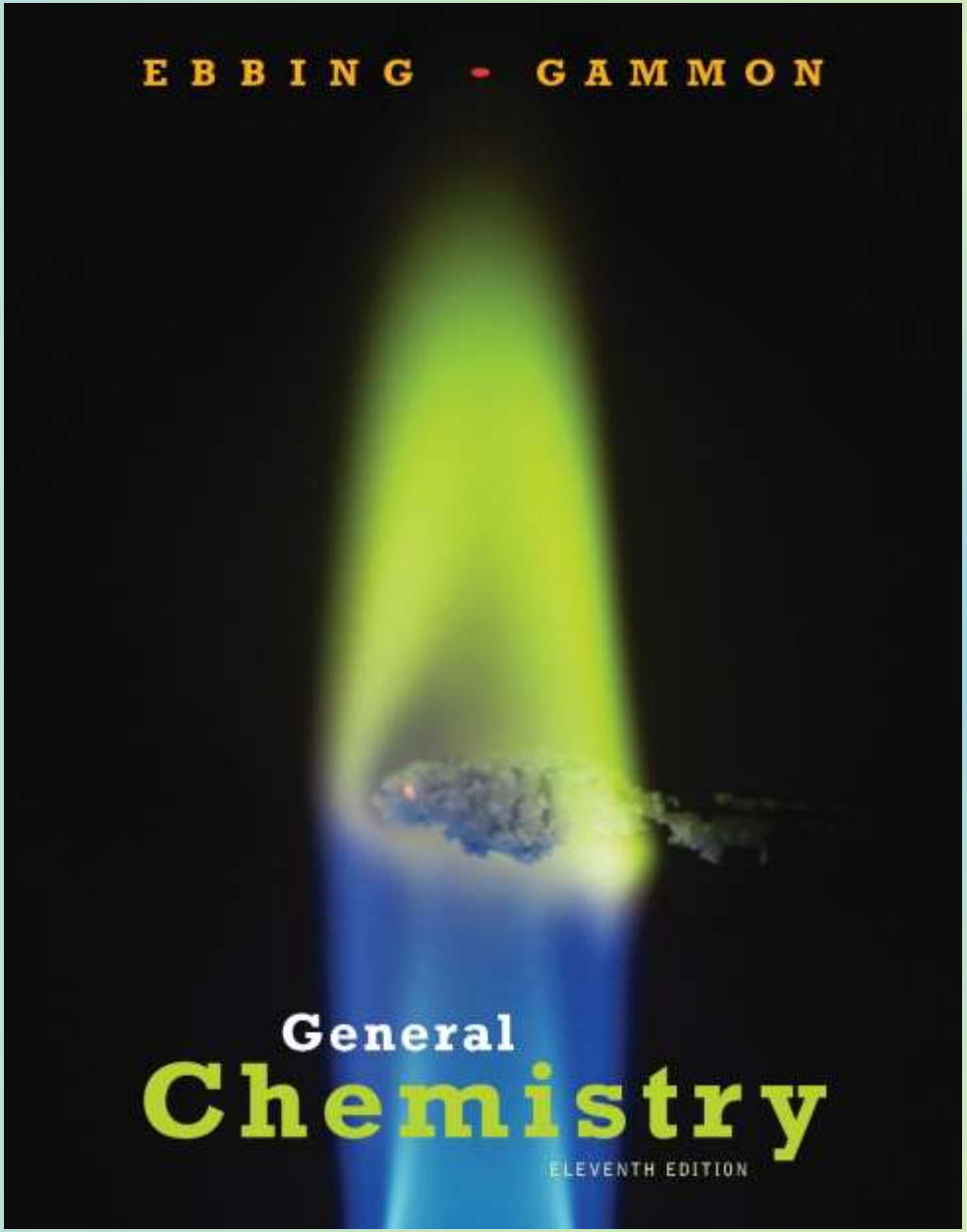


Chapter 2 Atoms, Molecules, and Ions

- Required sections:

2.3 Nuclear Structure and Isotopes
2.4 Atomic Weights
2.8 Naming Simple Compounds
2.9 Writing Chemical Equations
2.10 Balancing Chemical Equations

- *Excluded sections: 2.1, 2.2, 2.5, 2.6, 2.7*

2.3 Nuclear Structure; Isotopes

Mass number → $^{A}_{Z}E$ ← Element symbol

Atomic number → Z

e.g. $^{20}_{10}Ne$

Ca

Ca^{2+}

Cl^{-}

Atomic number = Z = number of protons in the nucleus = number of electrons

Mass number = A = number of protons + number of neutrons

Number of neutrons = $A - Z$

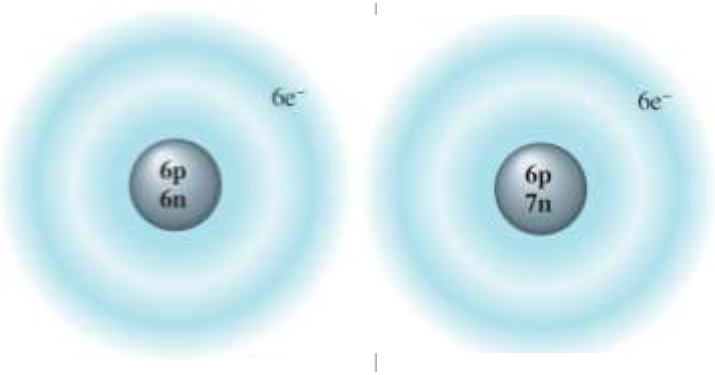


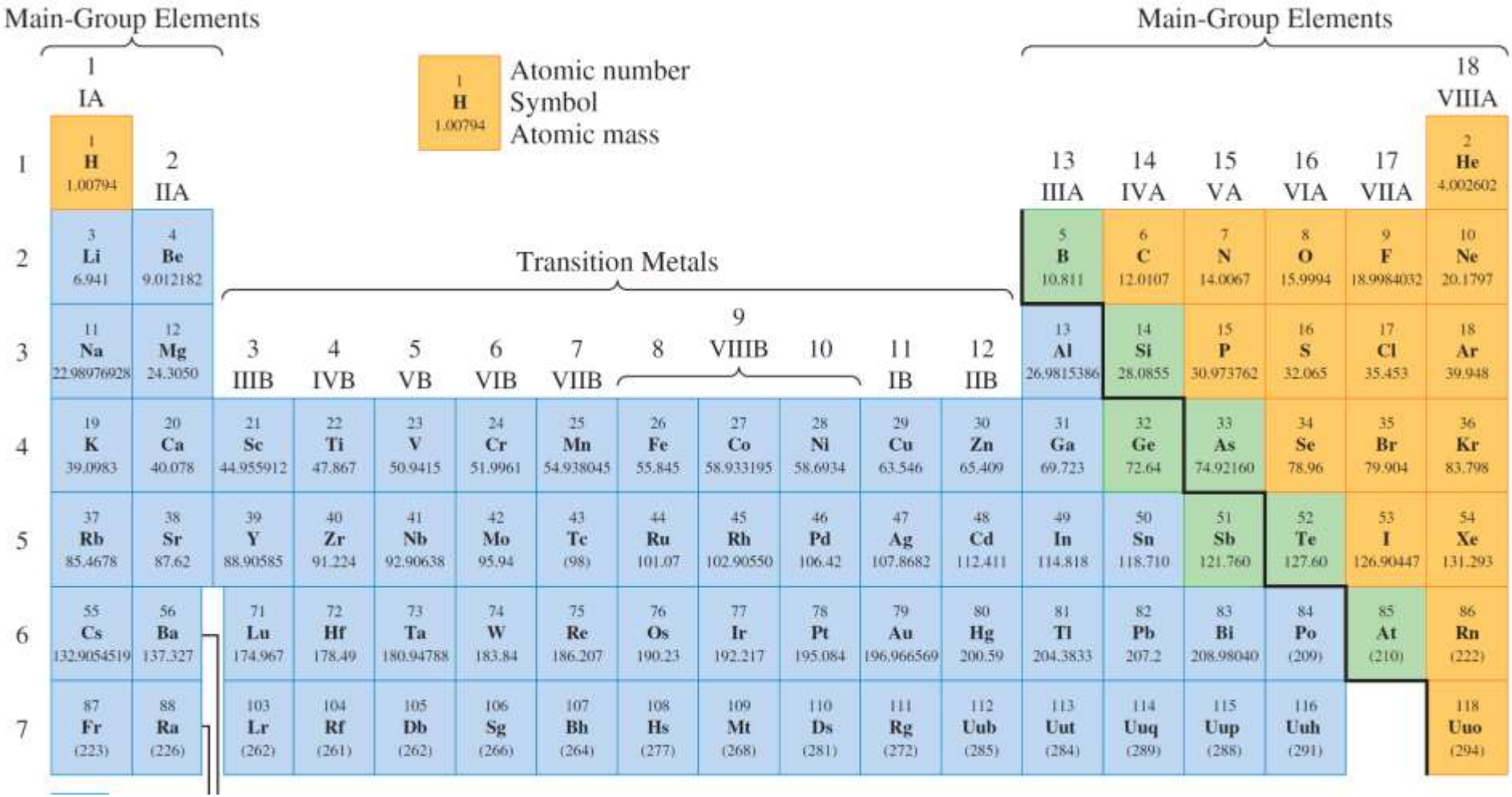
TABLE 2.1 Properties of the Electron, Proton, and Neutron

Particle	Mass (kg)	Charge (C)	Mass (amu)*	Charge (e)
Electron	9.10939×10^{-31}	-1.60218×10^{-19}	0.00055	−1
Proton	1.67262×10^{-27}	$+1.60218 \times 10^{-19}$	1.00728	+1
Neutron	1.67493×10^{-27}	0	1.00866	0

*The atomic mass unit (amu) equals 1.66054×10^{-27} kg; it is defined in Section 2.4.

Example 2.1:What is the nuclide symbol for a nucleus that contains 38 protons and 50 neutrons?

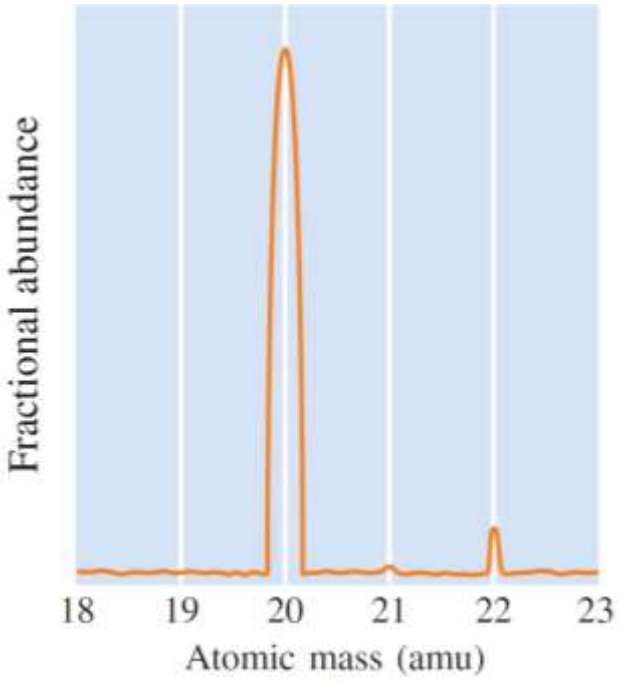
Periodic Table of The Elements

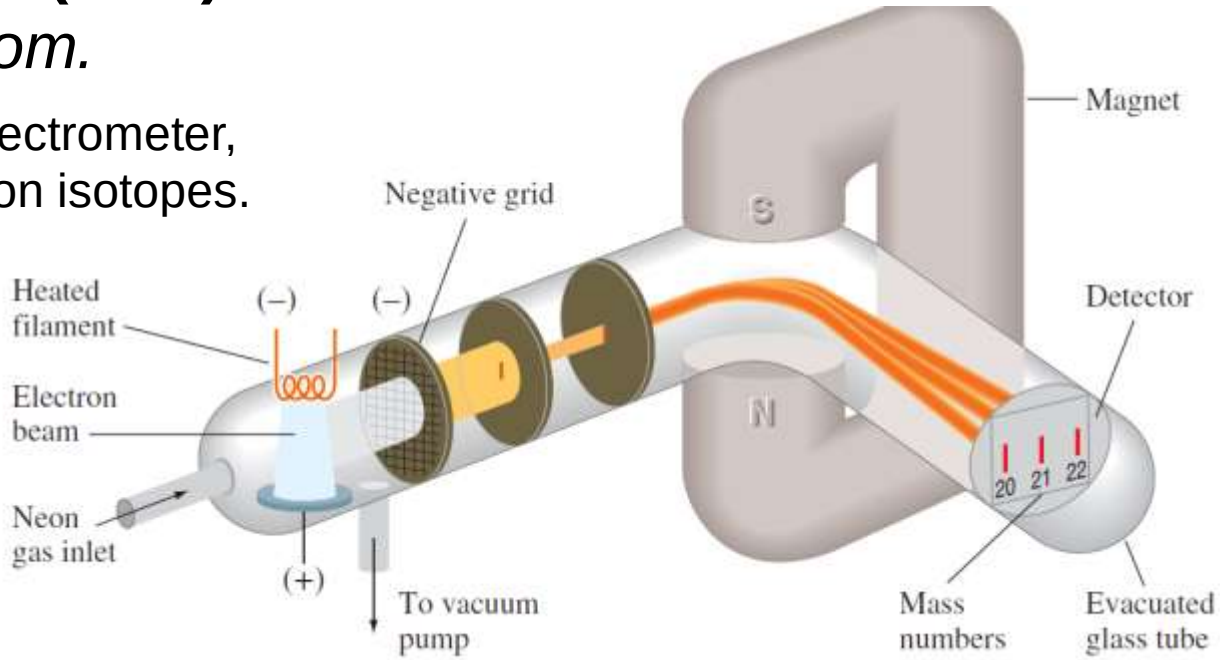


2.4 Atomic Masses and atomic mass Units (amu)

One **atomic mass unit (amu)** is *a mass unit = 1/12 of the mass of a carbon-12* (^{12}C)*atom.*

Diagram of a simple mass spectrometer, showing the separation of neon isotopes.





^{20}**Ne** (90.48%)
^{21}**Ne** (0.27%)
^{22}**Ne** (9.25%)

-Ne gas atoms form +ve ions when they collide with electrons.
-Ne^+ atoms are accelerated from this region by the negative grid and pass between the poles of a magnet.
-The beam of positively charged atoms is split into three beams by the magnetic field according to the **mass/charge ratios**.
-The three beams then travel to a detector at the end of the tube

Relative Atomic Masses (A_r)

Calculate the value of A_r for naturally occurring chlorine if the distribution of isotopes is 75.77% $^{35}_{17}Cl$ and 24.23% $^{37}_{17}Cl$. Accurate masses for ^{35}Cl and ^{37}Cl are 34.97 and 36.97.

Exercise 2.2 Chlorine consists of the following isotopes:

Isotope	*Isotopic Mass (amu)*	*Fractional Abundance*
Chlorine-35	34.96885	0.75771
Chlorine-37	36.96590	0.24229

What is the atomic mass of chlorine?

Example 2.2 Determining Atomic Mass from Isotopic Masses and Fractional Abundances

Chromium, Cr, has the following isotopic masses and fractional abundances:

Mass Number	*Isotopic Mass (amu)*	*Fractional Abundance*
50	49.9461	0.0435
52	51.9405	0.8379
53	52.9407	0.0950
54	53.9389	0.0236

What is the atomic mass of chromium?

Solution Multiply each isotopic mass by its fractional abundance, then sum:

$$\begin{aligned} 49.9461 \text{ amu} \times 0.0435 &= 2.17 \text{ amu} \\ 51.9405 \text{ amu} \times 0.8379 &= 43.52 \text{ amu} \\ 52.9407 \text{ amu} \times 0.0950 &= 5.03 \text{ amu} \\ 53.9389 \text{ amu} \times 0.0236 &= 1.27 \text{ amu} \\ &\overline{\quad\quad 51.99 \text{ amu}} \end{aligned}$$

The atomic mass of chromium is **51.99 amu.**

Answer Check The average mass (atomic mass)

If the relative atomic mass for Cl is 35.45, and the accurate masses of ^{35}Cl and ^{37}Cl are 34.97 and 36.97; What is the fractional abundance of ^{37}Cl ?

2.8 Naming Simple Compounds (Chemical nomenclature)

-nomenclature of some simple inorganic compounds

➢ Naming ionic Compounds

(Most ionic compounds contain **metal** + **nonmetal** atoms**)**

Cations

- Positively charged ions
- Formed from metals
- Atoms **lose** electrons

e.g., Na has 11 e^- and 11 *p*

Examples:
NaCl
K_2SO_4

Exception: NH_4Cl

Na^+ has 10 e^- and 11 *p*

Anions

- Negatively charged ions
- Formed from non-metals
- Atoms **gain** electrons

e.g., Cl has 17 e^- and 17 *p*

Cl^- has 18 e^- and 17 *p*

TABLE 2.3 Common Monatomic Ions of the Main-Group Elements*

	IA	IIA	IIIA	IVA	VA	VIA	VIIA
Period 1							H^-
Period 2	Li^+	Be^{2+}	B	C	N^{3-}	O^{2-}	F^-
Period 3	Na^+	Mg^{2+}	Al^{3+}	Si	P	S^{2-}	Cl^-
Period 4	K^+	Ca^{2+}	Ga^{3+}	Ge	As	Se^{2-}	Br^-
Period 5	Rb^+	Sr^{2+}	In^{3+}	Sn^{2+}	Sb	Te^{2-}	I^-
Period 6	Cs^+	Ba^{2+}	Tl^+, Tl^{3+}	Pb^{2+}	Bi^{3+}		

*Elements shown in color do not normally form compounds having monatomic ions.

➢ Rules for Predicting the Charges on Monatomic Ions:

1. In most main-group **metallic** elements :
   charge = group number in the periodic table (the Roman numeral).
2. Some metallic elements of high atomic number have more than one cation:

(i) Common cations, charge = (group number – 2)

(ii) Charge = group number.

Example (Pb): common ion Pb^{2+} in addition to Pb^{4+}

3. Most transition elements form more than one monatomic cation.

-Most of these elements have one ion with a charge of 2+.

Examples: (Fe) has common cations Fe^{2+} and Fe^{3+}.

(Cu) has common cations Cu^{+} and Cu^{2+}.

4. Charge on a monatomic anion for a **nonmetallic main-group element** = (**group number – 8**).

Example: (O) has the monatomic anion O^{2-}.

(The group number is 6; the charge is [(6-8)= -2]

➢ Rules for Naming Monatomic Ions

1. Monatomic cations are named after the element if there is only one such ion.

Example: Al^{3+} is called aluminum ion; Na^{+} is called sodium ion.

TABLE 2.5 Monatomic Negative Ions

H^-	Hydride	C^{4-}	Carbide	N^{3-}	Nitride	O^{2-}	Oxide	F^-	Fluoride
		Si^{4-}	Silicide	P^{3-}	Phosphide	S^{2-}	Sulfide	Cl^-	Chloride
				As^{3-}	Arsenide	Se^{2-}	Selenide	Br^-	Bromide
				Te^{2-}	Telluride	I^-	Iodide		

2. If there is more than one monatomic cation of an element→ Rule 1 is not sufficient →Use ***Stock system***

Example: Fe^{2+} is called iron(II) ion and Fe^{3+} is called iron(III) ion.

-Older system of nomenclature, such ions are named by adding the suffixes *-ous* and *-ic* to a stem name of the element to indicate the ions of lower and higher charge, respectively.

Examples:

Fe^{2+} (ferrous ion) and Fe^{3+} (ferric ion)

Cu^{+} (cuprous ion) and Cu^{2+} (cupric ion)

- Few transition metal cations , such as Zn, have only a single ion →usually name them by just the metal name.
- Also, It's not wrong to name Zn^{2+} as zinc(II) ion.

3. The names of the monatomic **anions** are obtained from a stem name of the element followed by the suffix *-ide.*

Example: Br^{-} is called **bromide** ion, from the stem name *brom-* for bromine and the suffix *-ide.*

TABLE 2.4 | Common Cations of the Transition Elements

Ion	Ion Name	Ion	Ion Name	Ion	Ion Name
Cr^{3+}	Chromium(III) or chromic	Co^{2+}	Cobalt(II) or cobaltous	Zn^{2+}	Zinc
Mn^{2+}	Manganese(II) or manganous	Ni^{2+}	Nickel(II) or nickel	Ag^{+}	Silver
Fe^{2+}	Iron(II) or ferrous	Cu^{+}	Copper(I) or cuprous	Cd^{2+}	Cadmium
Fe^{3+}	Iron(III) or ferric	Cu^{2+}	Copper(II) or cupric	Hg^{2+}	Mercury(II) or mercuric

➢ Polyatomic Ions (oxoanions)

TABLE 2.5 | Some Common Polyatomic Ions

Name	Formula	Name	Formula
Mercury(I) or mercurous	Hg_2^{2+}	Permanganate	MnO_4^-
Ammonium	NH_4^+	Nitrite	NO_2^-
Cyanide	CN^-	Nitrate	NO_3^-
Carbonate	CO_3^{2-}	Hydroxide	OH^-
Hydrogen carbonate (or bicarbonate)	HCO_3^-	Peroxide	O_2^{2-}
Acetate	$C_2H_3O_2^-$	Phosphate	PO_4^{3-}
Oxalate	$C_2O_4^{2-}$	Monohydrogen phosphate	HPO_4^{2-}
Hypochlorite	ClO^-	Dihydrogen phosphate	$H_2PO_4^-$
Chlorite	ClO_2^-	Sulfite	SO_3^{2-}
Chlorate	ClO_3^-	Sulfate	SO_4^{2-}
Perchlorate	ClO_4^-	Hydrogen sulfite (or bisulfite)	HSO_3^-
Chromate	CrO_4^{2-}	Hydrogen sulfate (or bisulfate)	HSO_4^-
Dichromate	$Cr_2O_7^{2-}$	Thiosulfate	$S_2O_3^{2-}$

➢ Polyatomic Ions

NO_2^-	nitrite ion
NO_3^-	nitrate ion
ClO^-	hypochlorite ion
ClO_2^-	chlorite ion
ClO_3^-	chlorate ion
ClO_4^-	perchlorate ion

➢ Naming an Ionic Compound from Its Formula

(Q) Name the following compounds:

Metal →nonmetal

Mg_3N_2 : magnesium nitride

$CrSO_4$: chromium(II) sulfate

$PbCrO_4$: Lead(II) chromate

$FeCl_2$: Iron (II) chloride

$FeCl_3$: Iron (III) chloride

Cr_2S_3: chromium(III) sulfide

"Criss-cross" rule

- K_2O potassium oxide
- NH_4ClO_3 ammonium chlorate
- $Mg(C_2H_3O_2)_2$ magnesium acetate
- Cr_2O_3 chromium(III) oxide
- $ZnBr_2$ zinc bromide

(Q) Determine The Formula of the following compounds:

Calcium hydroxide	$Ca(OH)_2$
Manganese(II) bromide	$MnBr_2$
Ammonium phosphate	$(NH_4)_3PO_4$
Mercury(I) Fluoride	Hg_2F_2
Mercury(II) Fluoride	HgF_2
Mercury(I) nitride	$(Hg_2)_3N_2$
Iron(II) phosphate	$Fe_3(PO_4)_2$
Titanium(IV) oxide	TiO_2
Thallium(III) nitrate	$Tl(NO_3)_3$

(Q) Which is the correct name for Cu_2S?

A. copper sulfide
B. copper(II) sulfide
C. copper(II) sulfate
D. copper(I) sulfide
E. copper(I) sulfite

(Q) Which is the correct formula for ammonium sulfite?

A. NH_4SO_3
B. $(NH_4)_2SO_3$
C. $(NH_4)_2SO_4$
D. NH_4S
E. $(NH_4)_2S$

(Q) Name the following compounds:

(a) $Fe(NO_3)_2$

(b) Na_2HPO_4

(c) $(NH_4)_2(C_2O_4)$

(Q)Write chemical formulas for the following compounds:

(a) cesium sulfide

(b) calcium phosphate

➢ Naming Hydrates

1. Name ionic compound
2. Give number of water molecules in formula using Greek prefixes

$Ca(SO_4).2H_2O$ calcium sulfate dihydrate

$CoCl_2.6H_2O$ cobalt(II) chloride hexahydrate

$FeI_3 \cdot 3H_2O$ iron(III) iodide trihydrate

$Fe(NO_2)_3.9H_2O$ iron(III) nitrite nonahydrate

TABLE 2.6

Greek Prefixes for Naming Compounds

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

➢ Naming Molecular Compounds:

(Non-metal + Non-metal) or (Non-metal + Metalliod)

-binary compounds: *composed of only two elements*
e.g. NaCl, $MgCl_2$ (**ionic**). CO, H_2O, CCl_4, NH_3 (**molecular**)

-Order of Elements in the Formula:
In ionic compounds: metal → non-metal
NaCl not ClNa

In molecular compounds:

Element	B	Si	C	Sb	As	P	N	H	Te	Se	S	I	Br	Cl	O	F
Group	3A	4A		5A					6A			7A				

NF_3 not F_3N
H_2S not SH_2
SbH_3 not H_3Sb

➢ Rules for Naming Binary Molecular Compounds

1. The name of the compound has the elements in the order given in the previous formula.
2. Name the first element using the exact element name.
3. Name the second element by writing the stem name of the element with the suffix *-ide*
4. You add a prefix, derived from the Greek, to each element name to denote the subscript of the element in the formula.

Note: the **prefix *mono***- is not used, unless it is needed to distinguish two compounds of the same two elements.

Examples:

N_2O_3 dinitrogentrioxide

HCl hydrogen chloride NOT monohydrogen monochloride

CO carbon monoxide

CO_2 carbon dioxide

SF_4 sulfur tetrafluoride

SF_6 sulfur hexafluoride

ClO_2 chlorine dioxide

Cl_2O_7 dichlorine heptoxide

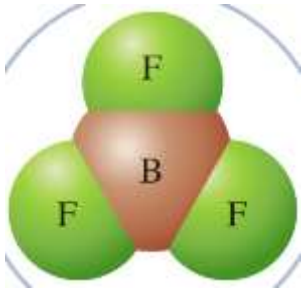
H_2S	dihydrogen sulfide	common name: hydrogen sulfide
NO	nitrogen monoxide	common name: nitric oxide
H_2O	water	
NH_3	ammonia	

NO_2	nitrogen dioxide
N_2O	dinitrogen monoxide
N_2O_4	dinitrogen **tetroxide**
P_4O_6	tetraphosphorus **hexoxide**
Cl_2O_6	dichlorine hexoxide
PCl_3	phosphorus trichloride
PCl_5	phosphorus pentachloride

disulfur dichloride	S_2Cl_2
tetraphosphorus trisulfide	P_4S_3
carbon disulfide	CS_2
sulfur trioxide	SO_3

nitrogen dioxide

Chlorine monofluoride



Boron trifluoride

Hydrogen selenide
Or dihydrogen selenide

$GaBr_3$	Gallium (III) bromide
$GeBr_4$	Germanium tetrabromide
$CaBr_2$	Calcium bromide
$Hg_2(NO_2)_2.H_2O$	Mercury(I) nitrite monohydrate

➢ Acids and Corresponding Anions

Anion Suffix	*Acid Suffix*
-ate	*-ic*
-ite	*-ous*

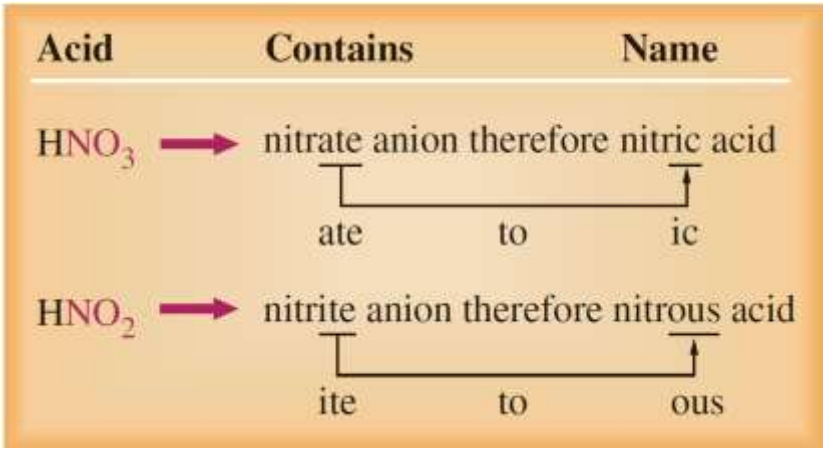
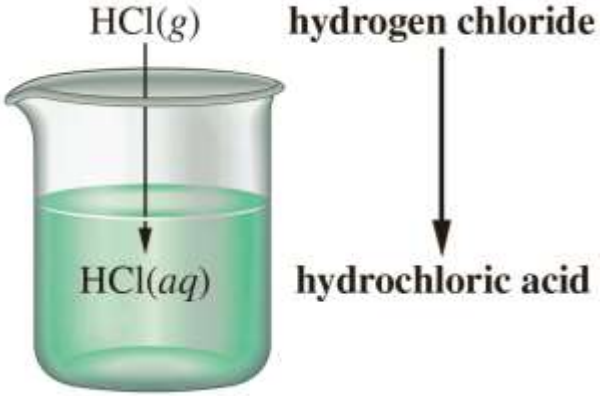


Table 2.8 Some Oxoanions and Their Corresponding Oxoacids

Oxoanion		Oxoacid	
CO_3^{2-}	Carbon*ate ion*	H_2CO_3	Carbon*ic acid*
NO_2^-	Nitr*ite ion*	HNO_2	Nitr*ous acid*
NO_3^-	Nitr*ate ion*	HNO_3	Nitr*ic acid*
PO_4^{3-}	Phosph*ate ion*	H_3PO_4	Phosphor*ic acid*
SO_3^{2-}	Sulf*ite ion*	H_2SO_3	Sulfur*ous acid*
SO_4^{2-}	Sulf*ate ion*	H_2SO_4	Sulfur*ic acid*
ClO^-	*Hypo*chlor*ite ion*	HClO	*Hypo*chlor*ous acid*
ClO_2^-	Chlor*ite ion*	$HClO_2$	Chlor*ous acid*
ClO_3^-	Chlor*ate ion*	$HClO_3$	Chlor*ic acid*
ClO_4^-	*Per*chlor*ate ion*	$HClO_4$	*Per*chlor*ic acid*

Binary Compound	*Acid Solution*
HBr(*g*), hydrogen bromide	*hydro*bromi*c acid,* HBr(*aq*)
HF(*g*), hydrogen fluoride	*hydro*fluori*c acid,* HF(*aq*)



(Q)Selenium has an oxoacid,H_2SeO_4, called selenic acid. What is the formula and name of the corresponding anion?
Selenate SeO_4^{2-}

Exercise 2.10
What are the name and formula of the anion corresponding to perbromic acid, $HBrO_4$?

BrO_4^- perbromate

➢ Chemical Reactions: Equations

Example 2.12 Balancing Simple Equations

Balance first the atoms for elements that occur in only one substance on each side of the equation.

(a) $H_3PO_3 \rightarrow H_3PO_4 + PH_3$

(b) $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$

(c) $Fe_2(SO_4)_3 + NH_3 + H_2O \rightarrow Fe(OH)_3 + (NH_4)_2SO_4$

Exercise 2.13

Find the coefficients that balance the following equations.

a. $O_2 + PCl_3 \rightarrow POCl_3$

b. $P_4 + N_2O \rightarrow P_4O_6 + N_2$

c. $As_2S_3 + O_2 \rightarrow As_2O_3 + SO_2$

d. $Ca_3(PO_4)_2 + H_3PO_4 \rightarrow Ca(H_2PO_4)_2$

Examples:

(Q)When the following equation is balanced and written with the smallest whole number coefficients, what is the coefficient of Al?

$$Fe_3O_4 + Al \rightarrow Al_2O_3 + Fe$$

(Q) When the following equation is balanced and written with the smallest whole number coefficients, what is the sum of coefficients of Al and Fe?

$$Fe_3O_4 + Al \rightarrow Al_2O_3 + Fe$$

(Q) When the following equation is balanced and written with the smallest whole number coefficients, what is the sum of all coefficients?

$$Fe(OH)_3 + 3HNO_3 \longrightarrow Fe(NO_3)_3 + 3\,H_2O$$