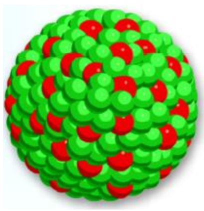
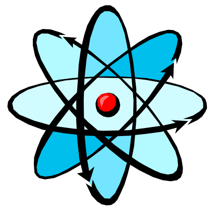
LECTURE 2

Atoms, Molecules and Ions





2.1 The Atomic Theories

2.2 The Structure of The Atom

2.3 Atomic Number, Mass Number and Isotopes

2.4 The Periodic Table

2.5 Molecules and Ions

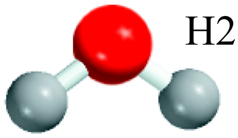
2.6 Chemical Formula

2.7 Naming Compounds

THE EVOLUTION OF THE ATOMIC MODEL

Dalton's Atomic Theory

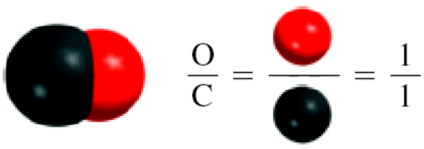
1. Elements are composed of extremely small particles called ***atoms***. ***Atoms*** of the same element all have the same size, mass and chemical properties. The atoms of one element are different from the atoms of all other element.
2. ***Compounds*** are composed of atoms of two or more elements. In any compound, the ratio of the numbers of atoms of any two of the elements present is either an integer or a simple fraction.
3. A ***chemical reaction*** involves only the separation, combination, or rearrangement of atoms; it does not result in their creation or destruction.


H2O

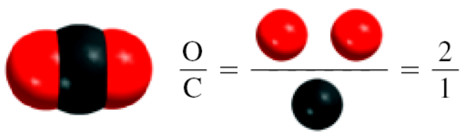
Law of Definite Proportions

- Different samples of the same compound always contains its elements in a definite proportion by mass.

Carbon monoxide

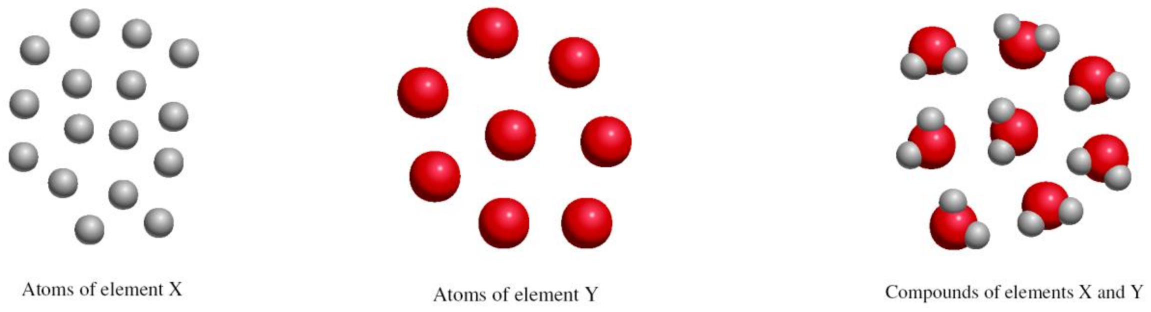


Carbon dioxide



Law of Multiple Proportions

- In different compounds of the same elements, the various masses of one element that combine with a fixed mass of another element are related by small whole-number ratios.



$$16\ X \quad + \quad 8\ Y \longrightarrow 8\ X_2Y$$

Law of Conservation of Mass

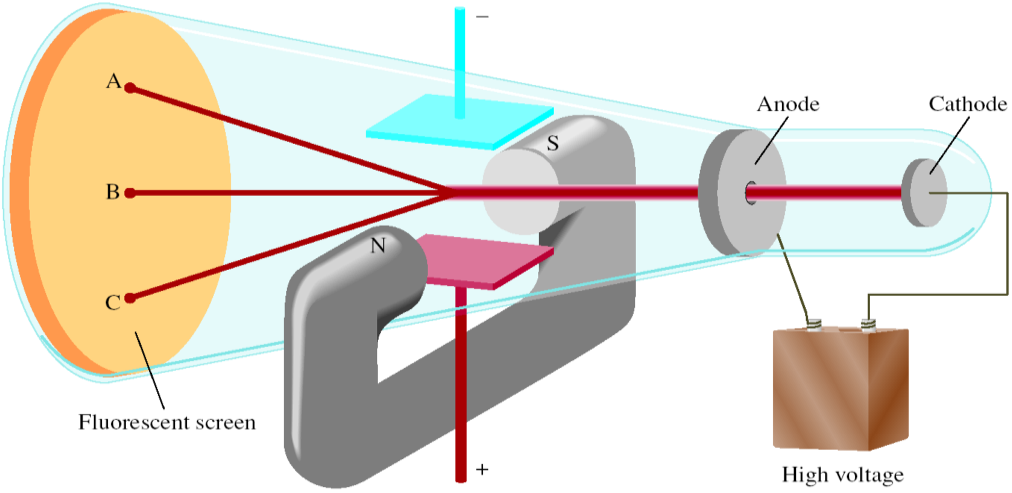
- Matter is neither created nor destroyed

The Modern View of Atomic Structure

Atom- the basic unit of an element that can enter into chemical combination (extremely small and indivisible)

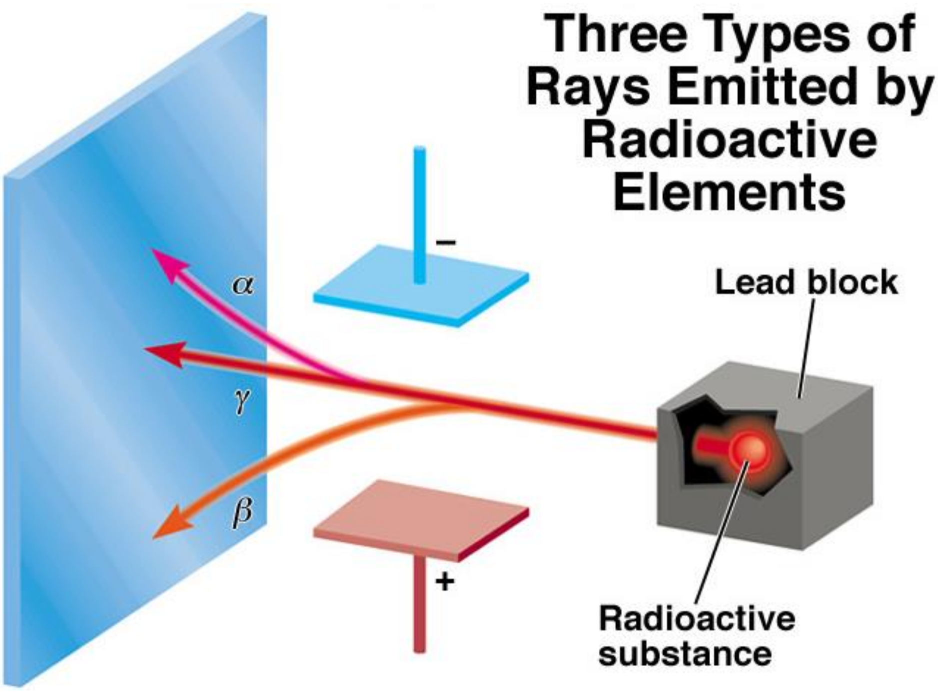
Three **subatomic particles -** electrons , protons, and neutrons.

Thomson Cathode Ray Tube experiment



- The cathode ray consist of negatively charged particles found in all matter

- Thomson together with Millikan concluded that the mass of an e - is exceedingly small (e - mass = 9.10×10^{-28} g).



(Uranium

Three types of rays produced by decay of radioactive substances such as "Uranium"..

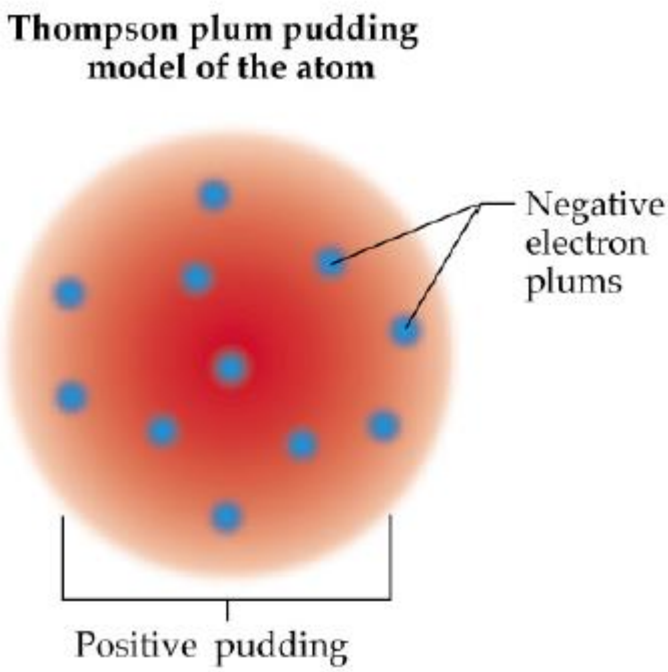
(i) **Alpha (α) rays** .. positively charged particles (α) particles .. deflected by positively charged plate

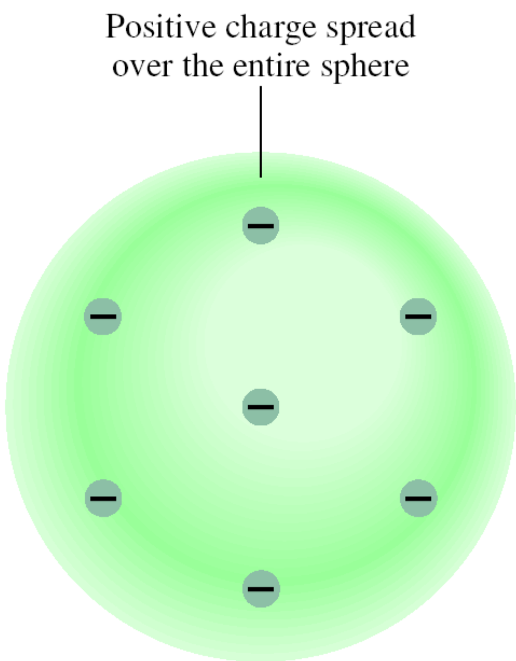
(ii) **Beta (β) rays** .. electrons .. deflected by negatively charged plate

(iii) **Gamma (γ) rays ..** high-energy rays .. no charge and are not affected by an external field.

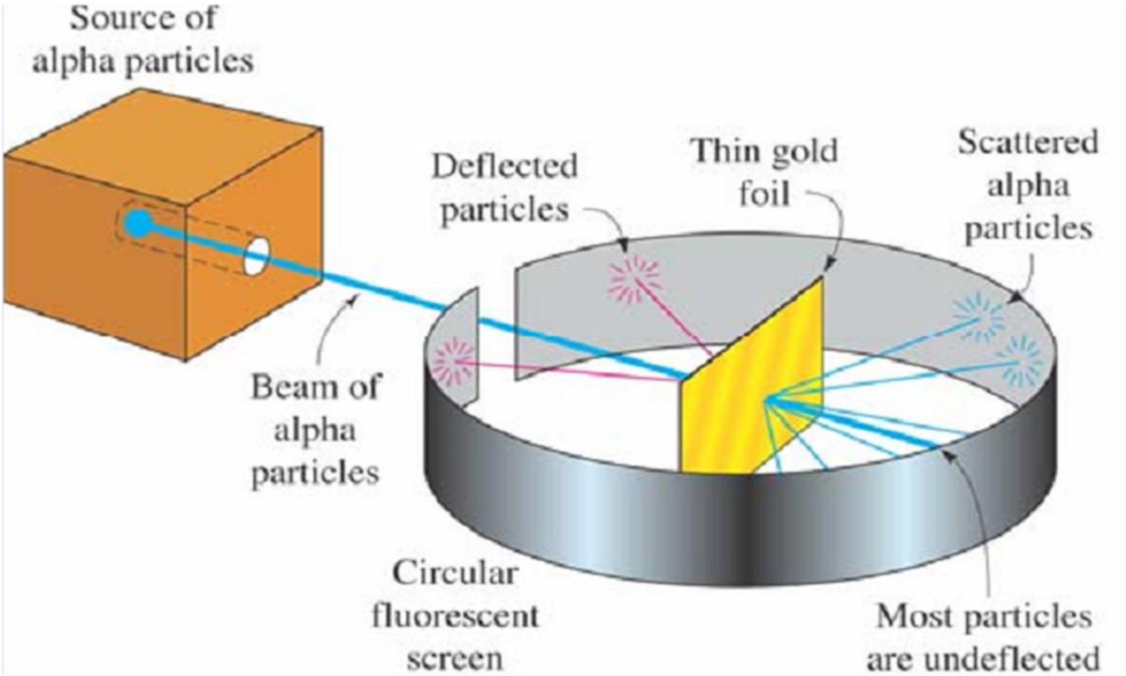
Thomson's Model

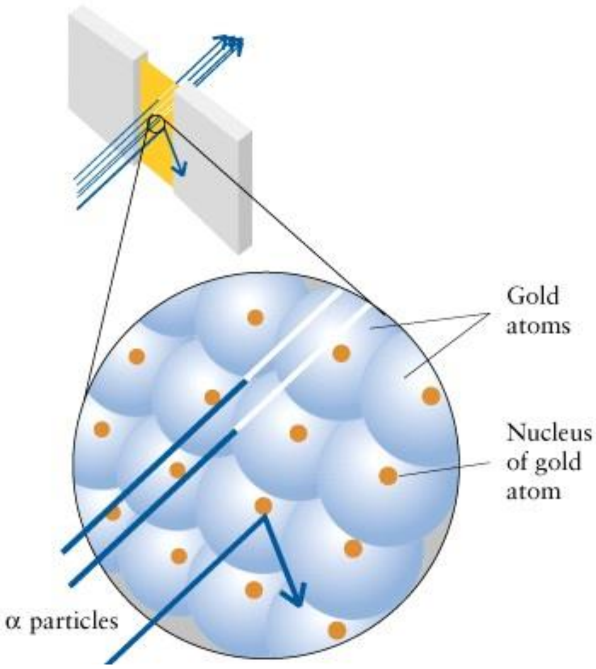
– a spherical atom composed of diffuse, positively charge matter, in which e- embedded like "**raisin in a plum pudding**".

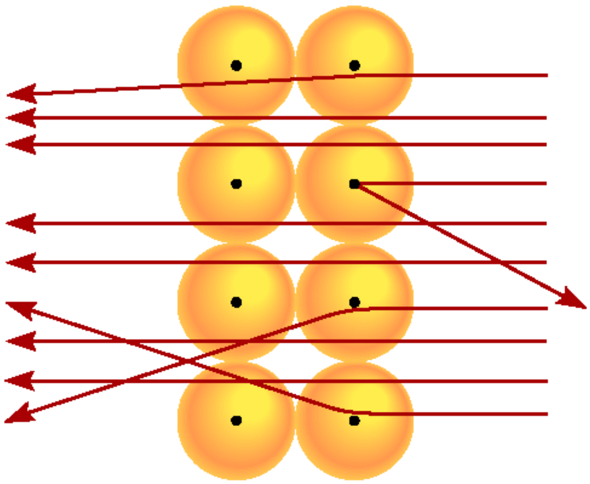




Rutherford's gold foil α-scattering experiment

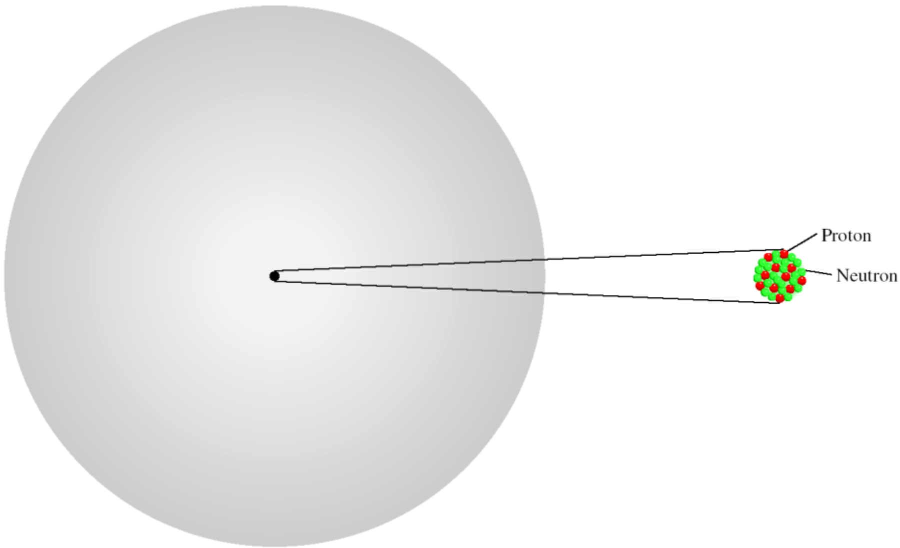






Rutherford's Model of the Atom

1. atoms positive charge is concentrated in the nucleus
2. proton (p) has opposite (+) charge of electron (-)
3. mass of p is 1840 x mass of e^- (1.67×10^{-24} g)



atomic radius ~ 100 pm = 1 x 10-10 m
nuclear radius ~ 5 x 10-3 pm = 5 x 10-15 m

Chadwick's Experiment (1932)

0n **2n**

H atoms - 1 p; He atoms - 2 p

mass He/mass H should = 2

measured mass He/mass H = 4

neutron (n) is neutral (charge = 0)
n mass ~ p mass = 1.67×10^{-24} g

TABLE 2.1 Mass and Charge of Subatomic Particles			
		Charge	
Particle	Mass (g)	Coulomb	Charge Unit
Electron*	9.10938×10^{-28}	-1.6022×10^{-19}	-1
Proton	1.67262×10^{-24}	$+1.6022 \times 10^{-19}$	$+1$
Neutron	1.67493×10^{-24}	0	0

*More refined measurements have given us a more accurate value of an electron's mass than Millikan's.

mass p ≈ mass n ≈ 1840 x mass e^-

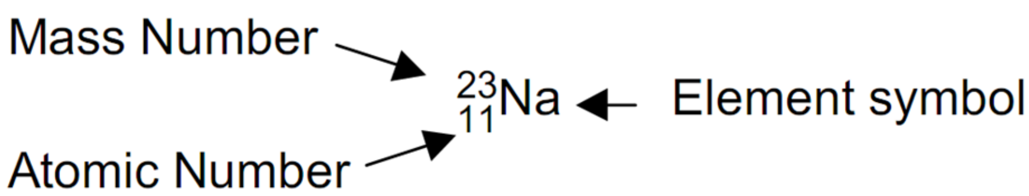
Atomic number, Mass number and Isotopes

Atomic number (Z) = number of protons in nucleus

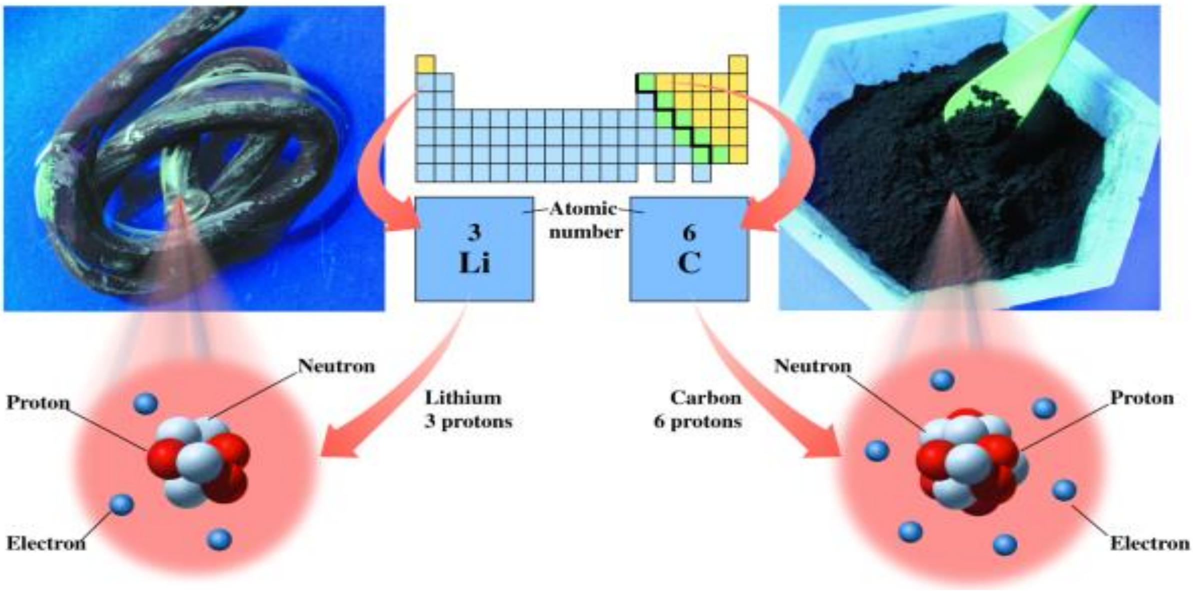
Mass number (A) = number of protons + number of neutrons

= atomic number (Z) + number of neutrons

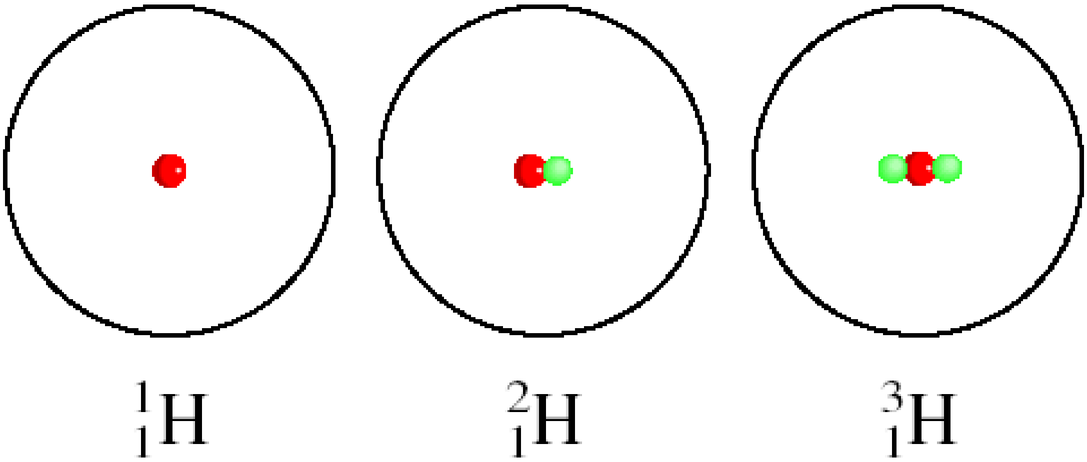
Isotopes are atoms of the same element (X) that have the same atomic number but different mass numbers



$^{1}_{1}H$ $^{2}_{1}H$ (D) $^{3}_{1}H$ (T) $^{235}_{92}U$ $^{238}_{92}U$



The Isotopes of Hydrogen



Isotope	Atomic Number	Number of protons	Number of Neutrons	Number of electrons	mass (amu)
Hydrogen-1	1	1	0	1	1
Hydrogen-2 (deuterium)	1	1	1	1	2
Hydrogen-3 (tritium)	1	1	2	1	3

How many protons, neutrons, and electrons are in $^{14}_{6}C$?

6 protons, 8 (14 - 6) neutrons, 6 electrons

How many protons, neutrons, and electrons are in $^{11}_{6}C$?

6 protons, 5 (11 - 6) neutrons, 6 electrons

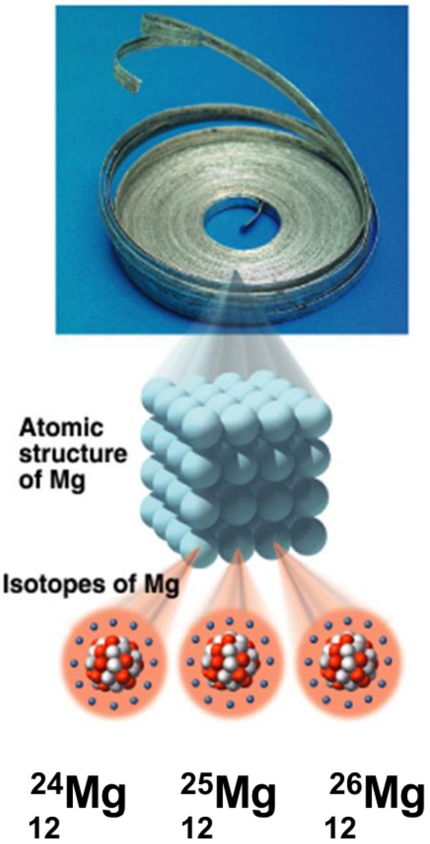
Naturally occurring carbon consists of three isotopes, ^{12}C, ^{13}C, and ^{14}C. State the number of protons, neutrons, and electrons in each of the following.

	$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
Proton	6	6	6
Neutron	6	7	8
Electron	6	6	6

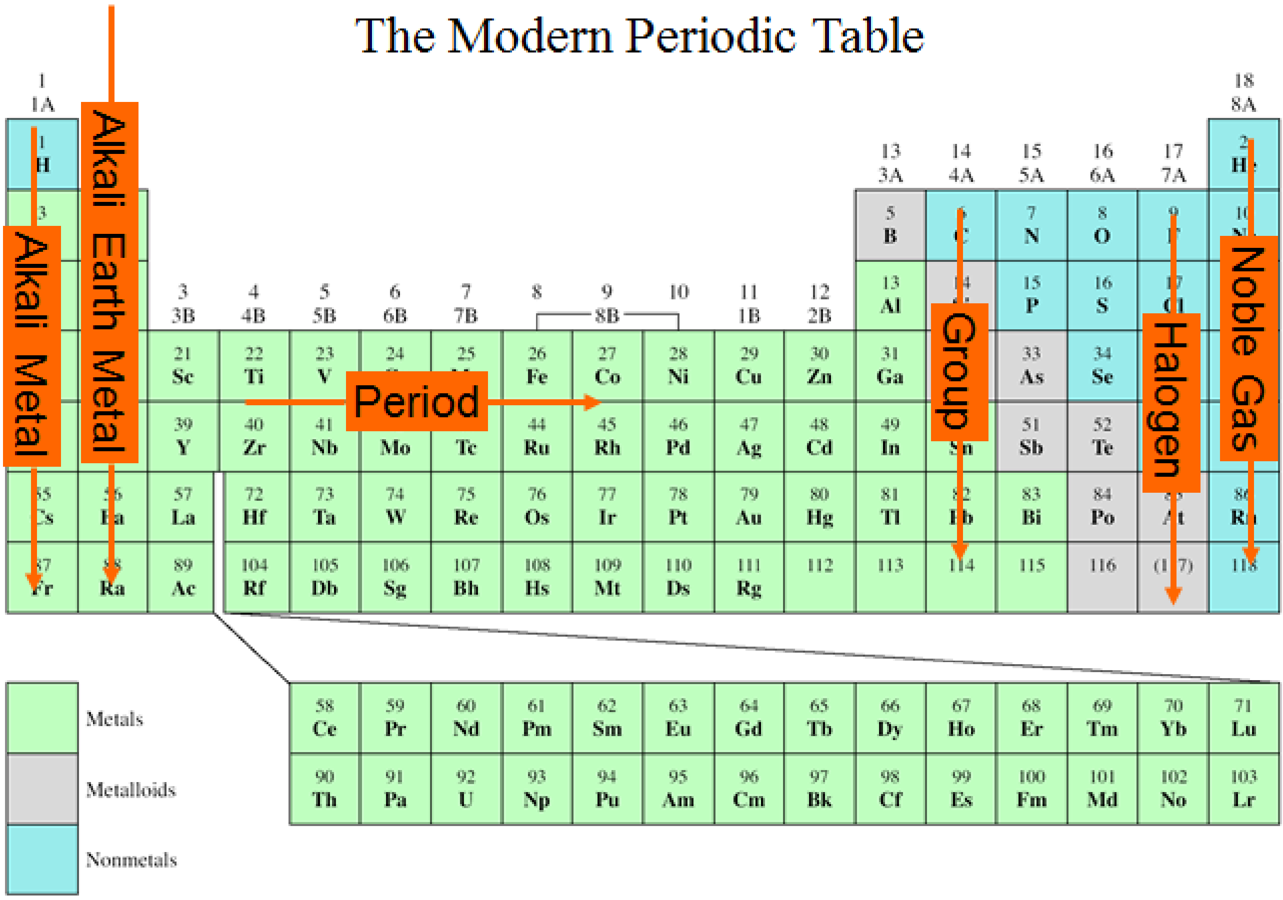
In naturally occurring magnesium, there are three isotopes.

Isotopes of Mg

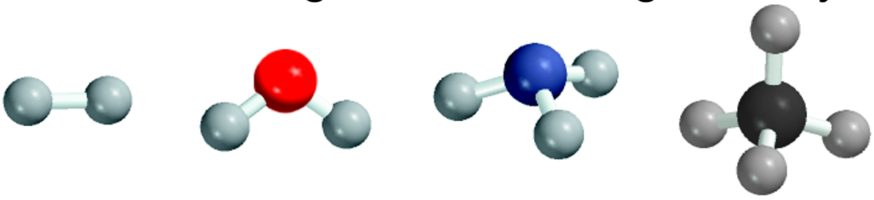
Atomic symbol	$^{24}_{12}Mg$	$^{25}_{12}Mg$	$^{26}_{12}Mg$
Number of protons	12	12	12
Number of electrons	12	12	12
Mass number	24	25	26
Number of neutrons	12	13	14



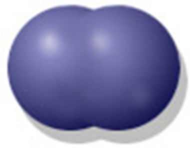
The Modern Periodic Table



A ***molecule*** is an aggregate of two or more atoms in a definite arrangement held together by chemical forces



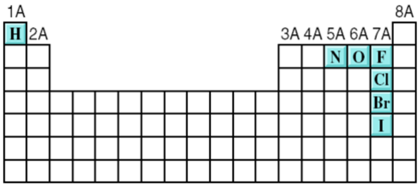
H_2 H_2O NH_3 CH_4



N_2
Nitrogen gas - a homonuclear molecule

A ***diatomic molecule*** contains only two atoms

H_2, N_2, O_2, Br_2, HCl, CO



diatomic elements

H_2O
Water - a heteronuclear molecule

A ***polyatomic molecule*** contains more than two atoms

O_3, H_2O, NH_3, CH_4

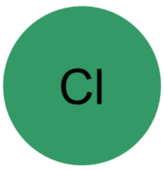
An ***ion*** is an atom, or group of atoms, that has a net positive or negative charge.

cation – ion with a positive charge
If a neutral atom **loses** one or more electrons it becomes a cation.

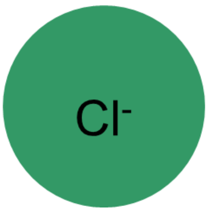
11 protons
11 electrons

11 protons
10 electrons

anion – ion with a negative charge
If a neutral atom **gains** one or more electrons it becomes an anion.



17 protons
17 electrons



17 protons
18 electrons

A ***monatomic ion*** contains only one atom

$$Na^{+}, Cl^{-}, Ca^{2+}, O^{2-}, Al^{3+}, N^{3-}$$

A ***polyatomic ion*** contains more than one atom

$$OH^{-}, CN^{-}, NH_4^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}, NO_2^{-}$$

The names of common polyatomic anions

- end in *ate.*

  NO_3^{-} nitr**ate** PO_4^{3-} phosph**ate**

- with **one oxygen less** end in *ite.*

  NO_2^{-} nitr**ite** PO_3^{3-} phosph**ite**

- with hydrogen attached use the prefix *hydrogen* (or *bi).*

  HCO_3^{-} **hydrogen** carbonate (**bi**carbonate)

  HSO_3^{-} **hydrogen** sulfite (**bi**sulfite)

Common Ions Shown on the Periodic Table

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
Li^+													C^{4-}	N^{3-}	O^{2-}	F^-	
Na^+	Mg^{2+}											Al^{3+}		P^{3-}	S^{2-}	Cl^-	
K^+	Ca^{2+}				Cr^{2+} Cr^{3+}	Mn^{2+} Mn^{3+}	Fe^{2+} Fe^{3+}	Co^{2+} Co^{3+}	Ni^{2+} Ni^{3+}	Cu^+ Cu^{2+}	Zn^{2+}				Se^{2-}	Br^-	
Rb^+	Sr^{2+}									Ag^+	Cd^{2+}		Sn^{2+} Sn^{4+}		Te^{2-}	I^-	
Cs^+	Ba^{2+}									Au^+ Au^{3+}	Hg_2^{2+} Hg^{2+}		Pb^{2+} Pb^{4+}				

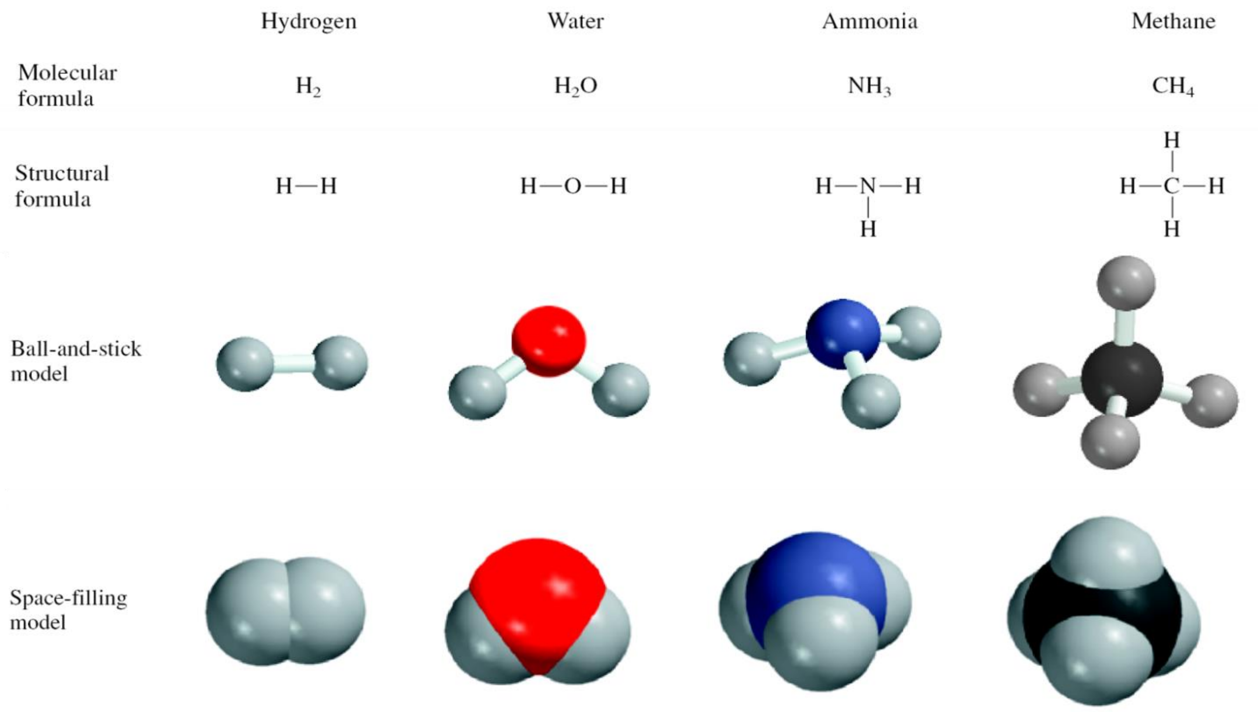
How many protons and electrons are in $^{27}_{13}Al^{3+}$?

13 protons, 10 (13 – 3) electrons

How many protons and electrons are in $^{78}_{34}Se^{2-}$?

34 protons, 36 (34 + 2) electrons

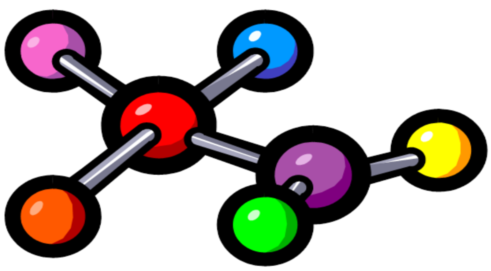
Formulas and Models



A ***molecular formula*** shows the exact number of atoms of each element in the smallest unit of a substance

An ***empirical formula*** shows the simplest whole-number ratio of the atoms in a substance

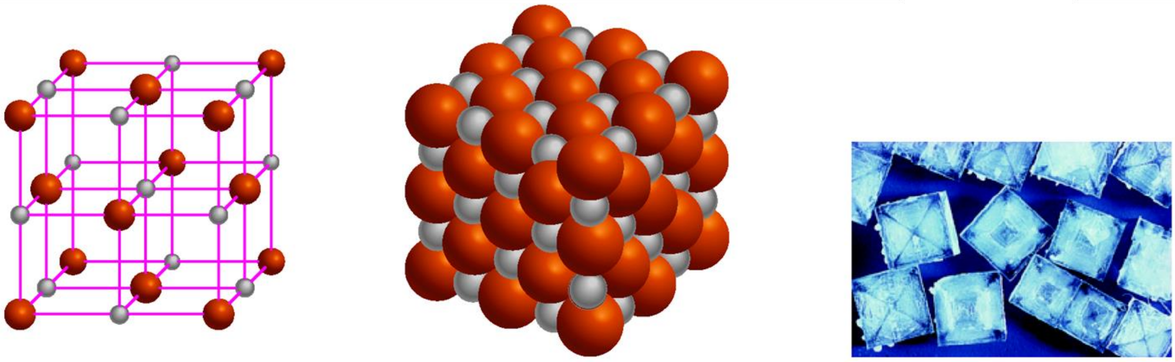
molecular	**empirical**
H_2O	H_2O
$C_6H_{12}O_6$	CH_2O
O_3	O
N_2H_4	NH_2

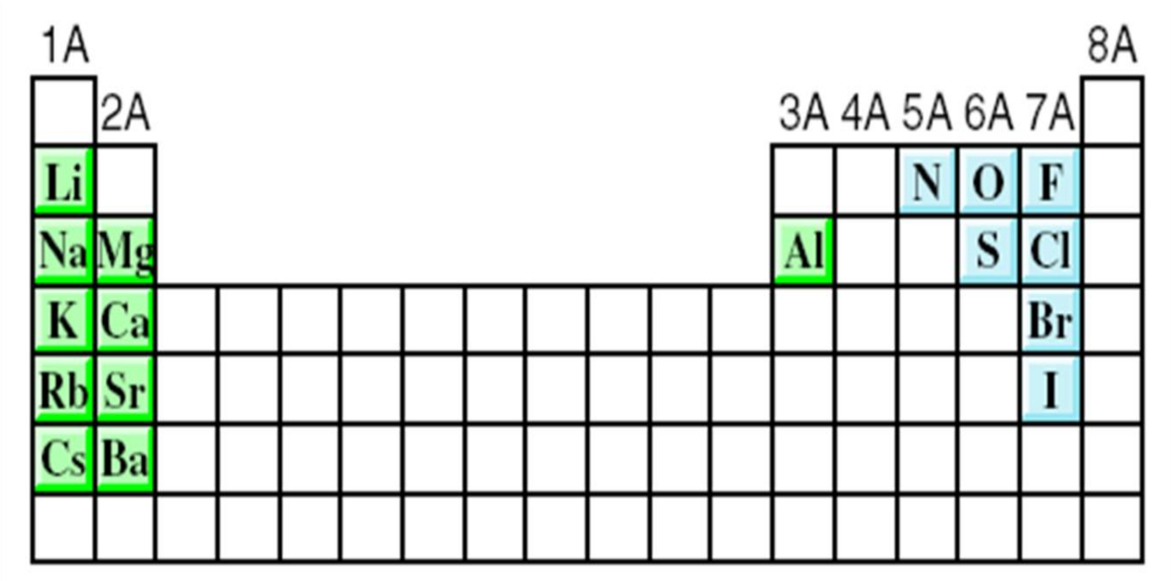


ionic compounds consist of a combination of cations and an anions

- The formula is usually the same as the empirical formula
- The sum of the charges on the cation(s) and anion(s) in each formula unit must equal zero

The ionic compound NaCl





The most reactive **metals** (green) and the most reactive **nonmetals** (blue) combine to form ionic compounds.

Formula of Ionic Compounds

$2 \times +3 = +6$ $3 \times -2 = -6$

Al_2O_3

Al^{3+} O^{2-}

$1 \times +2 = +2$ $2 \times -1 = -2$

$CaBr_2$

Ca^{2+} Br^{-}

$1 \times +2 = +2$ $1 \times -2 = -2$

Na_2CO_3

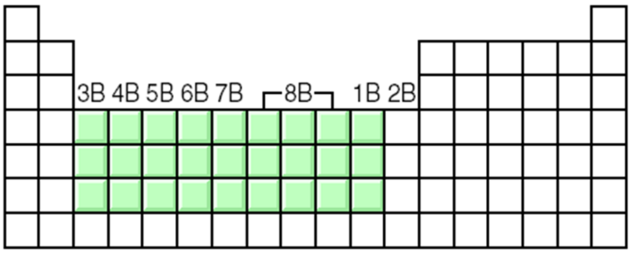
Na^{+} CO_3^{2-}

Chemical Nomenclature

- **Ionic Compounds**
  - Most are binary compounds, some are ternary compounds
  - Often a metal + nonmetal
  - Anion (nonmetal), add "ide" to element name

$BaCl_2$	barium chloride
K_2O	potassium oxide
$Mg(OH)_2$	magnesium hydroxide
KNO_3	potassium nitrate

- Transition metal ionic compounds
  - indicate charge on metal with **Roman numerals**



+1	+2	+3	+4	+5
(I)	(II)	(III)	(IV)	(V)

$FeCl_2$	2 Cl^- -2 so Fe is +2	iron(II) chloride
$FeCl_3$	3 Cl^- -3 so Fe is +3	iron(III) chloride
Cr_2S_3	3 S^{-2} -6 so Cr is +3 (6/2)	chromium(III) sulfide

Element	Possible Ions	Name of Ion
Chromium	Cr^{2+}	chromium(II)
	Cr^{3+}	chromium(III)
Copper	Cu^{+}	copper(I)
	Cu^{2+}	copper(II)
Gold	Au^{+}	gold(I)
	Au^{3+}	gold(III)
Iron	Fe^{2+}	iron(II)
	Fe^{3+}	iron(III)
Lead	Pb^{2+}	lead(II)
	Pb^{4+}	lead(IV)

$FeCl_2$	iron(II) chloride
$FeCl_3$	iron(III) chloride
Cu_2S	copper(I) sulfide
$CuCl_2$	copper(II) chloride
$SnCl_2$	tin(II) chloride
$PbBr_4$	lead(IV) bromide

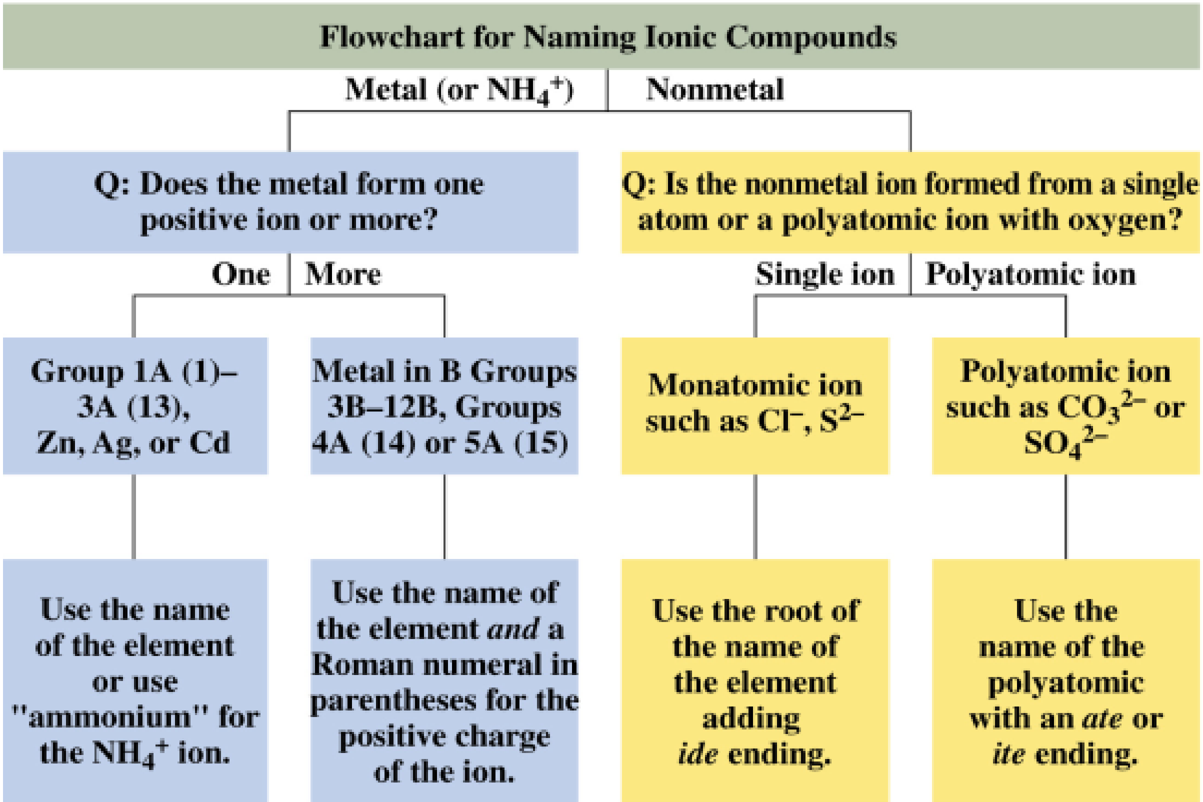
TABLE 2.2 The "-ide" Nomenclature of Some Common Monatomic Anions According to Their Positions in the Periodic Table

Group 4A	Group 5A	Group 6A	Group 7A
C carbide (C^{4-})*	N nitride (N^{3-})	O oxide (O^{2-})	F fluoride (F^{-})
Si silicide (Si^{4-})	P phosphide (P^{3-})	S sulfide (S^{2-})	Cl chloride (Cl^{-})
		Se selenide (Se^{2-})	Br bromide (Br^{-})
		Te telluride (Te^{2-})	I iodide (I^{-})

*The word "carbide" is also used for the anion C_2^{2-}.

TABLE 2.3	Names and Formulas of Some Common Inorganic Cations and Anions
Cation	**Anion**
aluminum (Al^{3+})	bromide (Br^-)
ammonium (NH_4^+)	carbonate (CO_3^{2-})
barium (Ba^{2+})	chlorate (ClO_3^-)
cadmium (Cd^{2+})	chloride (Cl^-)
calcium (Ca^{2+})	chromate (CrO_4^{2-})
cesium (Cs^+)	cyanide (CN^-)
chromium(III) or chromic (Cr^{3+})	dichromate ($Cr_2O_7^{2-}$)
cobalt(II) or cobaltous (Co^{2+})	dihydrogen phosphate ($H_2PO_4^-$)
copper(I) or cuprous (Cu^+)	fluoride (F^-)
copper(II) or cupric (Cu^{2+})	hydride (H^-)
hydrogen (H^+)	hydrogen carbonate or bicarbonate (HCO_3^-)
iron(II) or ferrous (Fe^{2+})	hydrogen phosphate (HPO_4^{2-})
iron(III) or ferric (Fe^{3+})	hydrogen sulfate or bisulfate (HSO_4^-)
lead(II) or plumbous (Pb^{2+})	hydroxide (OH^-)
lithium (Li^+)	iodide (I^-)
magnesium (Mg^{2+})	nitrate (NO_3^-)
manganese(II) or manganous (Mn^{2+})	nitride (N^{3-})
mercury(I) or mercurous (Hg_2^{2+})*	nitrite (NO_2^-)
mercury(II) or mercuric (Hg^{2+})	oxide (O^{2-})
potassium (K^+)	permanganate (MnO_4^-)
rubidium (Rb^+)	peroxide (O_2^{2-})
silver (Ag^+)	phosphate (PO_4^{3-})
sodium (Na^+)	sulfate (SO_4^{2-})
strontium (Sr^{2+})	sulfide (S^{2-})
tin(II) or stannous (Sn^{2+})	sulfite (SO_3^{2-})
zinc (Zn^{2+})	thiocyanate (SCN^-)

*Mercury(I) exists as a pair as shown.



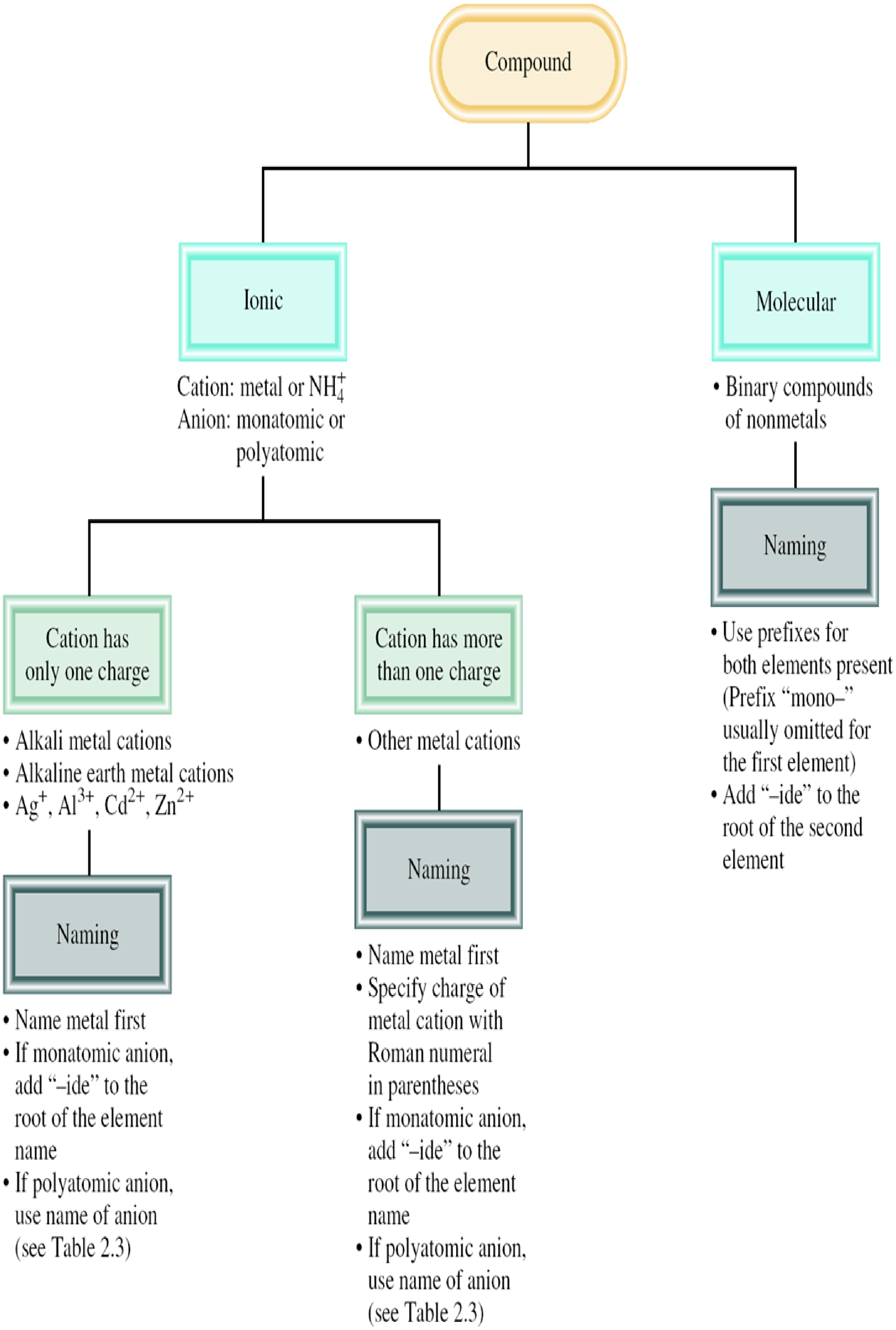
- **Molecular compounds**
  - Nonmetals or nonmetals + metalloids
  - Common names
    - H_2O, NH_3, CH_4,
  - Element furthest to the left in a period and closest to the bottom of a group on periodic table is placed first in formula
  - If more than one compound can be formed from the same elements, use prefixes to indicate number of each kind of atom
  - Last element name ends in *ide*

TABLE 2.4
Greek Prefixes Used in Naming Molecular Compounds

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

Molecular Compounds

HI	hydrogen iodide
NF_3	nitrogen trifluoride
SO_2	sulfur dioxide
N_2Cl_4	dinitrogen tetrachloride
NO_2	nitrogen dioxide
N_2O	dinitrogen monoxide


Compound
Ionic
Cation: metal or NH_4^+
Anion: monatomic or polyatomic
Molecular
• Binary compounds of nonmetals
Cation has only one charge
• Alkali metal cations
• Alkaline earth metal cations
• Ag^+, Al^{3+}, Cd^{2+}, Zn^{2+}
Cation has more than one charge
• Other metal cations
Naming
• Use prefixes for both elements present (Prefix "mono–" usually omitted for the first element)
• Add "–ide" to the root of the second element
Naming
• Name metal first
• Specify charge of metal cation with Roman numeral in parentheses
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)
Naming
• Name metal first
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)

An ***acid*** can be defined as a substance that yields hydrogen ions (H^+) when dissolved in water.

For example: HCl gas and HCl in water

- Pure substance, hydrogen chloride
- Dissolved in water (H_3O^+ and Cl^-), hydrochloric acid

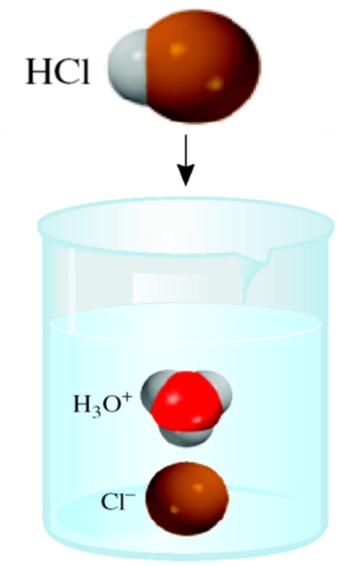


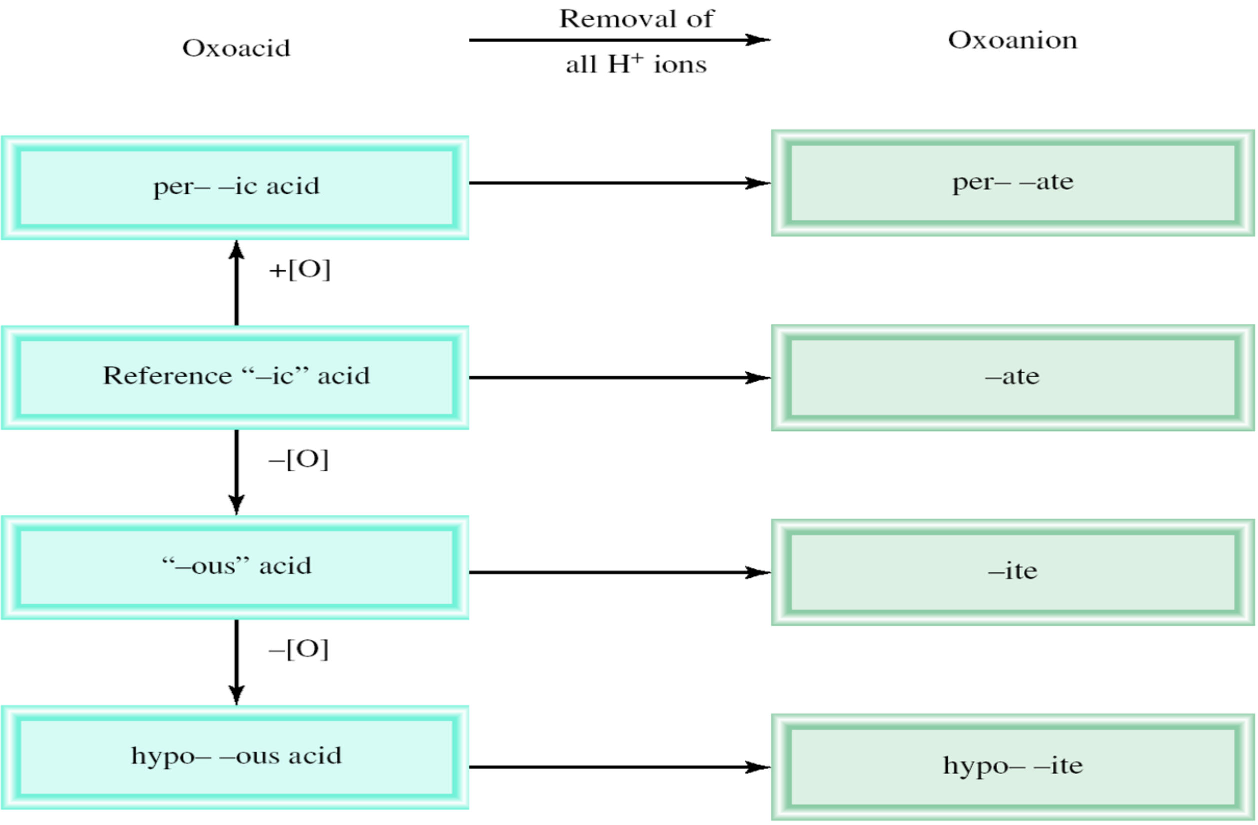
TABLE 2.5 Some Simple Acids

Anion	Corresponding Acid
F^- (fluoride)	HF (hydrofluoric acid)
Cl^- (chloride)	HCl (hydrochloric acid)
Br^- (bromide)	HBr (hydrobromic acid)
I^- (iodide)	HI (hydroiodic acid)
CN^- (cyanide)	HCN (hydrocyanic acid)
S^{2-} (sulfide)	H_2S (hydrosulfuric acid)

An ***oxoacid*** is an acid that contains hydrogen, oxygen, and another element (the central element).

HNO_3	nitric acid
HNO_2	nitrous acid
H_2SO_4	sulfuric acid
H_2SO_3	sulfurous acid
H_2CO_3	carbonic acid
H_3PO_4	phosphoric acid

Naming Oxoacids and Oxoanions



The rules for naming ***oxoanions,*** *anions of oxoacids,* are as follows:

1. When all the H ions are removed from the "-ic" acid, the anion's name ends with "-ate."
2. When all the H ions are removed from the "-ous" acid, the anion's name ends with "-ite."
3. The names of anions in which one or more but not all the hydrogen ions have been removed must indicate the number of H ions present.

   For example:
   - $H_2PO_4^-$ dihydrogen phosphate
   - HPO_4^{2-} hydrogen phosphate
   - PO_4^{3-} phosphate

TABLE 2.6 Names of Oxoacids and Oxoanions That Contain Chlorine

Acid	Anion
$HClO_4$ (perchloric acid)	ClO_4^- (perchlorate)
$HClO_3$ (chloric acid)	ClO_3^- (chlorate)
$HClO_2$ (chlorous acid)	ClO_2^- (chlorite)
HClO (hypochlorous acid)	ClO^- (hypochlorite)

A ***base*** can be defined as a substance that yields hydroxide ions (OH^-) when dissolved in water.

NaOH	sodium hydroxide
KOH	potassium hydroxide
$Ba(OH)_2$	barium hydroxide

Hydrates are compounds that have a specific number of water molecules attached to them.

$BaCl_2 \cdot 2H_2O$	barium chloride dihydrate
$LiCl \cdot H_2O$	lithium chloride monohydrate
$MgSO_4 \cdot 7H_2O$	magnesium sulfate heptahydrate
$Sr(NO_3)_2 \cdot 4H_2O$	strontium nitrate tetrahydrate

$CuSO_4 \cdot 5H_2O$ →  ← $CuSO_4$

TABLE 2.7 Common and Systematic Names of Some Compounds

Formula	Common Name	Systematic Name
H_2O	Water	Dihydrogen monoxide
NH_3	Ammonia	Trihydrogen nitride
CO_2	Dry ice	Solid carbon dioxide
$NaCl$	Table salt	Sodium chloride
N_2O	Laughing gas	Dinitrogen monoxide
$CaCO_3$	Marble, chalk, limestone	Calcium carbonate
CaO	Quicklime	Calcium oxide
$Ca(OH)_2$	Slaked lime	Calcium hydroxide
$NaHCO_3$	Baking soda	Sodium hydrogen carbonate
$Na_2CO_3 \cdot 10H_2O$	Washing soda	Sodium carbonate decahydrate
$MgSO_4 \cdot 7H_2O$	Epsom salt	Magnesium sulfate heptahydrate
$Mg(OH)_2$	Milk of magnesia	Magnesium hydroxide
$CaSO_4 \cdot 2H_2O$	Gypsum	Calcium sulfate dihydrate