CHAPTER 2
ATOMS, MOLECULES, AND IONS

Dr. Yuan Dan

2.1 Atomic Theory of Matter

- all matter—whether element, compound, or mixture—is composed of small particles called atoms

Postulates of Dalton's Atomic Theory

1. All matter is composed of indivisible atoms. An atom is an extremely small particle of matter that retains its identity during chemical reactions.

2.1 Atomic Theory of Matter

Postulates of Dalton's Atomic Theory

2. An element is a type of matter composed of only one kind of atom, each atom of a given kind having the same properties. The atoms of a given element have a characteristic mass.

3. A compound is a type of matter composed of atoms of two or more elements chemically combined in fixed proportions. The relative numbers of any two kinds of atoms in a compound occur in simple ratios.

2.1 Atomic Theory of Matter

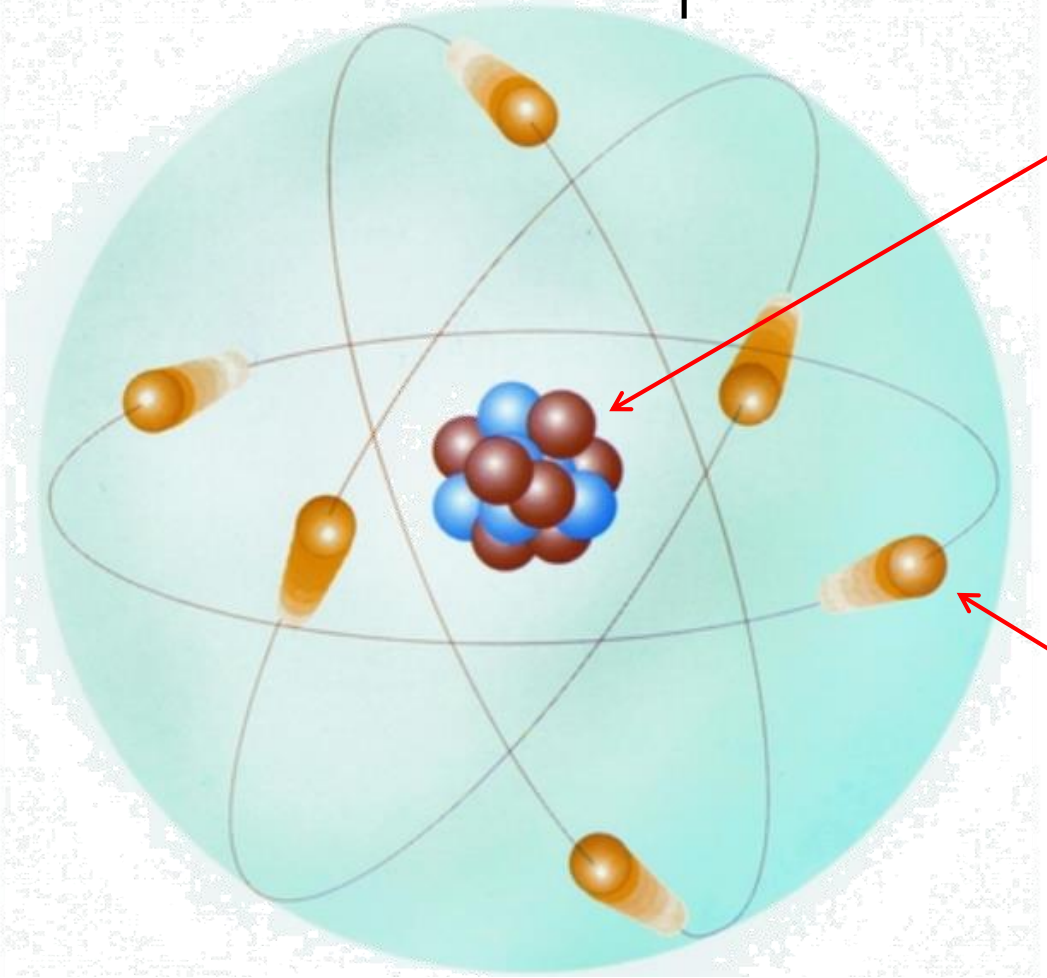
Postulates of Dalton's Atomic Theory

4. A chemical reaction consists of the rearrangement of the atoms present in the reacting substances to give new chemical combinations present in the substances formed by the reaction. Atoms are not created, destroyed, or broken into smaller particles by any chemical reaction.

2.2 The Structure of the Atom

The structure of the atom:

Atoms consist of particles



Nucleus

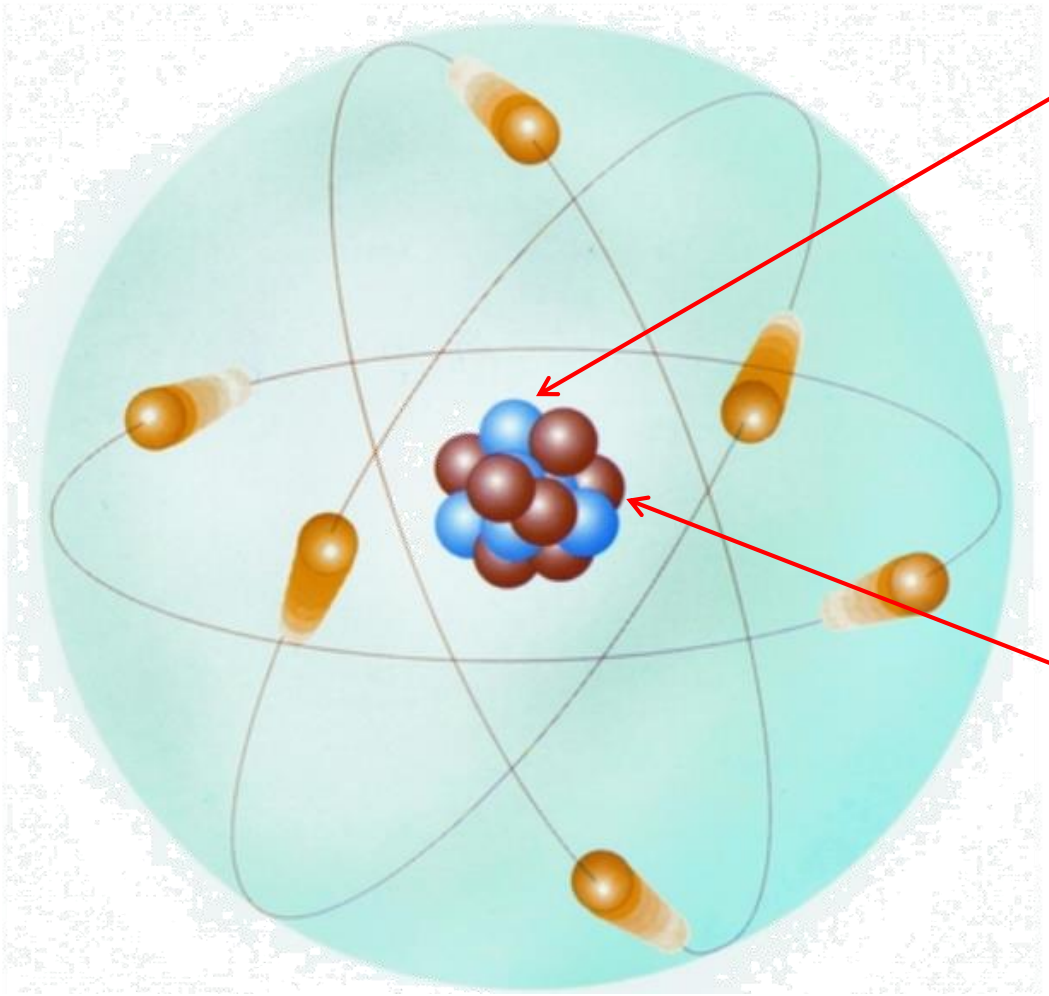
positively charged

Contains most of the atom's mass

Electron

negatively charged

2.3 Nuclear Structure; Isotopes



Proton
positive charged
atomic number (Z)

Neutron
no electric charge
Mass almost identical
to protons

2.3 Nuclear Structure; Isotopes

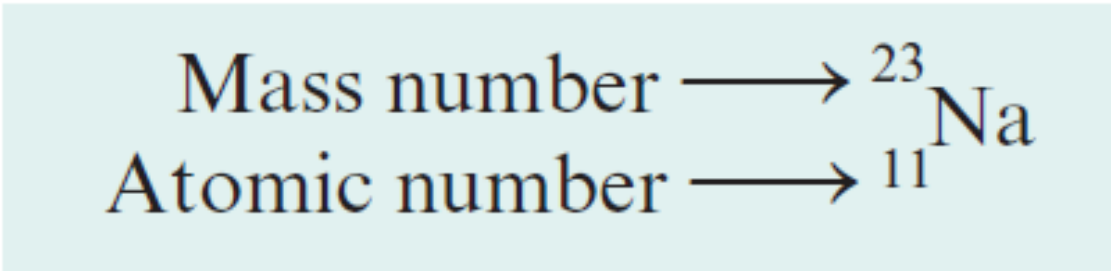
- Nuclear Structure

  atomic number (Z) = proton number

  mass number (A) =

  proton number + neutron number

nuclide



2.3 Nuclear Structure; Isotopes

- Element: a substance whose atoms all have the same atomic number

units of electron charge

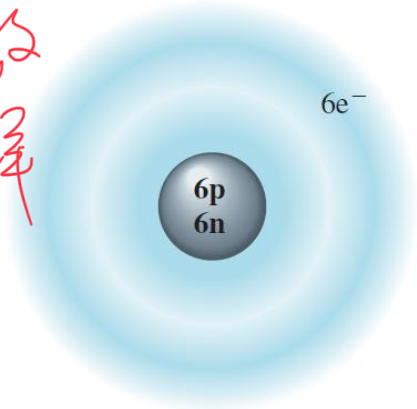
TABLE 2.1 Properties of the Electron, Proton, and Neutron

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

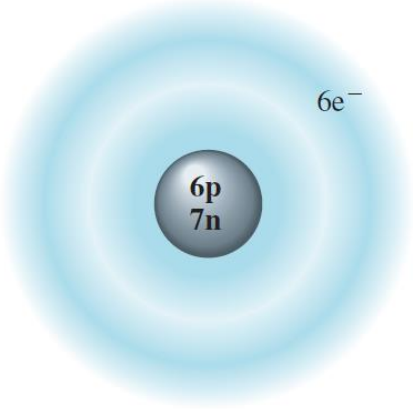
*The atomic mass unit (amu) equals 1.66054×10^{-27} kg; it is defined in Section 2.4.

2.3 Nuclear Structure; Isotopes

- Isotopes: atoms whose nuclei have the same atomic number but different mass numbers



carbon-12



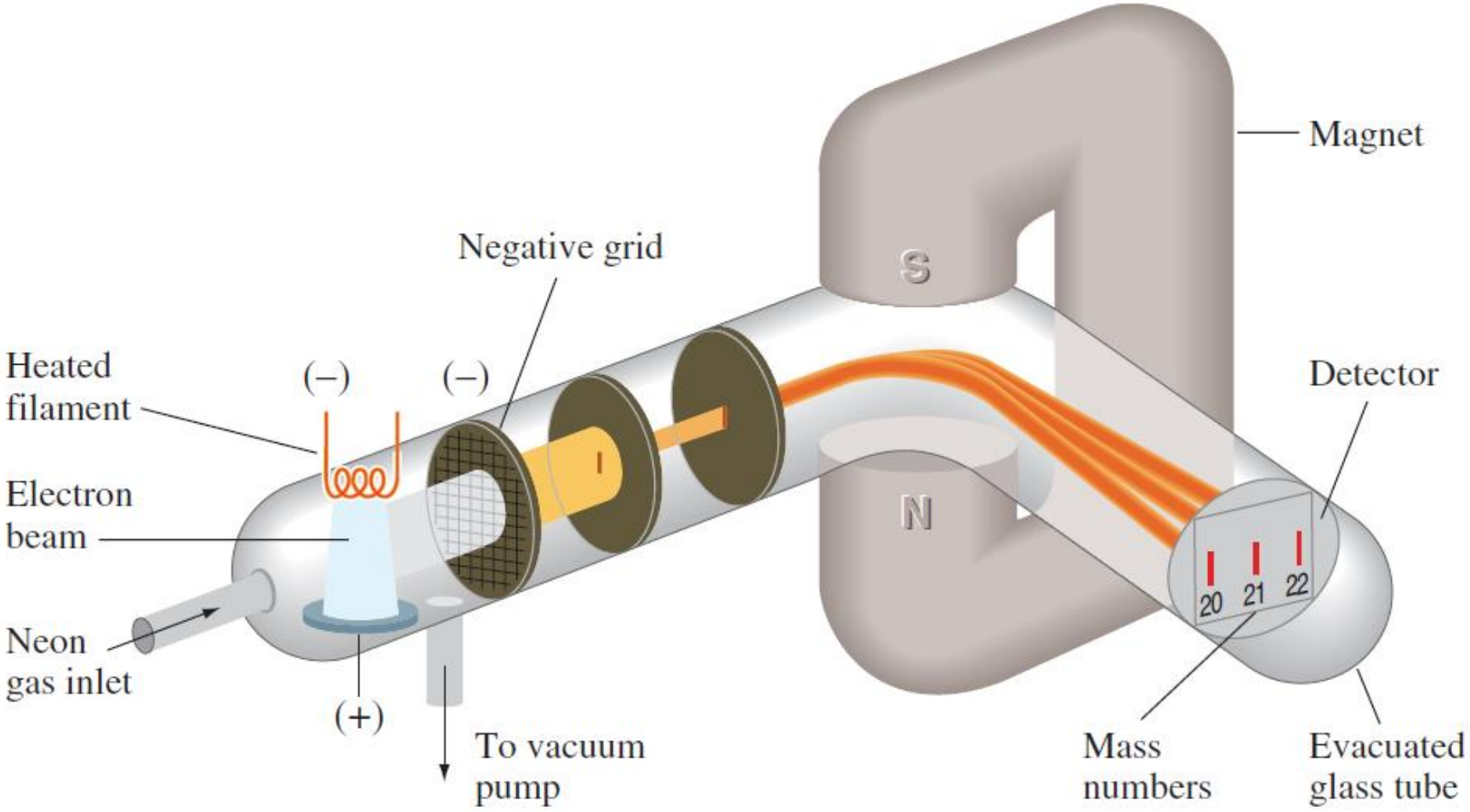
carbon-13

2.4 Atomic Masses

- atomic mass unit (amu): a mass unit equal to exactly one-twelfth the mass of a carbon-12 atom
- atomic mass: the average atomic mass for the naturally occurring element, expressed in atomic mass units

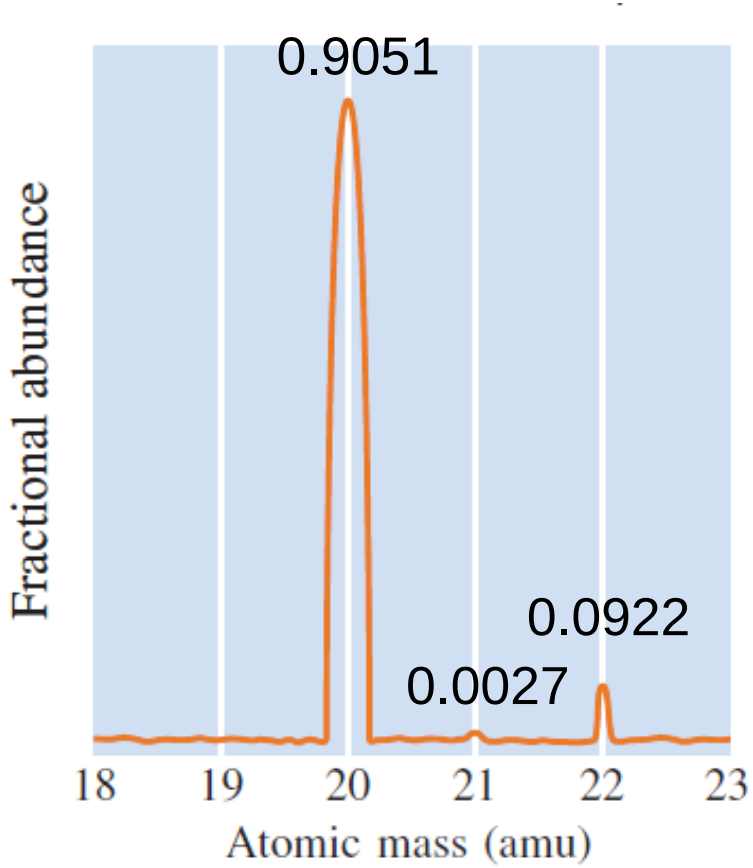
2.4 Atomic Masses

- **mass spectrometer**



2.4 Atomic Masses

- **The mass spectrum of neon**



fractional abundance: the fraction of the total number of atoms that is composed of a particular isotope

P51 Example 2.2

Example 2.2 | Determining Atomic Mass

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?

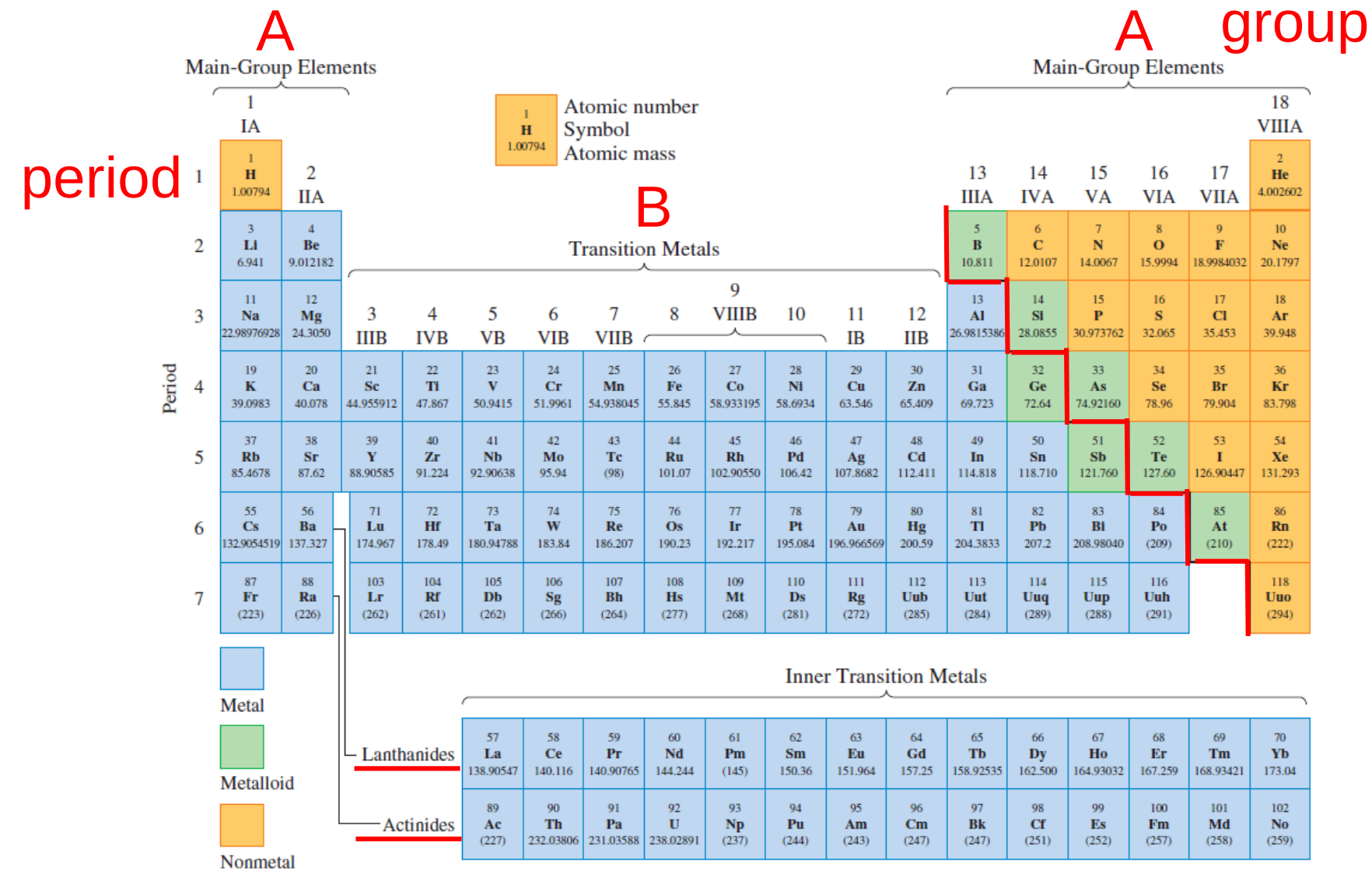
$$\begin{aligned} 49.9461 \text{ amu} \times 0.0435 &= 2.17 \text{ amu} \\ 51.9405 \text{ amu} \times 0.8379 &= 43.52 \text{ amu} \\ 52.9407 \text{ amu} \times 0.0950 &= 5.03 \text{ amu} \\ 53.9389 \text{ amu} \times 0.0236 &= 1.27 \text{ amu} \\ &\overline{\quad\quad\quad} \\ &51.99 \text{ amu} \end{aligned}$$

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

2.5 Periodic Table of the Elements

- Periodic table: A tabular arrangement of elements in rows and columns, highlighting the regular repetition of properties of the elements

2.5 Periodic Table of the Elements



2.5 Periodic Table of the Elements

- Metal: a substance or mixture that has a characteristic luster, or shine, and is generally a good conductor of heat and electricity.
- Nonmetal: an element that does not exhibit the characteristics of a metal

2.5 Periodic Table of the Elements

- Metalloid, or semimetal: an element having both metallic and nonmetallic properties. *E.g.*, Si, Ge are good semiconductors.

2.5 Periodic Table of the Elements

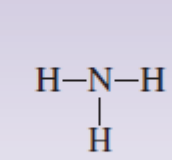
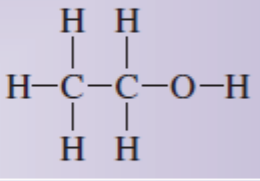
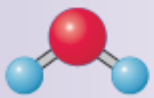
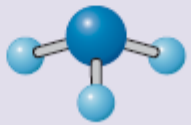
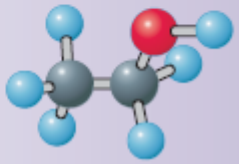
- Periodic Table of the Elements
  - H: hydrogen
  - He: helium
  - Li: lithium
  - B: boron
  - C: carbon
  - N: nitrogen
  - O: oxygen
  - F: fluorine
  - Na: sodium
  - Mg: magnesium
  - Al: aluminium
  - Cl: chlorine
  - K: potassium
  - Ca: calcium
  - Fe: iron
  - Au: gold

2.6 Chemical Formulas; Molecular and Ionic Substances

- Chemical formula: a notation that uses atomic symbols with numerical subscripts to convey the relative proportions of atoms of the different elements in the substance. *E.g.*, Al_2O_3.

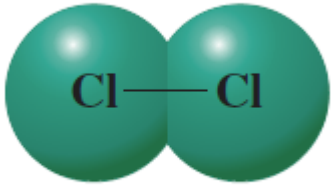
2.6 Chemical Formulas; Molecular and Ionic Substances

- Molecular Substances
  - Molecule: a definite group of atoms that are chemically bonded together
  - Molecular formula: gives the exact number of different atoms of an element in a molecule

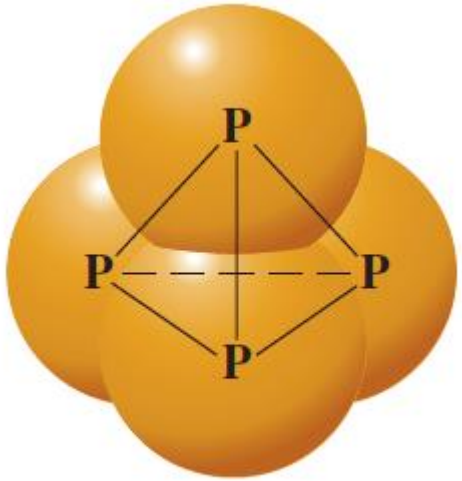
	Water	Ammonia	Ethanol
Molecular formula	H_2O	NH_3	C_2H_6O
Structural formula	H–O–H		
Molecular model (ball-and-stick type)			

2.6 Chemical Formulas; Molecular and Ionic Substances

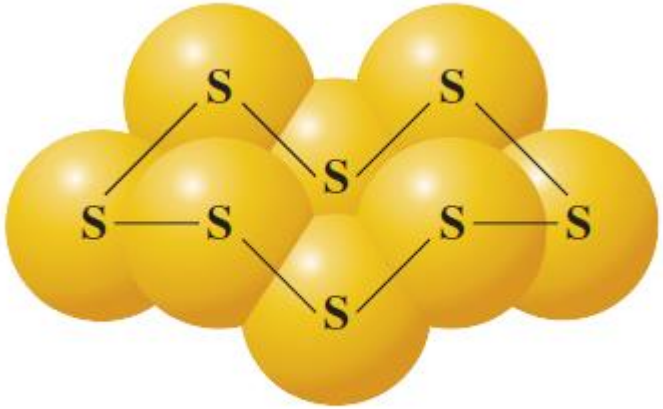
- Molecular models of some elementary substances



Cl_2



P_4



S_8

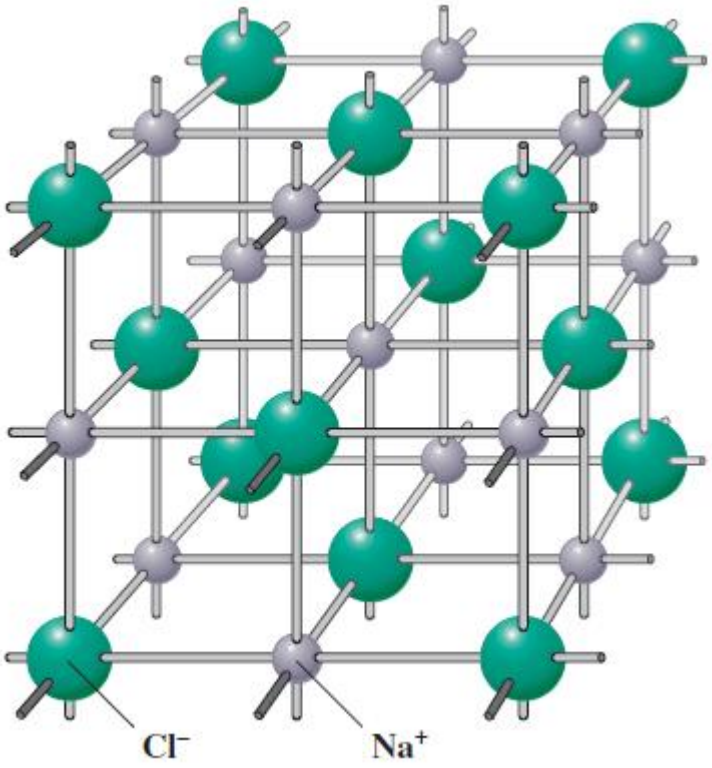
He, C_{60}

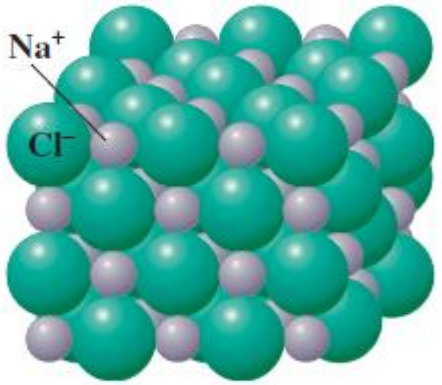
2.6 Chemical Formulas; Molecular and Ionic Substances

- Ionic Substances

cation

anion





NaCl

$Fe_2(SO_4)_3$

P58 Example 2.3

Example 2.3 Writing an Ionic Formula, Given the Ions

a. Chromium(III) oxide is used as a green paint pigment (Figure 2.22). It is a compound composed of Cr^{3+} and O^{2-} ions. What is the formula of chromium(III) oxide?

b. Strontium oxide is a compound composed of Sr^{2+} and O^{2-} ions. Write the formula of this compound.

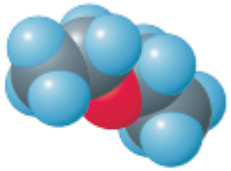
2.7 Organic Compounds

Must contain carbon and hydrogen

CH_4
Methane

C_2H_6
Ethane

CH_3OH
Methanol



$CH_3CH_2OCH_2CH_3$
Diethyl ether

C_3H_8
Propane

C_2H_2
Acetylene

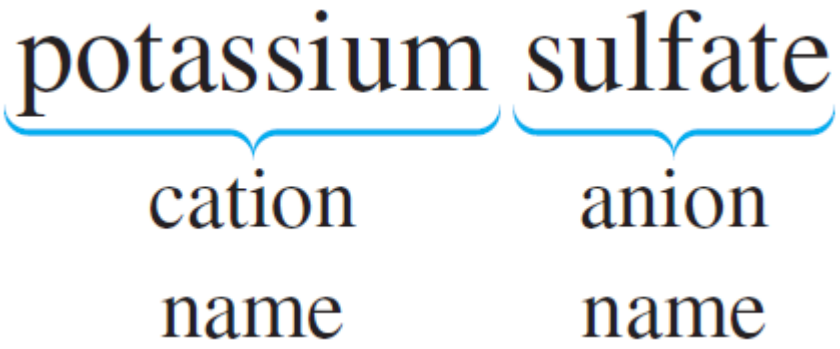
C_6H_6
Benzene

TABLE 2.2 **Examples of Organic Functional Groups**

Functional Group	Name of Functional Group	Example Molecule	Common Use
—OH	Alcohol	Methyl alcohol (CH_3OH)	Windshield washer
—O—	Ether	Dimethyl ether (CH_3OCH_3)	Solvent
—COOH	Carboxylic acid	Acetic acid (CH_3COOH)	Acid in vinegar

2.8 Naming Simple Compounds

- Nomenclature: systematic naming
- Ionic compounds



2.8 Naming Simple Compounds

- Ionic compounds NaCl?

  monoatomic cations: element name

  monoatomic anions: a stem name of the element followed by the suffix -ide

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.

2.8 Naming Simple Compounds

- Ionic compounds

  monoatomic cations: element name

  monoatomic anions: a stem name of the element followed by 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

2.8 Naming Simple Compounds

- Ionic compounds Potassium sulfate?

SO_3^{2-} sulfite ion

SO_4^{2-} sulfate ion

NO_2^- nitrite ion

NO_3^- nitrate ion

2.8 Naming Simple Compounds

- Ionic Compounds

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	$S_2O_3^{2-}$

P64 Example 2.4

chromium(II) sulfate

Name the following: a. Mg_3N_2, b. $CrSO_4$.

magnesium nitride

2.8 Naming Simple Compounds

- Binary Molecular Compounds

Element	B	Si	C	Sb	As	P	N	H	Te	Se	S	I	Br	Cl	O	F
Group	IIIA	IVA		VA					VIA			VIIA				

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-

N_2O_3: dinitrogen trioxide

HCl: hydrogen chloride

CO: carbon monoxide

CO_2: carbon dioxide

P66 Example 2.6

tetraphosphorus hexoxide

Name the following compounds: a. N_2O_4, b. P_4O_6.

dinitrogen tetroxide

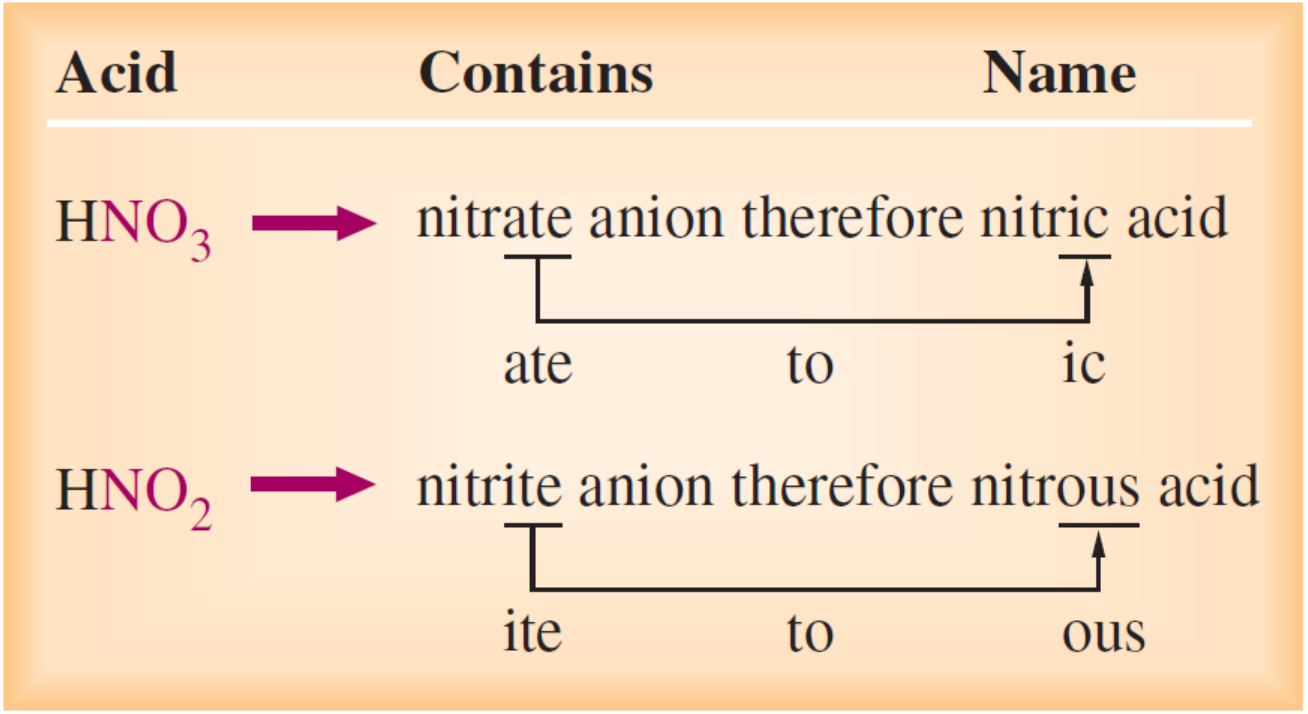
2.8 Naming Simple Compounds

- Acids and Corresponding Anions
- Oxoacid: an acid containing hydrogen, oxygen, and another element (often called the central atom)

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

2.8 Naming Simple Compounds

- Acids and Corresponding Anions (oxoacid)



H_2SO_4 ?
H_2SO_3

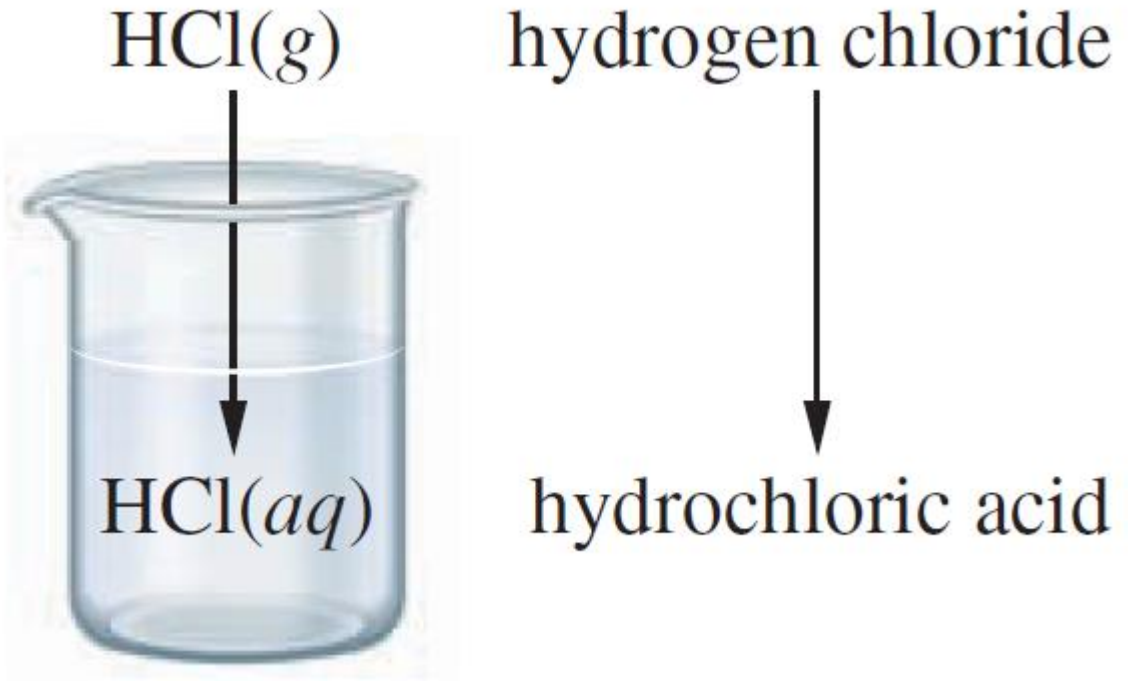
Table 2.7

TABLE 2.7 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*

2.8 Naming Simple Compounds

- Acids and Corresponding Anions



HF
HBr ?

2.8 Naming Simple Compounds

- Hydrates: a compound that contains water molecules weakly bound in its crystals

FIGURE 2.27 ▲

Copper(II) sulfate
The hydrate $CuSO_4 \cdot 5H_2O$ is blue; the anhydrous compound, $CuSO_4$, is white.

2.9 Writing Chemical Equations

coefficient

$$2NaNO_3(s) \xrightarrow{\Delta} 2NaNO_2(s) + O_2(g)$$

reactant
starting material

product

a balanced equation

catalyst

$$2H_2O_2(aq) \xrightarrow{Pt} 2H_2O(l) + O_2(g)$$

2.10 Balancing Chemical Equations

CH_4	+	$2O_2$	$\longrightarrow$	CO_2	+	$2H_2O$
one molecule	+	two molecules	react to	one molecule	+	two molecules
of methane		of oxygen	form	of carbon dioxide		of water

$$C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$$

P73 Example 2.12

Example 2.12 Balancing Simple Equations

Balance the following equations.

a. $H_3PO_3 \longrightarrow H_3PO_4 + PH_3$ b. $Ca + H_2O \longrightarrow Ca(OH)_2 + H_2$

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

$$\mathbf{4H_3PO_3 \longrightarrow 3H_3PO_4 + PH_3}$$

$$\mathbf{Ca + 2H_2O \longrightarrow Ca(OH)_2 + H_2}$$

$$\mathbf{Fe_2(SO_4)_3 + 6NH_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3(NH_4)_2SO_4}$$