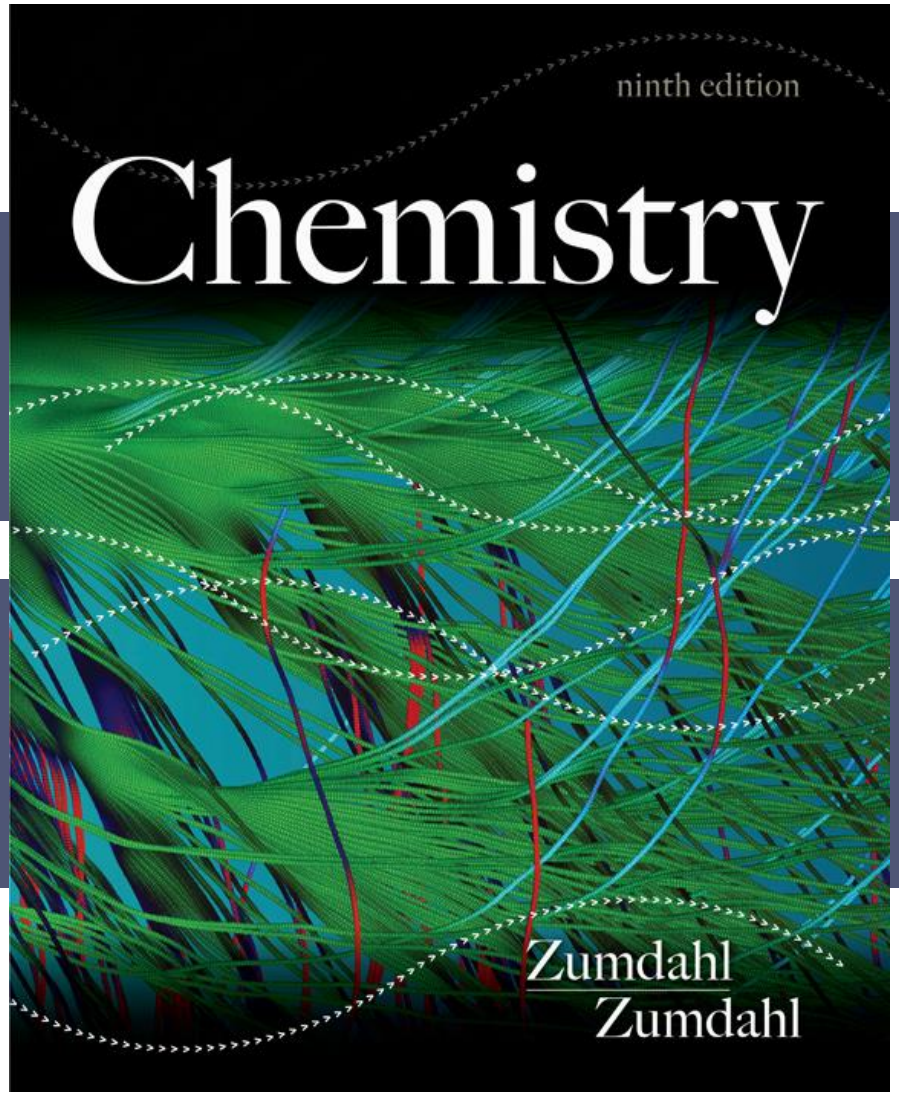
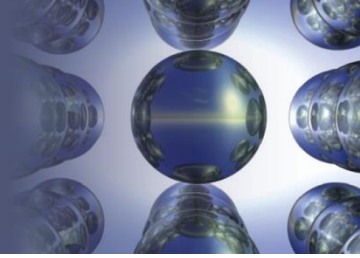


Chapter 2

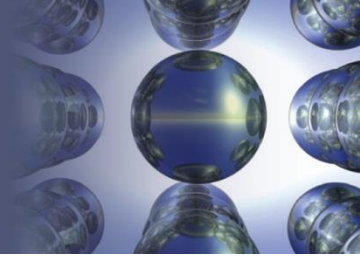
Atoms, Molecules, and Ions



- The atom contains:
  - *Electrons* – found outside the nucleus; negatively charged.
  - *Protons* – found in the nucleus; positive charge equal in magnitude to the electron's negative charge.

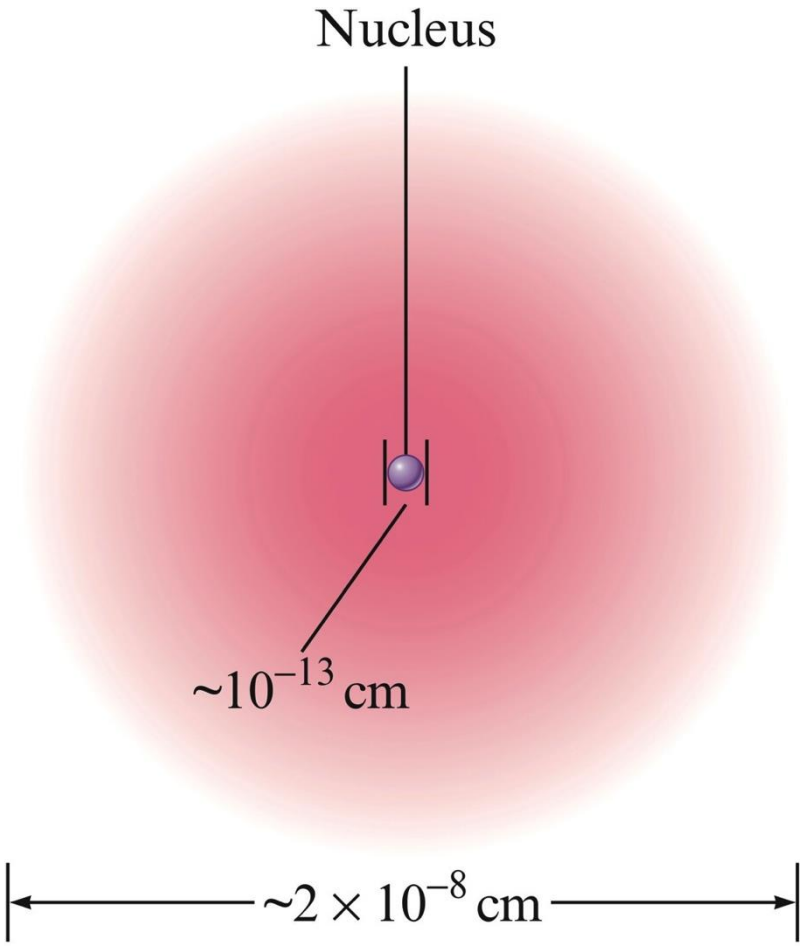
The number of protons in an atom is called the atomic number, (Z).

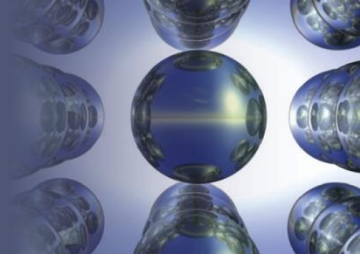
  - *Neutrons* – found in the nucleus; no charge; virtually same mass as a proton.



- The nucleus is:
  - Small compared with the overall size of the atom.
  - Extremely dense; accounts for almost all of the atom's mass.

Nuclear Atom Viewed in Cross Section

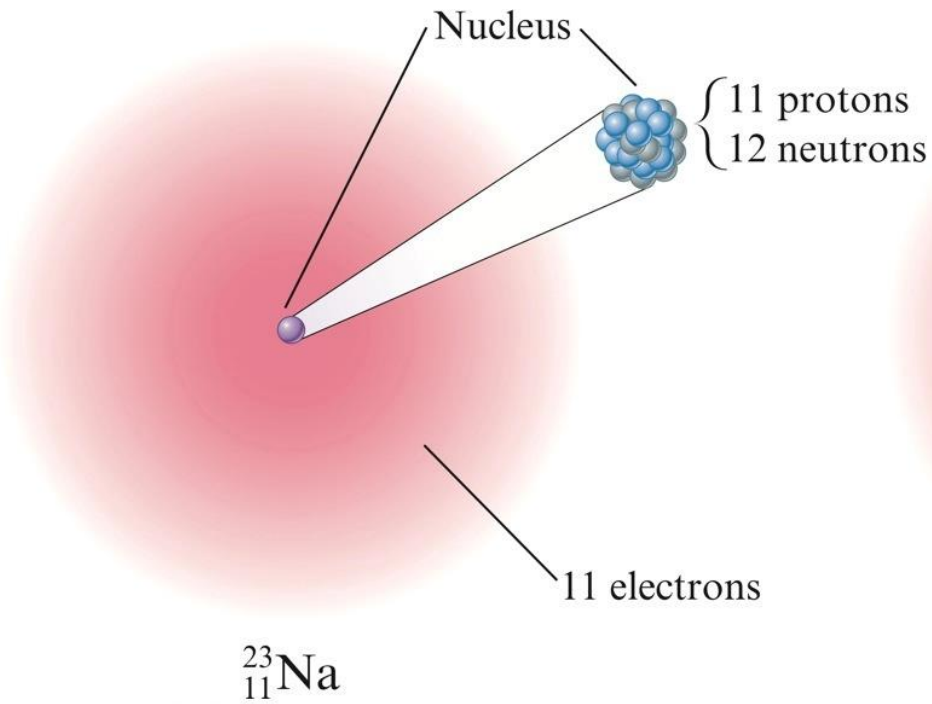


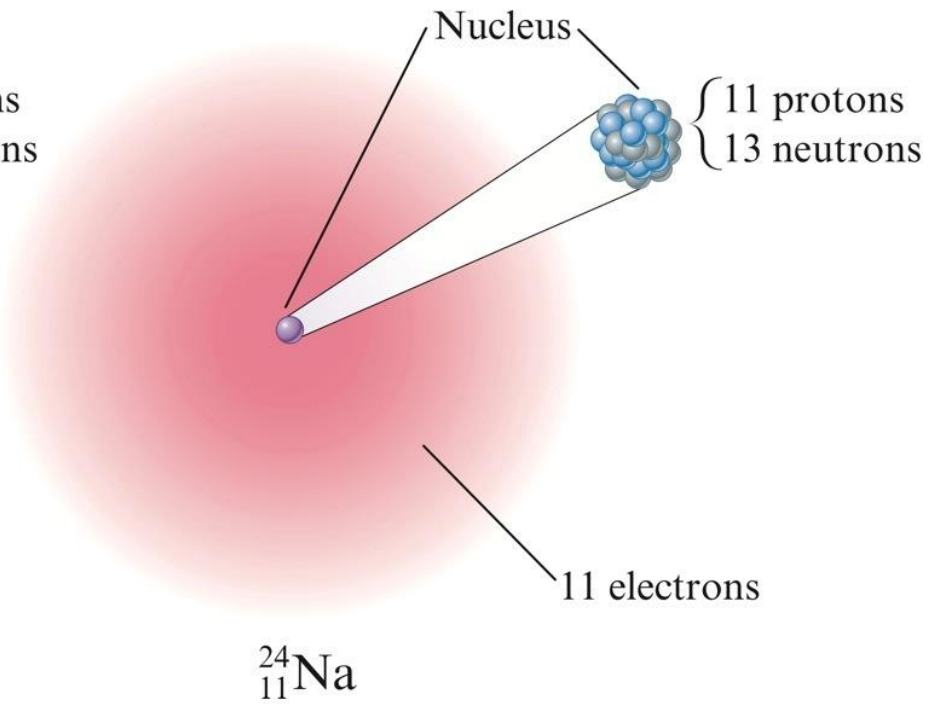


Isotopes

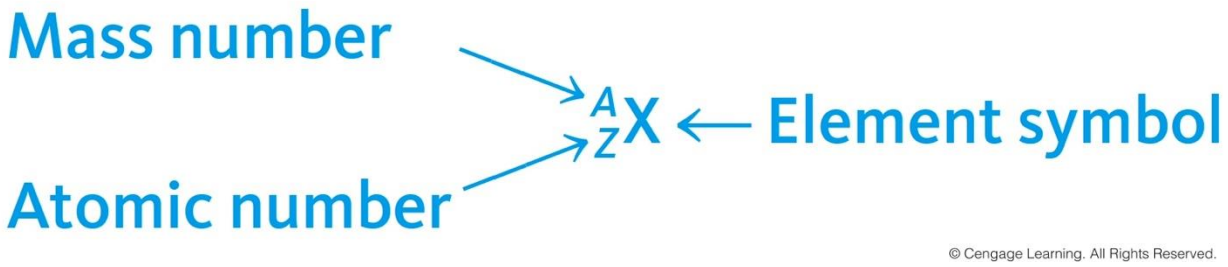
- Atoms with the same number of protons but different numbers of neutrons.
- Show almost identical chemical properties; chemistry of atom is due to its electrons.
- In nature most elements contain mixtures of isotopes.

Two Isotopes of Sodium

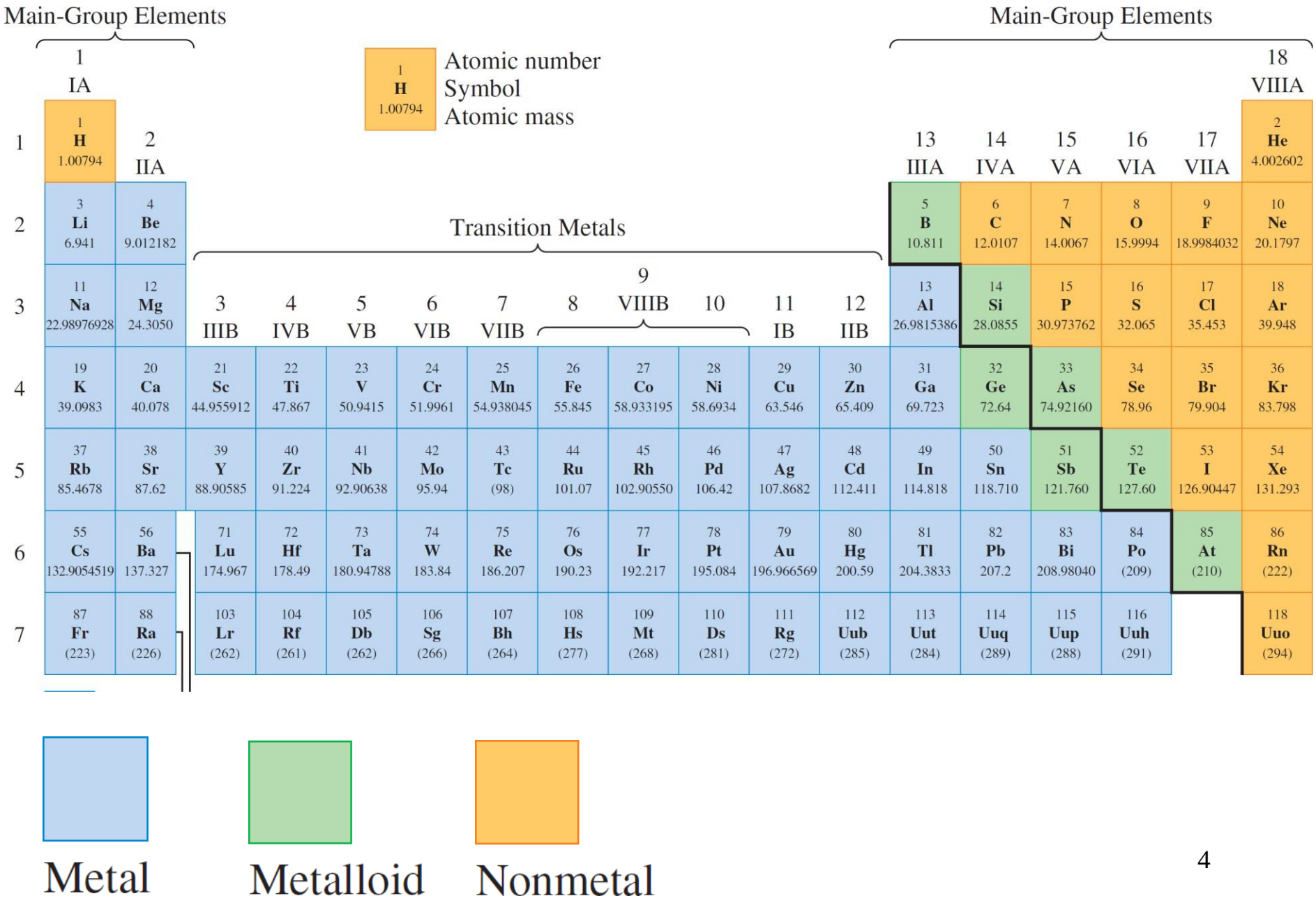


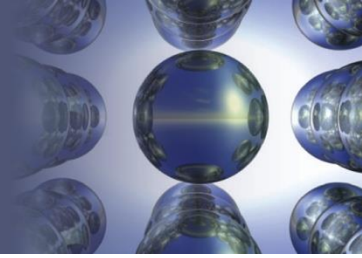


- Isotopes are identified by:
  - Atomic Number (Z) – number of protons
  - Mass Number (A) – number of protons plus number of neutrons



Periodic Table of The Elements





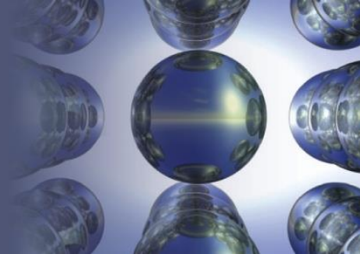
EXERCISE!

A certain isotope X contains 23 protons and 28 neutrons.

- What is the mass number of this isotope?
- Identify the element.

Mass Number = 51

Vanadium

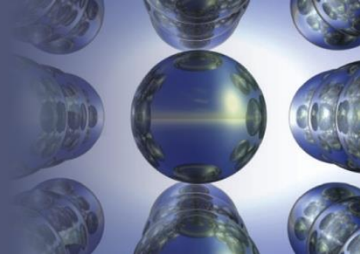


EXERCISE!

A certain isotope X^+ contains 54 electrons and 78 neutrons.

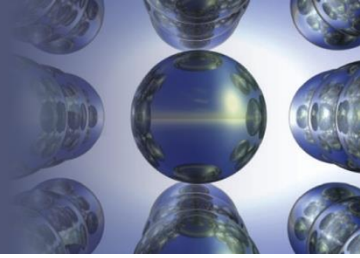
- What is the mass number of this isotope?

133



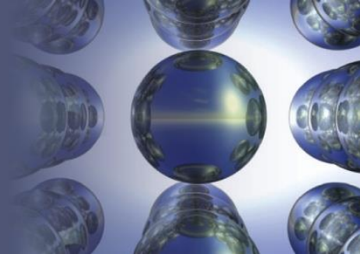
Chemical Bonds

- Covalent Bonds
  - Bonds form between atoms by sharing electrons.
  - Resulting collection of atoms is called a molecule.



Chemical Bonds

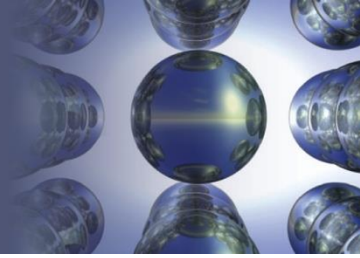
- Ionic Bonds
  - Bonds form due to force of attraction between oppositely charged ions.
  - *Ion* – atom or group of atoms that has a net positive or negative charge.
  - *Cation* – positive ion; lost electron(s).
  - *Anion* – negative ion; gained electron(s).



CONCEPT CHECK!

Which of the following statements regarding Dalton's atomic theory are still believed to be true?

I. Elements are made of tiny particles called atoms.
II. All atoms of a given element are identical.
III. A given compound always has the same relative numbers and types of atoms.
IV. Atoms are indestructible.

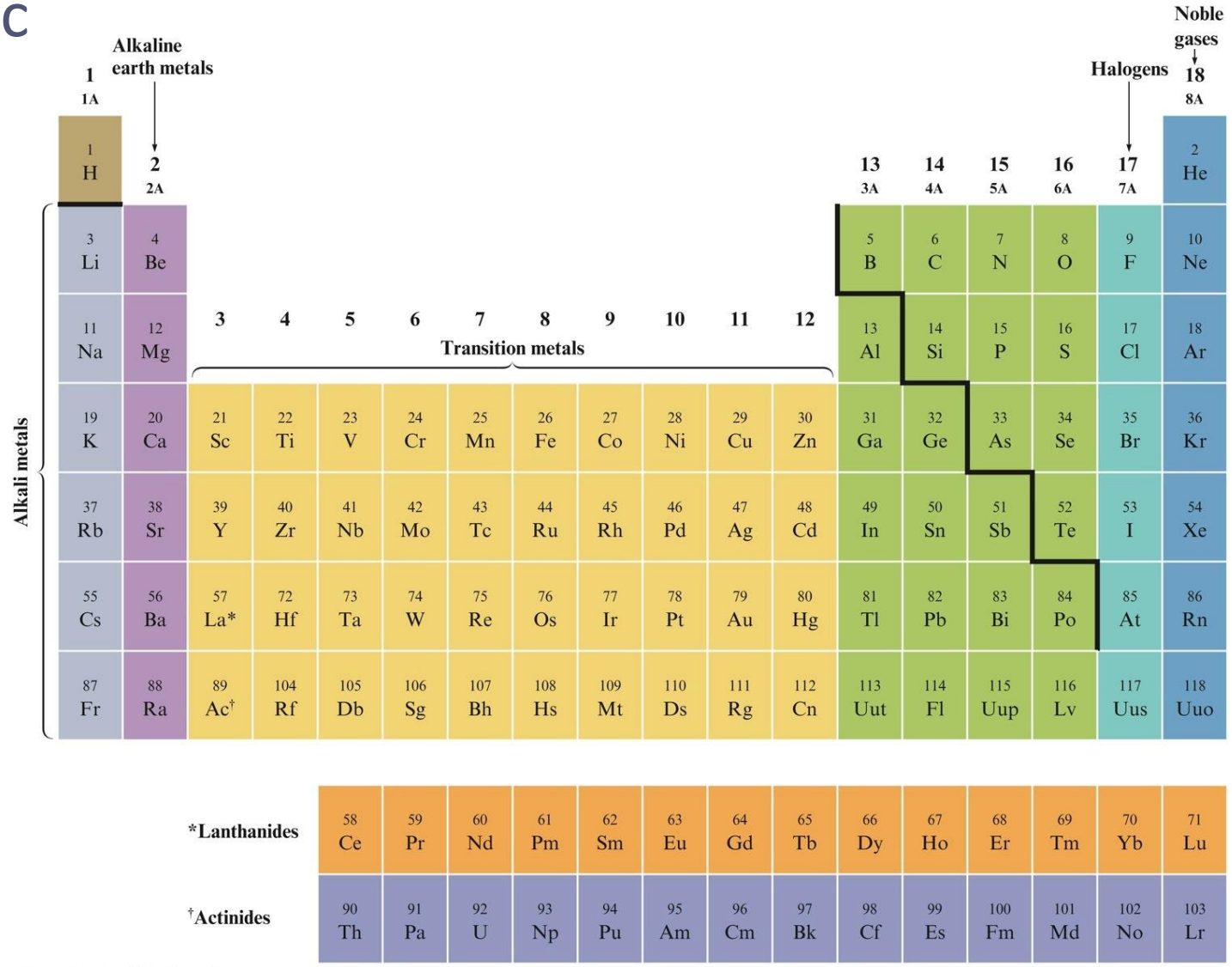


The Periodic Table

- *Metals vs. Nonmetals*
- *Groups or Families* – elements in the same vertical columns; have similar chemical properties
- *Periods* – horizontal rows of elements

Section 2.7
An Introduction to the Periodic Table

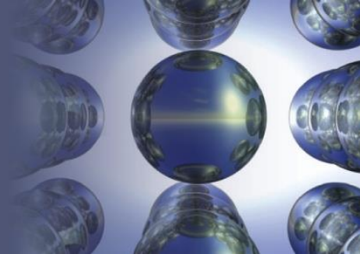
The Periodic Table



Groups or Families

- Table of common charges formed when creating ionic compounds.

Group or Family	Charge
Alkali Metals (1A)	1+
Alkaline Earth Metals (2A)	2+
Halogens (7A)	1–
Noble Gases (8A)	0



Naming Compounds

- Binary Compounds
  - Composed of two elements (CO, H_2O, CCl_4, NH_3)
  - Ionic and covalent compounds included
- Binary Ionic Compounds
  - Metal—nonmetal (Mg_3N_2 , NaCl)
- Binary Covalent Compounds
  - Nonmetal—nonmetal (SF_6)

2.8 Naming Simple Compounds (Chemical nomenclature)

-nomenclature of some simple inorganic compounds

- **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.**

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.

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.*

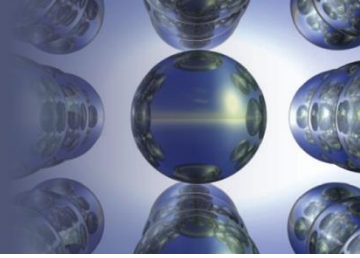
TABLE 2.4 | Common Cations of the Transition Elements

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)

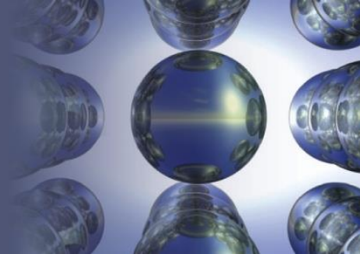
TABLE 2.5 | Some Common Polyatomic Ions

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	$S_2O_3^{2-}$



Binary Ionic Compounds (Type I)

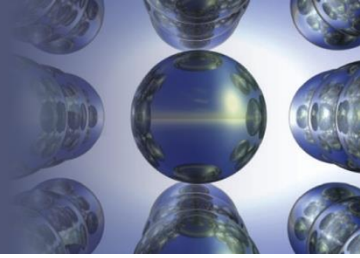
1. The cation is always named first and the anion second.
2. A monatomic cation takes its name from the name of the parent element.
3. A monatomic anion is named by taking the root of the element name and adding –*ide*.



Binary Ionic Compounds (Type I)

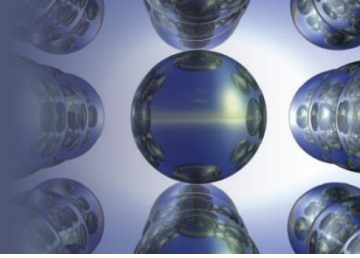
- Examples:

KCl	Potassium chloride
$MgBr_2$	Magnesium bromide
CaO	Calcium oxide



Binary Ionic Compounds (Type II)

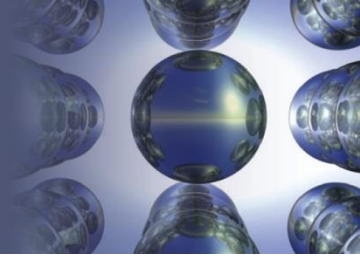
- Metals in these compounds form more than one type of positive ion.
- Charge on the metal ion must be specified.
- Roman numeral indicates the charge of the metal cation.
- Transition metal cations usually require a Roman numeral.
- Elements that form only one cation do not need to be identified by a roman numeral.



Binary Ionic Compounds (Type II)

- Examples:

CuBr	Copper(I) bromide
FeS	Iron(II) sulfide
PbO_2	Lead(IV) oxide



Polyatomic Ions

- Must be memorized (see Table 2.5 on pg. 65 in text).
- Examples of compounds containing polyatomic ions:

NaOH	Sodium hydroxide
$Mg(NO_3)_2$	Magnesium nitrate
$(NH_4)_2SO_4$	Ammonium sulfate

- **Polyatomic Ions** → mono, di, etc

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	$Tl(NO_3)_3$

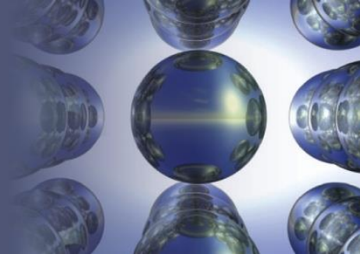
(Q) Which is the correct name for Cu_2S?

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. $(NH_4)_2S$

Section 2.8
Naming Simple Compounds



- For each of the following binary compounds, decide whether the compound is expected to be ionic or molecular.

- A) SeF_4 — Molecular
- B) LiBr — Ionic
- C) SiF_4 — Molecular
- D) Cs_2O — Ionic

(Q) Name the following compounds:

(a) $Fe(NO_3)_2$ iron(II) nitrate

(b) Na_2HPO_4 Sodium hydrogen phosphate

(c) $(NH_4)_2(C_2O_4)$ Ammonium oxalate

(Q) Write chemical formulas for the following compounds:

(a) cesium sulfide Cs_2S

(b) calcium phosphate $Ca_3(PO_4)_2$

Binary Covalent Compounds (Type III):

(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.

N_2O_3 dinitrogentrioxide

HCl hydrogen chloride NOT monohydrogen monochloride

CO carbon monoxide CO_2 carbon dioxide

NOT monocarbon monoxide

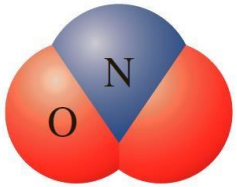
SF_4 sulfur tetrafluoride ClO_2 chlorine dioxide

SF_6 sulfur hexafluoride Cl_2O_7 dichlorine heptoxide

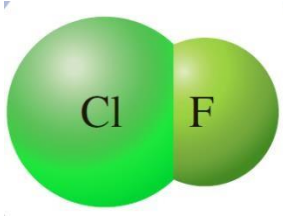
H_2S	dihydrogen sulfide	common name: hydrogen sulfide
NO	nitrogen monoxide	common name: nitric oxide
H_2O	water	
NH_3	ammonia	

N_2O_4	dinitrogen tetroxide
P_4O_6	tetraphosphorus hexoxide
Cl_2O_6	dichlorine hexoxide
PCl_3	phosphorus trichloide
PCl_5	phosphorus pentachloide

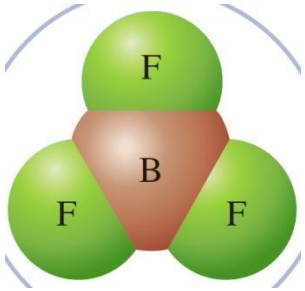
disulfur dichloride	S_2Cl_2
tetraphosphorus trisulfide	P_4S_3
carbon disulfide	CS_2
sulfur trioxide	SO_3



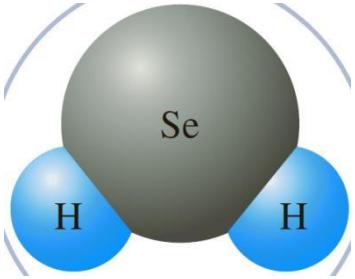
nitrogen dioxide



Chlorine monofluoride

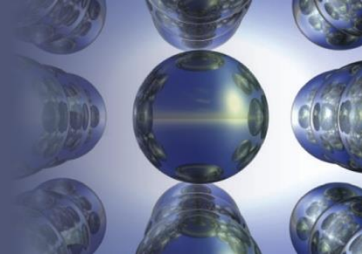


Boron trifluoride



Hydrogen selenide
Or dihydrogen selenide

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

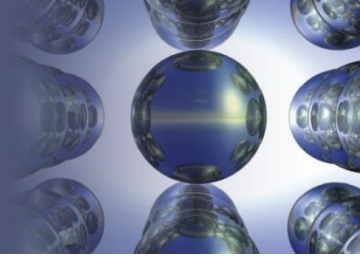


Prefixes Used to Indicate Number in Chemical Names

covalent
Type 3

Table 2.6 | Prefixes Used to Indicate Number in Chemical Names

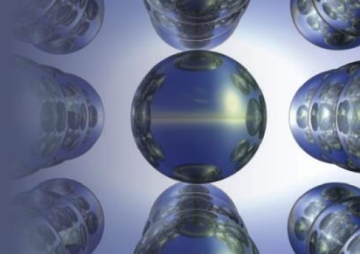
Prefix	Number Indicated
mono-	1
di-	2
tri-	3
tetra-	4
penta-	5
hexa-	6
hepta-	7
octa-	8
nona-	9
deca-	10



Binary Covalent Compounds (Type III)

- Formed between two nonmetals.

1. The first element in the formula is named first, using the full element name.
2. The second element is named as if it were an anion.
3. Prefixes are used to denote the numbers of atoms present.
4. The prefix *mono-* is never used for naming the first element.



Binary Covalent Compounds (Type III)

- Examples:

CO_2	Carbon dioxide
SF_6	Sulfur hexafluoride
N_2O_4	Dinitrogen tetroxide

Naming Hydrates

- Hydrate is a compound that contains water molecules weakly bound in the crystals

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

$FeI_3.3H_2O$ iron(III) iodide trihydrate

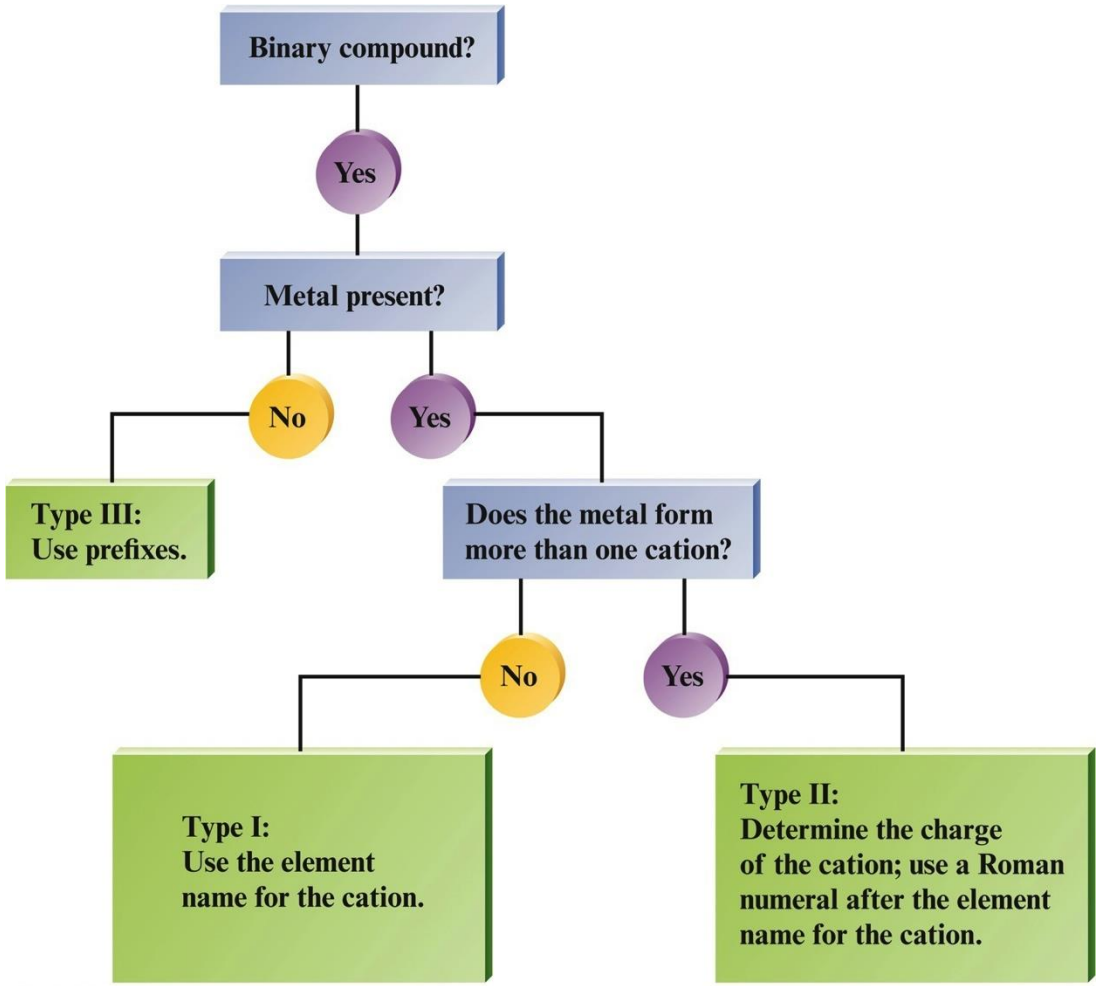
$Fe(NO_2)_3.9H_2O$ iron(III) nitrite nonahydrate

TABLE 2.6

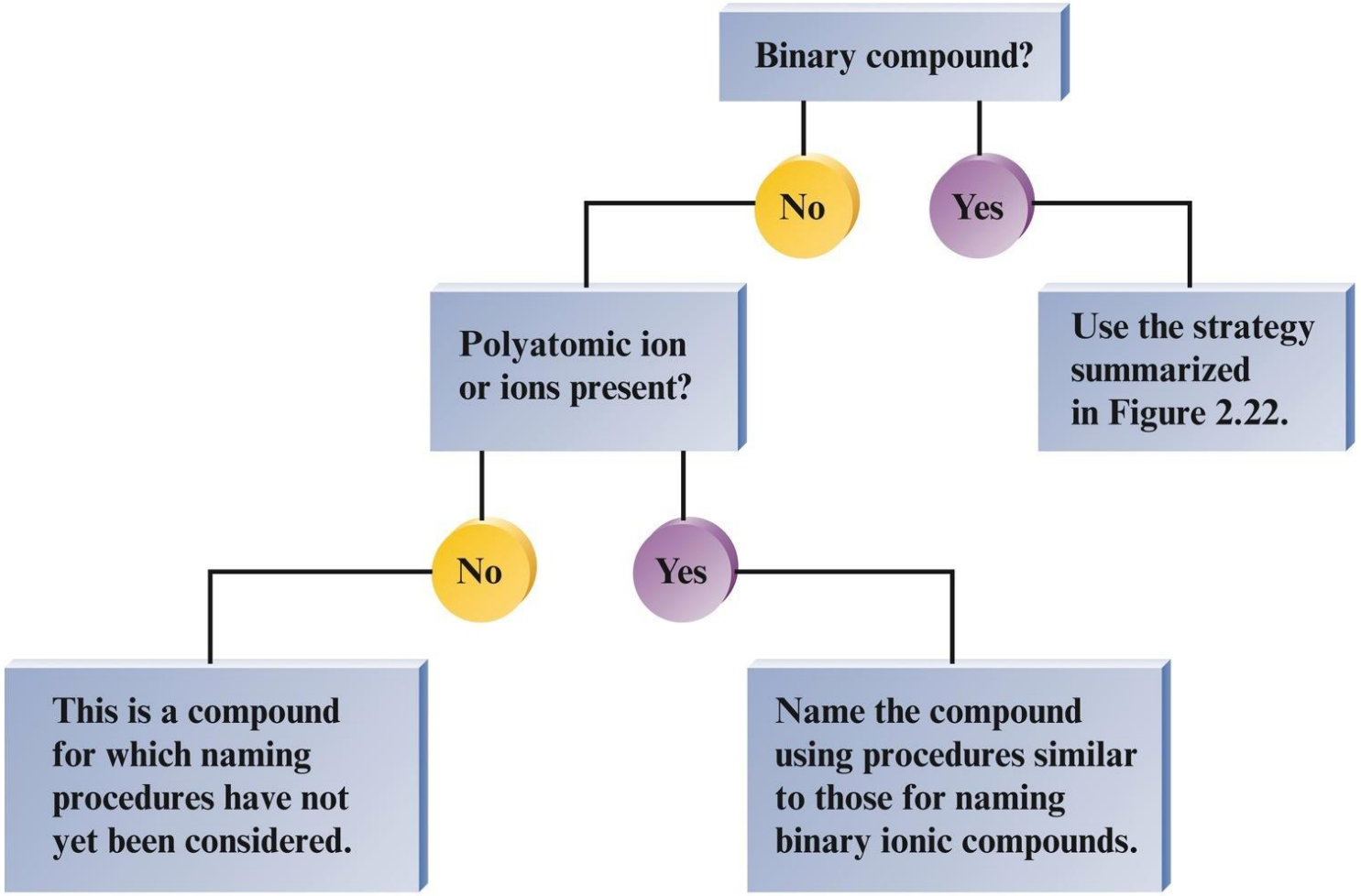
Greek Prefixes for Naming Compounds

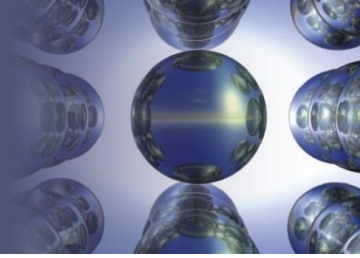
Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Flowchart for Naming Binary Compounds



Overall Strategy for Naming Chemical Compounds





Acids

- Acids can be recognized by the hydrogen that appears first in the formula—HCl.
- Molecule with one or more H^+ ions attached to an anion.

Section 2.8
Naming Simple Compounds

Acids

- If the anion does *not* contain oxygen, the acid is named with the prefix *hydro–* and the suffix *–ic*.
- Examples:

HCl	Hydrochloric acid
HCN	Hydrocyanic acid
H_2S	Hydrosulfuric acid

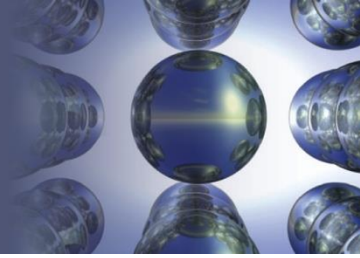
Acids

- If the anion *does* contain oxygen:
  - The suffix *–ic* is added to the root name if the anion name ends in *–ate*.
- Examples:

HNO_3	Nitric acid
H_2SO_4	Sulfuric acid
$HC_2H_3O_2$	Acetic acid

ic → ate

ite → ous



Acids

- If the anion *does* contain oxygen:
  - The suffix *–ous* is added to the root name if the anion name ends in *–ite*.
- Examples:

  HNO_2 Nitrous acid

  H_2SO_3 Sulfurous acid

  $HClO_2$ Chlorous acid

➢ Acids and Corresponding Anions

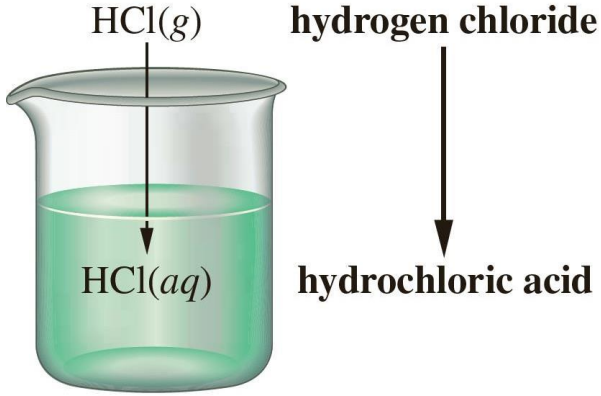
Anion Suffix	*Acid Suffix*
-ate	*-ic*
-ite	*-ous*

Acid	Contains	Name
HNO_3	→ nitrate anion	therefore nitric acid
	ate to ic	
HNO_2	→ nitrite anion	therefore nitrous acid
	ite to 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*brom*ic acid,* HBr(*aq*)
HF(*g*), hydrogen fluoride	*hydro*fluor*ic acid,* HF(*aq*)



Selenium has an oxoacid, H_2SeO_4, called selenic acid. What is the formula and name of the corresponding anion?

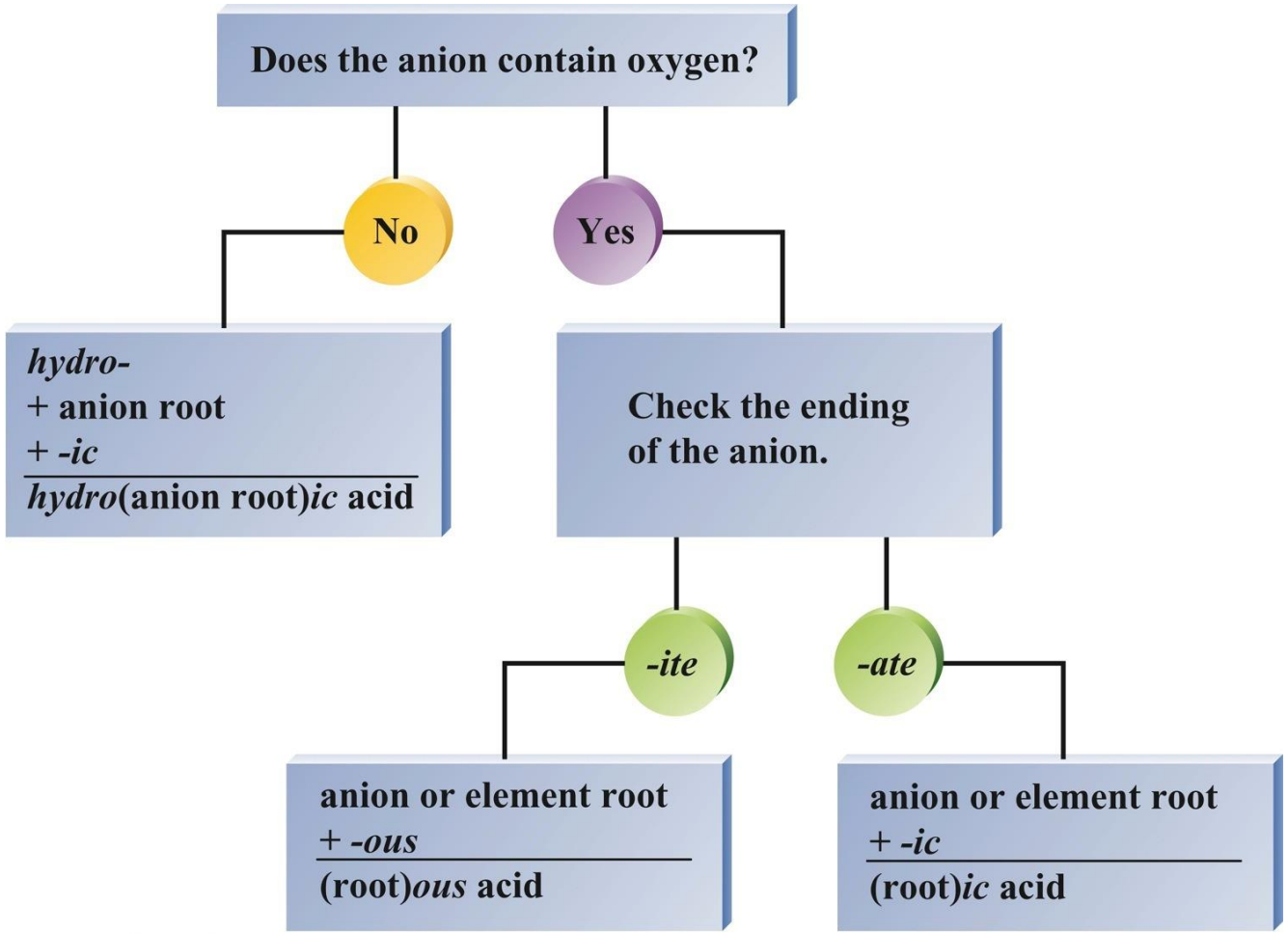
Selenate SeO_4^{2-}

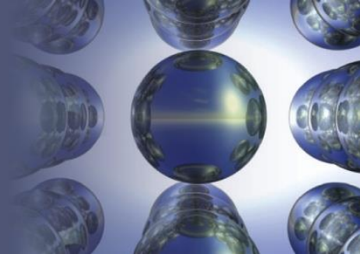
Exercise

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

BrO_4^- perbromate

Flowchart for Naming Acids





EXERCISE!

Which of the following compounds is named incorrectly?

a) KNO_3	potassium nitrate
b) TiO_2	titanium(II) oxide
c) $Sn(OH)_4$	tin(IV) hydroxide
d) PBr_5	phosphorus pentabromide
e) $CaCrO_4$	calcium chromate