \[\rightarrow\] ion $^{\text{2}+}$
Group 3A(13) metals \[\rightarrow\] ion $^{\text{3}+}$
Formation of a Sodium Ion, Na⁺

Sodium achieves an octet by losing its one valence electron.
Charge of Sodium Ion, Na$^+$

With the loss of its valence electron, the sodium ion has a 1+ charge.

<table>
<thead>
<tr>
<th>Sodium atom</th>
<th>Sodium ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>11p$^+$</td>
<td>11p$^+$</td>
</tr>
<tr>
<td>11e$^-$</td>
<td>10e$^-$</td>
</tr>
<tr>
<td>0</td>
<td>1+</td>
</tr>
</tbody>
</table>
Formation of $\text{Mg}^{2+}$

- Magnesium achieves an octet by losing its two valence electrons.
Charge of Magnesium Ion \( \text{Mg}^{2+} \)

With the loss of two valence electrons, magnesium forms a positive ion with a 2+ charge.

\[
\begin{array}{ll}
\text{Mg atom} & \text{Mg}^{2+} \text{ ion} \\
12p^+ & 12p^+ \\
12e^- & 10e^- \\
0 & 2+
\end{array}
\]

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Formation of Negative Ions

In ionic compounds, nonmetals
- Achieve an octet arrangement.
- Gain electrons.
- Form negatively charged ions with 3-, 2-, or 1- charges.
Formation of Chloride Ion, Cl⁻

- Chlorine achieves an octet by adding an electron to its valence electrons.
Charge of a Chloride Ion, Cl⁻

A chlorine ion forms
- When Cl gains one electron
- With a 1- charge.

Chlorine atom       Chloride ion
17p⁺ 17p⁺
17e⁻ 18e⁻
0  1⁻
### Some Ionic Charges

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Number of Valence Electrons</th>
<th>Electron Change to Give an Octet</th>
<th>Ionic Charge</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A (1)</td>
<td>1</td>
<td>Lose 1</td>
<td>1+</td>
<td>Li⁺, Na⁺, K⁺</td>
</tr>
<tr>
<td>2A (2)</td>
<td>2</td>
<td>Lose 2</td>
<td>2+</td>
<td>Mg²⁺, Ca²⁺</td>
</tr>
<tr>
<td>3A (13)</td>
<td>3</td>
<td>Lose 3</td>
<td>3+</td>
<td>Al³⁺</td>
</tr>
<tr>
<td><strong>Nonmetals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A (15)</td>
<td>5</td>
<td>Gain 3</td>
<td>3−</td>
<td>N³⁻, P³⁻</td>
</tr>
<tr>
<td>6A (16)</td>
<td>6</td>
<td>Gain 2</td>
<td>2−</td>
<td>O²⁻, S²⁻</td>
</tr>
<tr>
<td>7A (17) I⁻</td>
<td>7</td>
<td>Gain 1</td>
<td>1−</td>
<td>F⁻, Cl⁻, Br⁻,</td>
</tr>
</tbody>
</table>
Ionic Charge from Group Numbers

• The charge of a positive ion is equal to its Group number.
  
  Group 1A(1) = 1+
  Group 2A(2) = 2+
  Group 3A(13) = 3+

• The charge of a negative ion is obtained by subtracting 8 or 18 from its Group number.
  
  Group 6A(16) = 6 - 8 = 2-
  or 16 - 18 = 2-
Upon loss or gain of electrons, the electronic arrangement of the ion is “**isoelectronic**” with its nearest noble gas.
Octet Rule - What is special about “8”? 

An octet

• Is 8 valence electrons
• Is associated with the stability of the noble gases
• He is stable with two valence electrons (duet).

<table>
<thead>
<tr>
<th>Element</th>
<th>Valence Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>1s²</td>
</tr>
<tr>
<td>Ne</td>
<td>1s² 2s² 2p⁶</td>
</tr>
<tr>
<td>Ar</td>
<td>1s² 2s² 2p⁶ 3s² 3p⁶</td>
</tr>
<tr>
<td>Kr</td>
<td>1s² 2s² 2p⁶ 3s² 3p⁶ 4s² 3d¹⁰ 4p⁶</td>
</tr>
</tbody>
</table>
Quiz Questions 1-4

[30 seconds for each question]
Select the correct answer for aluminum 3A(13):

1. Number of valence electrons (1 pt)
   A) 1e-  B) 2e-  C) 3e-

2. Electron change for octet (1 pt)
   A) loss of 3e-  B) gain of 3e-  C) gain of 5e-

3. Ionic charge of aluminum ion (1 pt)
   A) 3-  B) 13-  C) 3+ 

4. The symbol for the aluminum ion (2 pt)
   1) Al^{3+}  2) Al^{3-}  C) Al^+ 

   A  B  C
Quiz Questions 5 - 8
[30 seconds for each question]

Select the correct answer for sulfur 6A(17):

5. Number of valence electrons (1 pt)
   A) 4e-      B) 6e-      C) 8e-

6. Change in electrons for octet (1 pt)
   A) loss of 2e-   B) gain of 2e-   C) gain of 8e-

7. Ionic charge of sulfide ion (1 pt)
   A) 2+      B) 2-      C) 4-

8. The symbol for the sulfide ion (2 pt)
   A) S\(^{1-}\)  B) S\(^{1+}\)  C) S\(^{2-}\)
• Compounds - Compounds result from the formation of chemical bonds between two or more different elements.
Chemical bond: attractive force holding two or more atoms together.
**Ionic Bonds** - electron transfer process. Typically between a metal and a nonmetals

**Covalent Bonds** - electrons shared. Typically involving nonmetals.
Ionic Compounds

Ionic compounds
• Consist of positive and negative ions.
• Have *ionic bonds* between positively and negatively charged ions.
• Have high melting and boiling points.
• Are solid at room temperature.
Salt is An Ionic Compound

Sodium chloride (table salt) is an example of an ionic compound.
An ionic formula

- Consists of positively and negatively charged ions.
- Is neutral.
- Has charge balance.
  \[
  \text{total positive charge} = \text{total negative charge}
  \]
- Uses subscripts to indicate the number of ions needed to give charge balance.
Ionic Formula of NaCl

In an ionic formula

- The symbol of the metal is written first followed by the symbol of the nonmetal.
- The charges of the ions in the compound are not shown.
Charge Balance in NaF

- The formulas of ionic compounds are determined from the charges on the ions.

\[ \text{atoms} \quad \rightarrow \quad \text{ions} \]

\[ \text{sodium} \quad + \quad \text{fluorine} \quad \rightarrow \quad \text{sodium fluoride} \]

\[ \text{Na}^+ \quad \text{F}^- \quad = \quad \text{NaF} \]

\[ (1+) \quad + \quad (1-) \quad = \quad 0 \]

The overall charge of NaF is zero (0).
Charge Balance In MgCl$_2$

In forming MgCl$_2$

- A Mg atom loses two valence electrons.
- Two Cl atoms each gain one electron.

Loses $2e^-$ Each gains $1e^-$

One magnesium ion \( \text{Mg}^{2+} \)  
Two chloride ions \( 2\text{Cl}^- \)

\[
(2^+) + 2(1^-) = 0
\]

\( \text{MgCl}_2, \text{magnesium chloride} \)
Using Lewis Electron Dot Symbols

\[ \text{Ca} + \text{Br} \rightarrow \text{CaBr}_2 \]
Using Lewis Electron Dot Symbols

\[ \text{Al} + \text{N} \rightarrow \text{Al}^3+ + \text{N}^3- \]
Writing Ionic Formulas from Charges

Charge balance is used to write the formula for sodium nitride, a compound containing Na$^+$ and N$^{3-}$.

\[
\begin{align*}
3 & \quad \text{Na}^+ \\
& + \quad \text{N}^{3-} \\
\hline
& = \quad \text{Na}_3\text{N}
\end{align*}
\]

\[
3(+1) \quad + \quad 1(3-) \quad = \quad 0
\]

Note: the subscript 3 for three sodium ions.
Formula from Ionic Charges

Write the ionic formula of the compound with Ba\(^{2+}\) and Cl\(^{-}\).

- Write the symbols of the ions.
  \[
  \text{Ba}^{2+} \quad \text{Cl}^{-}
  \]

- Balance the charges.
  \[
  \text{Ba}^{2+} \quad \text{Cl}^{-} \quad \text{two Cl}^{-} \text{ needed}
  \]

- Write the ionic formula using a *subscript 2* for two chloride ions.
  \[
  \text{BaCl}_2
  \]
Learning Check

Write the correct formula for the ionic compounds formed by the following ions:

1. Na\(^+\) and S\(^2-\)
   - A) NaS
   - B) Na\(_2\)S
   - C) NaS\(_2\)

2. Al\(^{3+}\) and Cl\(^-\)
   - A) AlCl\(_3\)
   - B) AlCl
   - C) Al\(_3\)Cl

3. Mg\(^{2+}\) and N\(^3-\)
   - A) MgN
   - B) Mg\(_2\)N\(_3\)
   - C) Mg\(_3\)N\(_2\)
Naming and Writing Ionic Formulas
Naming of Ionic Compounds

In the name of an ionic compound

• The positive ion (first ion) is named as the element.

• The negative ion (second ion) is named by changing the end of the element name to –ide.
# Names of Some Common Ions

## Table 6.3  Formulas and Names of Some Common Ions

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Formula of Ion</th>
<th>Name of Ion</th>
<th>Group Number</th>
<th>Formula of Ion</th>
<th>Name of Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td></td>
<td></td>
<td>Nonmetals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A (1)</td>
<td>Li$^+$</td>
<td>Lithium</td>
<td>5A (15)</td>
<td>N$^{3-}$</td>
<td>Nitride</td>
</tr>
<tr>
<td></td>
<td>Na$^+$</td>
<td>Sodium</td>
<td></td>
<td>P$^{3-}$</td>
<td>Phosphide</td>
</tr>
<tr>
<td></td>
<td>K$^+$</td>
<td>Potassium</td>
<td>6A (16)</td>
<td>O$^{2-}$</td>
<td>Oxide</td>
</tr>
<tr>
<td>2A (2)</td>
<td>Mg$^{2+}$</td>
<td>Magnesium</td>
<td>7A (17)</td>
<td>F$^-$</td>
<td>Fluoride</td>
</tr>
<tr>
<td></td>
<td>Ca$^{2+}$</td>
<td>Calcium</td>
<td></td>
<td>Cl$^-$</td>
<td>Chloride</td>
</tr>
<tr>
<td></td>
<td>Ba$^{2+}$</td>
<td>Barium</td>
<td></td>
<td>Br$^-$</td>
<td>Bromide</td>
</tr>
<tr>
<td>3A (13)</td>
<td>Al$^{3+}$</td>
<td>Aluminum</td>
<td></td>
<td>I$^-$</td>
<td>Iodide</td>
</tr>
</tbody>
</table>
## Learning Check

Complete the names of the following ions:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Ba}^{2+})</td>
<td>barium</td>
</tr>
<tr>
<td>(\text{Al}^{3+})</td>
<td>aluminum</td>
</tr>
<tr>
<td>(\text{K}^+)</td>
<td>potassium</td>
</tr>
<tr>
<td>(\text{N}^{3-})</td>
<td>nitride</td>
</tr>
<tr>
<td>(\text{O}^{2-})</td>
<td>oxide</td>
</tr>
<tr>
<td>(\text{F}^-)</td>
<td>fluoride</td>
</tr>
<tr>
<td>(\text{P}^{3-})</td>
<td>phosphide</td>
</tr>
<tr>
<td>(\text{S}^{2-})</td>
<td>sulfide</td>
</tr>
<tr>
<td>(\text{Cl}^-)</td>
<td>chloride</td>
</tr>
</tbody>
</table>
Naming Ionic Compounds with Two Elements

To name a compound that contains two elements:

- Identify the cation and anion.
- Name the positive metal ion (cation) as the element.
- Name the anion by changing the ending to *ide*.
- Name the cation first followed by the name of the anion.
Charges of Representative Elements
Guide to Naming

Guide to Naming Ionic Compounds with Metals That Form a Single Ion

STEP 1
Identify the cation and anion.

STEP 2
Name the cation by its element name.

STEP 3
Name the anion by changing the last part of its element name to ide.

STEP 4
Write the name of the cation first and the name of the anion second.

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## Some Ionic Compounds with Two Elements

<table>
<thead>
<tr>
<th>Formula</th>
<th>Ions</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>Na$^+$ Cl$^-$</td>
<td>sodium chloride</td>
</tr>
<tr>
<td>K$_2$S</td>
<td>K$^+$ S$^{2-}$</td>
<td>potassium sulfide</td>
</tr>
<tr>
<td>MgO</td>
<td>Mg$^{2+}$ O$^{2-}$</td>
<td>magnesium oxide</td>
</tr>
<tr>
<td>CaI$_2$</td>
<td>Ca$^{2+}$ I$^-$</td>
<td>calcium iodide</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>Al$^{3+}$ O$^{2-}$</td>
<td>aluminum oxide</td>
</tr>
</tbody>
</table>
More Ionic Compounds

<table>
<thead>
<tr>
<th>Compound</th>
<th>Metal Ion</th>
<th>Nonmetal Ion</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaF</td>
<td>Na⁺</td>
<td>F⁻</td>
<td>sodium fluoride</td>
</tr>
<tr>
<td>MgBr₂</td>
<td>Mg²⁺</td>
<td>Br⁻</td>
<td>magnesium bromide</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>Al³⁺</td>
<td>O²⁻</td>
<td>aluminum oxide</td>
</tr>
</tbody>
</table>

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Homework Assignment:

Name:________________________

Write the formulas and names for compounds of the following ions:

<table>
<thead>
<tr>
<th></th>
<th>N(^3\text{-})</th>
<th>Br(^-)</th>
<th>S(^2\text{-})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(^+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al(^3+)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Homework Assignment:

Name:__________________________________________

Write the names of the following compounds:

1) CaO __________________
2) KBr __________________
3) Al₂O₃ __________________
4) MgCl₂ __________________
Most Transition Metals form Two or More Positive Ions

Most of the transition metals

• Form 2 or more positive ions.

For example,

• Copper forms Cu$^+$ and Cu$^{2+}$
• Iron forms Fe$^{2+}$ and Fe$^{3+}$
• Gold form Au$^+$ and Au$^{3+}$
# Metals that form more than One Cation

## Table 6.4  Some Metals That Form More Than One Positive Ion

<table>
<thead>
<tr>
<th>Element</th>
<th>Possible Ions</th>
<th>Name of Ion</th>
<th>Element</th>
<th>Possible Ions</th>
<th>Name of Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>Cr$^{2+}$</td>
<td>chromium(II)</td>
<td>Manganese</td>
<td>Mn$^{2+}$</td>
<td>manganese(II)</td>
</tr>
<tr>
<td></td>
<td>Cr$^{3+}$</td>
<td>chromium(III)</td>
<td></td>
<td>Mn$^{3+}$</td>
<td>manganese(III)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co$^{2+}$</td>
<td>cobalt(II)</td>
<td>Mercury</td>
<td>Hg$_2$$^{2+}$</td>
<td>mercury(I)*</td>
</tr>
<tr>
<td></td>
<td>Co$^{3+}$</td>
<td>cobalt(III)</td>
<td></td>
<td>Hg$^{2+}$</td>
<td>mercury(II)</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu$^+$</td>
<td>copper(I)</td>
<td>Nickel</td>
<td>Ni$^{2+}$</td>
<td>nickel(II)</td>
</tr>
<tr>
<td></td>
<td>Cu$^{2+}$</td>
<td>copper(II)</td>
<td></td>
<td>Ni$^{3+}$</td>
<td>nickel(III)</td>
</tr>
<tr>
<td>Gold</td>
<td>Au$^+$</td>
<td>gold(I)</td>
<td>Tin</td>
<td>Sn$^{2+}$</td>
<td>tin(II)</td>
</tr>
<tr>
<td></td>
<td>Au$^{3+}$</td>
<td>gold(III)</td>
<td></td>
<td>Sn$^{4+}$</td>
<td>tin(IV)</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe$^{2+}$</td>
<td>iron(II)</td>
<td>Lead</td>
<td>Pb$^{2+}$</td>
<td>lead(II)</td>
</tr>
<tr>
<td></td>
<td>Fe$^{3+}$</td>
<td>iron(III)</td>
<td></td>
<td>Pb$^{4+}$</td>
<td>lead(IV)</td>
</tr>
</tbody>
</table>
Periodic Table and Some Ions

![Periodic Table Image](image-url)
Naming with Variable Charge Metals

Guide to Naming Ionic Compounds with Variable Charge Metals

STEP 1
Determine the charge of the cation from the anion.

STEP 2
Name the cation by its element name and a Roman numeral in parentheses for the charge.

STEP 3
Name the anion by changing the last part of its element name to ide.

STEP 4
Write the name of the cation first and the name of the anion second.
Naming Variable Charge Metals

Transition metals

- With two different ions use a **Roman numeral** after the name of the metal to indicate ionic charge.
- Only zinc, silver, and cadmium form one ion (Zn$^{2+}$, Ag$^+$, and Cd$^{2+}$)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeCl$_2$</td>
<td>iron(II) chloride</td>
</tr>
<tr>
<td>FeCl$_3$</td>
<td>iron(III) chloride</td>
</tr>
<tr>
<td>Cu$_2$S</td>
<td>copper(I) sulfide</td>
</tr>
<tr>
<td>CuCl$_2$</td>
<td>copper(II) chloride</td>
</tr>
<tr>
<td>SnCl$_2$</td>
<td>tin(II) chloride</td>
</tr>
<tr>
<td>PbBr$_4$</td>
<td>lead(IV) bromide</td>
</tr>
</tbody>
</table>
Naming FeCl\textsubscript{2}

To name FeCl\textsubscript{2}  [ 1 Iron ion  +  2 chloride ions ]

1. Determine the charge of the cation using the charge of the anion (Cl\textsuperscript{-}).

   \[
   \text{Fe ion} + 2 \text{Cl}^- = 1(?) + 2(1-) = 0
   \]

   \[
   \text{Fe ion} = 2^+ \quad \text{Fe}^{2+}
   \]

2. Name the cation by the element name and a Roman numeral in parenthesis to show charge.

   \[
   \text{Fe}^{2+} = \text{iron(II)}
   \]

3. Write the name of the anion with an \textit{ide} ending.

   \[
   \text{iron(II) chloride} = \text{FeCl}_2
   \]
Naming $\text{Cr}_2\text{O}_3$

To name $\text{Cr}_2\text{O}_3$

1. Determine the charge of cation from the anion ($\text{O}^{2-}$).

\[ 2\text{Cr ions} + 3 \text{O}^{2-} = ? + 3(2-) = ? - 6 = 0 \]

\[ ? = +6 \quad +6 / 2\text{Cr ions} = +3 \]

\[ \text{Cr ion} = 3+ \quad \text{Cr}^{3+} \]

2. Name the cation by the element name and use a Roman numeral in parenthesis to show its charge.

\[ \text{Cr}^{3+} = \text{chromium(III)} \]

3. Write the name of the anion with -$\text{ide}$ ending.

\[ \text{chromium (III) oxide} = \text{Cr}_2\text{O}_3 \]

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Learning Check

Select the correct name for each.

1. \( \text{Fe}_2\text{S}_3 \)
   A) iron sulfide
   B) iron(II) sulfide
   C) iron (III) sulfide

2. \( \text{CuO} \)
   A) copper oxide
   B) copper(I) oxide
   C) copper (II) oxide
Guide to Writing Formulas from the Name

Guide to Writing Formulas from the Name of an Ionic Compound

STEP 1
Identify the cation and anion.

STEP 2
Balance the charges.

STEP 3
Write the formula, cation first, using subscripts from charge balance.

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Writing Formulas

Write the formula of potassium sulfide.

STEP 1 Identify the cation and anion.
- potassium = K⁺
- sulfide = S²⁻

STEP 2 Balance the charges.
K⁺ S²⁻
K⁺
2(1+) + 2(1-) = 0

STEP 3 2 K⁺ and 1 S²⁻ = K₂S
Writing Formulas

Write the formula of cobalt(III) chloride.

STEP 1. Identify the cation and anion.

- cobalt (III) = Co\textsuperscript{3+} (III = charge of 3+)
- chloride = Cl\textsuperscript{−}

STEP 2. Balance the charges.

\[
\begin{align*}
\text{Co}^{3+} & \quad \text{Cl}^{-} \\
\text{Cl}^{-} & = (3+) + 3(1-) = 0 \\
\text{Cl}^{-} &
\end{align*}
\]

STEP 3. 1 Co\textsuperscript{3+} and 3 Cl\textsuperscript{−} = CoCl\textsubscript{3}
Learning Check

The correct formula for each of the following is:

1. Copper (I) nitride
   - A) CuN
   - B) CuN₃
   - C) Cu₃N

2. Lead (IV) oxide
   - A) PbO₂
   - B) PbO
   - C) Pb₂O₄
Polyatomic Ions

Window cleaner
NH$_4$OH

NH$_4^+$
Ammonium ion

OH$^-$
Hydroxide ion

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Polyatomic Ions

A polyatomic ion

- Is a group of atoms.
- Has an overall ionic charge.

Some examples of polyatomic ions are

- $\text{NH}_4^+$ ammonium
- $\text{OH}^-$ hydroxide
- $\text{NO}_3^-$ nitrate
- $\text{NO}_2^-$ nitrite
- $\text{CO}_3^{2-}$ carbonate
- $\text{PO}_4^{3-}$ phosphate
- $\text{HCO}_3^-$ hydrogen carbonate (bicarbonate)
Some Compounds with Polyatomic Ions

Plaster molding \( \text{CaSO}_4 \)

Fertilizer \( \text{NaNO}_3 \)

\( \text{Ca}^{2+} \) \( \text{SO}_4^{2-} \) Sulfate ion

\( \text{Na}^+ \) \( \text{NO}_3^- \) Nitrate ion

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More Names of Polyatomic Ions

The names of common polyatomic anions

• End in *ate*.
  \[ \text{NO}_3^- \quad \text{nitr}ate \quad \text{PO}_4^{3-} \quad \text{phosph}ate \]

• With one oxygen less end in *ite*.
  \[ \text{NO}_2^- \quad \text{nitri}te \quad \text{PO}_3^{3-} \quad \text{phosphi}te \]

• With hydrogen attached use prefix *hydrogen* (or *bi*).
  \[ \text{HCO}_3^- \quad \text{hydrogen} \quad \text{carbonate} \quad \text{(bicarbonate)} \]
  \[ \text{HSO}_3^- \quad \text{hydrogen} \quad \text{sulfite} \quad \text{(bisulfite)} \]

\[ \text{SO}_4^{2-} \quad \text{sulfate} \quad \text{HSO}_4^- \quad \text{hydrogen sulfi}te \]
## Names and Formulas of Common Polyatomic Ions

<table>
<thead>
<tr>
<th>Nonmetal</th>
<th>Formula of Ion</th>
<th>Name of Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>OH(^-)</td>
<td>Hydroxide</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>NH(_4^+)</td>
<td>Ammonium</td>
</tr>
<tr>
<td></td>
<td>NO(_3^-)</td>
<td>Nitrate</td>
</tr>
<tr>
<td></td>
<td>NO(_2^-)</td>
<td>Nitrite</td>
</tr>
<tr>
<td>Chlorine</td>
<td>ClO(_4^-)</td>
<td>Perchlorate</td>
</tr>
<tr>
<td></td>
<td>ClO(_3^-)</td>
<td>Chlorate</td>
</tr>
<tr>
<td></td>
<td>ClO(_2^-)</td>
<td>Chlorite</td>
</tr>
<tr>
<td></td>
<td>ClO(^-)</td>
<td>Hypochlorite</td>
</tr>
<tr>
<td>Carbon</td>
<td>CO(_3^{2-})</td>
<td>Carbonate</td>
</tr>
<tr>
<td></td>
<td>HCO(_3^-)</td>
<td>Hydrogen carbonate (or bicarbonate)</td>
</tr>
<tr>
<td></td>
<td>CN(^-)</td>
<td>Cyanide</td>
</tr>
<tr>
<td></td>
<td>C(_2)H(_3)O(_2^-)(\text{CH}_3\text{COO}^-)</td>
<td>Acetate</td>
</tr>
<tr>
<td></td>
<td>SCN(^-)</td>
<td>Thiocyanate</td>
</tr>
</tbody>
</table>
# Names and Formulas of Common Polyatomic Ions

<table>
<thead>
<tr>
<th>Nonmetal</th>
<th>Formula of Ion $\text{a}$</th>
<th>Name of Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>$\text{SO}_4^{2-}$</td>
<td>Sulfate</td>
</tr>
<tr>
<td></td>
<td>HSO$_4^-$</td>
<td>Hydrogen sulfate (or bisulfate)</td>
</tr>
<tr>
<td></td>
<td>$\text{SO}_3^{2-}$</td>
<td>Sulfite</td>
</tr>
<tr>
<td></td>
<td>HSO$_3^-$</td>
<td>Hydrogen sulfite (or bisulfite)</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>$\text{PO}_4^{3-}$</td>
<td>Phosphate</td>
</tr>
<tr>
<td></td>
<td>HPO$_4^{2-}$</td>
<td>Hydrogen phosphate</td>
</tr>
<tr>
<td></td>
<td>$\text{H}_2\text{PO}_4^-$</td>
<td>Dihydrogen phosphate</td>
</tr>
<tr>
<td></td>
<td>$\text{PO}_3^{3-}$</td>
<td>Phosphite</td>
</tr>
<tr>
<td>Chromium</td>
<td>$\text{CrO}_4^{2-}$</td>
<td>Chromate</td>
</tr>
<tr>
<td></td>
<td>$\text{Cr}_2\text{O}_7^{2-}$</td>
<td>Dichromate</td>
</tr>
<tr>
<td>Manganese</td>
<td>$\text{MnO}_4^-$</td>
<td>Permanganate</td>
</tr>
</tbody>
</table>

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Prefixes for Names of Polyatomic Ions of Halogens

Polyatomic ions of the halogens require prefixes.

\[
\begin{align*}
\text{ClO}_4^- & \quad \text{perchlorate} & \text{one oxygen more} \\
\text{ClO}_3^- & \quad \text{chlorate} & \text{most common form} \\
\text{ClO}_2^- & \quad \text{chlorite} & \text{one oxygen less} \\
\text{ClO}^- & \quad \text{hypochlorite} & \text{two oxygens less}
\end{align*}
\]
Naming Compounds with Polyatomic Ions

- The positive ion is named first followed by the name of the polyatomic ion.

\[ \text{NaNO}_3 \] \hspace{1cm} \text{sodium nitrate}
\[ \text{K}_2\text{SO}_4 \] \hspace{1cm} \text{potassium sulfate}
\[ \text{Fe(}\text{HCO}_3\text{)}_3 \] \hspace{1cm} \text{iron(III) bicarbonate or}
\hspace{2cm} \text{iron(III) hydrogen carbonate}
\[ (\text{NH}_4)_3\text{PO}_3 \] \hspace{1cm} \text{ammonium phosphite}
Some Compounds with Polyatomic Ions

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaSO₄</td>
<td>Barium sulfate</td>
<td>X-ray contrast medium</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>Calcium carbonate</td>
<td>Antacid, calcium supplement</td>
</tr>
<tr>
<td>Ca₃(PO₄)₂</td>
<td>Calcium phosphate</td>
<td>Calcium replenisher</td>
</tr>
<tr>
<td>CaSO₃</td>
<td>Calcium sulfite</td>
<td>Preservative in cider and fruit juices</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>Calcium sulfate</td>
<td>Plaster casts</td>
</tr>
<tr>
<td>AgNO₃</td>
<td>Silver nitrate</td>
<td>Topical anti-infective</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>Sodium bicarbonate</td>
<td>Antacid</td>
</tr>
<tr>
<td>Zn₃(PO₄)₂</td>
<td>Zinc phosphate</td>
<td>Dental cements</td>
</tr>
<tr>
<td>FePO₄</td>
<td>Iron(III) phosphate</td>
<td>Food and bread enrichment</td>
</tr>
<tr>
<td>K₂CO₃</td>
<td>Potassium carbonate</td>
<td>Alkalizer, diuretic</td>
</tr>
<tr>
<td>Al₂(SO₄)₃</td>
<td>Aluminum sulfate</td>
<td>Antiperspirant, anti-infective</td>
</tr>
<tr>
<td>AIPO₄</td>
<td>Aluminum phosphate</td>
<td>Antacid</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>Magnesium sulfate</td>
<td>Cathartic, Epsom salts</td>
</tr>
</tbody>
</table>

Table 5.7 Some Compounds That Contain Polyatomic Ions

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Learning Check

Select the correct formula for each:

1. aluminum nitrate
   A) AlNO₃  B) Al(NO)₃  C) Al(NO₃)₃

2. copper(II) nitrate
   A) CuNO₃  B) Cu(NO₃)₂  C) Cu₂(NO₃)₁
e

3. iron (III) hydroxide
   A) FeOH  B) Fe₃OH  C) Fe(OH)₃
e

4. tin(IV) hydroxide
   A) Sn(OH)₄  B) Sn(OH)₂  C) Sn₄(OH)
Learning Check

Match each formula with the correct name:

1. MgS  A) magnesium sulfite
2. MgSO₃  B) magnesium sulfate
3. MgSO₄  C) magnesium sulfide
4. Ca(ClO₃)₂  D) calcium chlorate
5. Ca(ClO)₂  E) calcium chlorite
6. Ca(ClO₂)₂  F) calcium hypochlorite
Learning Check

Name each of the following compounds:

1. Mg(NO₃)₂  magnesium nitrate
2. Cu(ClO₃)₂  copper(II) chlorate
3. PbO₂      lead (IV) oxide
4. Fe₂(SO₄)₃  iron(III) sulfate
5. Ba₃(PO₃)₂  barium phosphite
Writing Formulas with Polyatomic Ions

The formula of an ionic compound

- Containing a polyatomic ion must have a charge balance that equals zero(0).

  \[
  \text{Na}^+ \quad \text{and} \quad \text{NO}_3^- \quad \rightarrow \quad \text{NaNO}_3
  \]

- With two or more polyatomic ions encloses the polyatomic ions in parentheses.

  \[
  \text{Mg}^{2+} \quad \text{and} \quad 2\text{NO}_3^- \quad \rightarrow \quad \text{Mg(NO}_3)_2
  \]

  *subscript 2 for charge balance*
Learning Check

Write the correct formula for each:

1. potassium bromate
   \[ \text{KBrO}_3 \]

2. calcium carbonate
   \[ \text{CaCO}_3 \]

3. sodium phosphate
   \[ \text{Na}_3\text{PO}_4 \]

4. iron(III) oxide
   \[ \text{Fe}_2\text{O}_3 \]

5. iron (II) nitrite
   \[ \text{Fe(NO}_2)_2 \]
# Naming Ionic Compounds

## Review:

Table 5.8  **Rules for Naming Ionic Compounds**

<table>
<thead>
<tr>
<th>Type</th>
<th>Formula Feature</th>
<th>Naming Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic compound (two elements)</td>
<td>Symbol of metal followed by symbol of nonmetal; subscripts used for charge balance.</td>
<td>Use element name for metal; Roman numeral required if more than one positive ion is possible. For nonmetal use element name with <em>ide</em> ending.</td>
</tr>
<tr>
<td></td>
<td>Examples:</td>
<td>Examples:</td>
</tr>
<tr>
<td></td>
<td>Na₂O</td>
<td>Sodium oxide</td>
</tr>
<tr>
<td></td>
<td>Fe₂S₃</td>
<td>Iron(III) sulfide</td>
</tr>
<tr>
<td>Ionic compound (more than two elements)</td>
<td>Usually symbol of metal followed by a polyatomic ion composed of nonmetals; parentheses may enclose polyatomic ion for charge balance.</td>
<td>Use element name for metal, with Roman numeral if needed, followed by name of polyatomic ion.</td>
</tr>
<tr>
<td></td>
<td>Examples:</td>
<td>Examples:</td>
</tr>
<tr>
<td></td>
<td>Mg(NO₃)₂</td>
<td>Magnesium nitrate</td>
</tr>
<tr>
<td></td>
<td>CuSO₄</td>
<td>Copper(II) sulfate</td>
</tr>
<tr>
<td></td>
<td>(NH₄)₂CO₃</td>
<td>Ammonium carbonate</td>
</tr>
</tbody>
</table>

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Flowchart for Naming Ionic Compounds

Q: Does the metal form one positive ion or more?
- One
  - Group 1A (1)–3A (13), Zn, Ag, or Cd
  - Use the name of the element or use "ammonium" for the NH₄⁺ ion.
- More
  - Metal in B Groups 3B–12B, Groups 4A (14) or 5A (15)
  - Use the name of the element and a Roman numeral in parentheses for the positive charge of the ion.

Q: Is the nonmetal ion formed from a single atom or a polyatomic ion with oxygen?
- Single ion
  - Monatomic ion such as Cl⁻, S²⁻
  - Use the root of the name of the element adding ide ending.
- Polyatomic ion such as CO₃²⁻ or SO₄²⁻
  - Polyatomic ion
  - Use the name of the polyatomic with an ate or ite ending.
Learning Check

Name the following compounds:

A. $\text{Ca}_3(\text{PO}_4)_2$ calcium phosphate
B. $\text{FeBr}_3$ iron(III) bromide
C. $\text{Al}_2\text{S}_3$ aluminum sulfide
D. $\text{Mn(NO}_2)_2$ manganese(II) nitrite
E. $\text{NaHCO}_3$ sodium hydrogen carbonate
Learning Check

Write the formulas for the following:

A. calcium nitrate \[ \text{Ca}^{+2}(\text{NO}_3^{-}) \quad \text{Ca}_2(\text{NO}_3)_2 \]

B. iron(II) hydroxide \[ \text{Fe}^{+2}(\text{OH}) \quad \text{Fe}_2(\text{OH})_2 \]

C. aluminum carbonate \[ \text{Al}^{+3} \text{CO}_3^- \quad \text{Al}_2(\text{CO}_3)_3 \]

D. copper(II) hypobromite \[ \text{Cu}^{+2}(\text{BrO}) \quad \text{Cu}(\text{BrO})_2 \]

E. lithium phosphate \[ \text{Li}^+ (\text{PO}_4^3-) \quad \text{Li}_3(\text{PO}_4) \]
Covalent Compounds and Their Names

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Forming a \( \text{H}_2 \) Molecule

Energy

Distance between nuclei decreases

\( \text{H}^+ \) Far apart; no attractions

\( \text{H}^+ \) Attraction pull atoms closer

\( \text{H}_2 \) molecule
H₂, A Covalent Molecule

In a hydrogen (H₂) molecule

- Two hydrogen atoms share electrons to form a covalent single bond.
- Each H atom acquires two (2) electrons.
- Each H becomes stable like helium (He).

\[ \text{H\textbullet{} + \bullet{}H} \rightarrow \text{H:}\text{H} \rightarrow \text{H}\text{―\text{H}} = \text{H}_2 \]

Electrons to share  A shared pair of electrons  A covalent bond  A hydrogen molecule

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Diatomic Elements

- These elements share electrons to form **diatomic, covalent molecules**.

**Table 6.9 Elements That Exist as Diatomic, Covalent Molecules**

<table>
<thead>
<tr>
<th>Element</th>
<th>Diatomic Molecule</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>H₂</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>N</td>
<td>N₂</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>O</td>
<td>O₂</td>
<td>Oxygen</td>
</tr>
<tr>
<td>F</td>
<td>F₂</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Cl</td>
<td>Cl₂</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Br</td>
<td>Br₂</td>
<td>Bromine</td>
</tr>
<tr>
<td>I</td>
<td>I₂</td>
<td>Iodine</td>
</tr>
</tbody>
</table>

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Electron-Dot Formulas

Electron-dot formulas show

- The order of bonded atoms in a covalent compound.
- The bonding pairs of electrons between atoms.
- The unshared (lone) valence electrons if they exist.
- A central atom with an octet.
Electron-Dot Formulas and Models of Some Covalent Compounds

Table 5.10  Electron-Dot Formulas for Some Covalent Compounds

<table>
<thead>
<tr>
<th></th>
<th>CH₄</th>
<th>NH₃</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using Electron Dots Only</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>H</td>
<td>:O:</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Using Bonds and Electron Dots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>H</td>
<td>:O:</td>
</tr>
<tr>
<td></td>
<td>H—ːC—ːH</td>
<td>H—ːN—ːH</td>
<td>:ːOːH</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Molecular Models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane molecule</td>
<td><img src="image" alt="Methane molecule" /></td>
<td>Ammonia molecule</td>
<td><img src="image" alt="Ammonia molecule" /></td>
</tr>
</tbody>
</table>
Names of Covalent Compounds

Prefixes are used

- In the names of covalent compounds.
- Because typically two nonmetals can form two or more different compounds.

Examples of compounds of N and O:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>nitrogen oxide</td>
</tr>
<tr>
<td>NO₂</td>
<td>nitrogen dioxide</td>
</tr>
<tr>
<td>N₂O</td>
<td>dinitrogen oxide</td>
</tr>
<tr>
<td>N₂O₄</td>
<td>dinitrogen tetroxide</td>
</tr>
<tr>
<td>N₂O₅</td>
<td>dinitrogen pentoxide</td>
</tr>
</tbody>
</table>
Naming Covalent Compounds

**STEP 1** Name the first nonmetal as the element.

**STEP 2** End the name of the second nonmetal with *-ide*

**STEP 3** Use *prefixes* to show the number of atoms (subscripts).

*Mono* is usually omitted.

---

**Table 6.11** Prefixes Used in Naming Covalent Compounds

<table>
<thead>
<tr>
<th>Number of Atoms</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mono</td>
</tr>
<tr>
<td>2</td>
<td>Di</td>
</tr>
<tr>
<td>3</td>
<td>Tri</td>
</tr>
<tr>
<td>4</td>
<td>Tetra</td>
</tr>
<tr>
<td>5</td>
<td>Penta</td>
</tr>
<tr>
<td>6</td>
<td>Hexa</td>
</tr>
<tr>
<td>7</td>
<td>Hepta</td>
</tr>
<tr>
<td>8</td>
<td>Octa</td>
</tr>
<tr>
<td>9</td>
<td>Nona</td>
</tr>
<tr>
<td>10</td>
<td>Deca</td>
</tr>
</tbody>
</table>

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Naming Covalent Compounds

What is the name of SO$_3$?

**STEP 1**  The first nonmetal is S sulfur.

**STEP 2**  The second nonmetal is O named oxide.

**STEP 3**  The subscript 3 of O is shown as the prefix *tri*.

SO$_3$  \(\rightarrow\)  sulfur trioxide

The subscript 1(for S) or *mono* is understood.
Naming Covalent Compounds

Name $P_4S_3$

**STEP 1** The first nonmetal P is phosphorus.

**STEP 2** The second nonmetal S is sulfide.

**STEP 3** The subscript 4 of P is shown as *tetra*.

The subscript 3 of O is shown as *tri*.

$P_4S_3 \rightarrow$ tetraphosphorus trisulfide
# Formulas and Names of Some Covalent Compounds

## Table 6.12: Some Common Covalent Compounds

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
<th>Commercial Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS₂</td>
<td>carbon disulfide</td>
<td>Manufacture of rayon</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
<td>Carbonation of beverages, fire extinguishers, propellant in aerosols, dry ice</td>
</tr>
<tr>
<td>SiO₂</td>
<td>silicon dioxide</td>
<td>Manufacture of glass, computer parts</td>
</tr>
<tr>
<td>NCl₃</td>
<td>nitrogen trichloride</td>
<td>Bleaching of flour in some countries (prohibited in U.S.)</td>
</tr>
<tr>
<td>SO₂</td>
<td>sulfur dioxide</td>
<td>Preserving fruits, vegetables; disinfectant in breweries; bleaching textiles</td>
</tr>
<tr>
<td>SO₃</td>
<td>sulfur trioxide</td>
<td>Manufacture of explosives</td>
</tr>
<tr>
<td>SF₆</td>
<td>sulfur hexafluoride</td>
<td>Electrical circuits (insulation)</td>
</tr>
<tr>
<td>ClO₂</td>
<td>chlorine dioxide</td>
<td>Bleaching pulp (for making paper), flour, leather</td>
</tr>
<tr>
<td>ClF₃</td>
<td>chlorine trifluoride</td>
<td>Rocket propellant</td>
</tr>
</tbody>
</table>

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Learning Check

Select the correct name for each compound.

A. $\text{SiCl}_4$  
   1) silicon chloride  
   2) tetrasilicon chloride  
   3) silicon tetrachloride

B. $\text{P}_2\text{O}_5$  
   1) phosphorus oxide  
   2) phosphorus pentoxide  
   3) diphosphorus pentoxide

C. $\text{Cl}_2\text{O}_7$  
   1) dichlorine heptoxide  
   2) dichlorine oxide  
   3) chlorine heptoxide
Learning Check

Write the name of each covalent compound:

CO   carbon monoxide
CO₂  carbon dioxide
PCl₃ phosphorus trichloride
CCl₄ carbon tetrachloride
N₂O  dinitrogen oxide
Guide to Writing Formulas

STEP 1  Write the symbols in the order of the elements in the name.

STEP 2  Write any prefixes as subscripts.

Example: Write the formula for carbon disulfide.

STEP 1  Elements are C and S

STEP 2  No prefix for carbon means 1 C

Prefix di = 2

Formula: $CS_2$
Learning Check

Write the correct formula for each of the following:

A. phosphorus pentachloride

B. dinitrogen trioxide

C. sulfur hexafluoride
Learning Check

Identify each compound as ionic or covalent and give its correct name.

1. $\text{SO}_3$ covalent - sulfur trioxide
2. $\text{MnCl}_2$ ionic - manganese(II) chloride
3. $(\text{NH}_4)_3\text{PO}_3$ ionic - ammonium phosphite
4. $\text{Cu}_2\text{CO}_3$ ionic – copper(I) carbonate
5. $\text{N}_2\text{O}_4$ covalent – dinitrogen tetroxide
Learning Check

Identify each compound as ionic or covalent and give its correct name.

1. \( \text{Ca}_3(\text{PO}_4)_2 \) ionic – calcium phosphate
2. \( \text{FeBr}_3 \) ionic – iron(III) bromide
3. \( \text{SCl}_2 \) covalent – sulfur dichloride
4. \( \text{Cl}_2\text{O} \) covalent – dichlorine oxide