CHAPTER 2
ATOMS, MOLECULES, AND IONS

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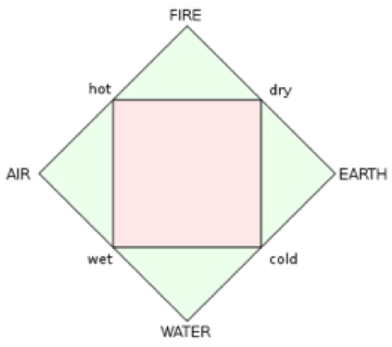
ATOMS, MOLECULES, AND IONS

Early Ideas In Atomic Theory [2.1]

- Democritis (500 BC)
- Aristotle
- John Dalton



Daltons Atomic Theory (1803)

(1) Elements made of small, indivisible particles called “ATOMS”

(2) All atoms of a given element are IDENTICAL, & have same mass

(3) Atoms of any element are DISTINCT from atoms of any other, & hence have different masses

(4) LAW OF MULTIPLE PROPORTIONS—
Compounds = elements combine in small, whole-number ratios.
(textbook, “A compound consists of atoms of two or more elements combined in a small, whole-number ratio. In a given
compound, the numbers of atoms of each of its elements are always present in the same ratio.” p67/75)

(5) CONSERVATION OF MATTER—in a chem rxn, atoms only re-arrange. [Antione Lavoisier, ~1785]

Law of Constant Composition

For compounds comprised of the same elements (e.g., NO and N_2O_3), atoms of different elements combined together, in fixed ratios [Joseph Proust]

[whiteboard]

(EX) Law Of Multiple Proportions
¿What is the ratio of the numbers of oxygen atoms that are combined with a given number of nitrogen atoms in the compounds N2O3 and NO?

$$\frac{N_2O_3}{NO} = \frac{N_2O_3}{2(NO)} = \frac{30/2N}{20/2N} = \frac{3}{2}$$

(oxygen, not "0")

This means N_2O_3 has 1.5x more oxygen than NO_2, per nitrogen atom.

[Textbook discussion, p69/77]

A Process for Determining the Multiple Proportion

① ratio the two compounds being compared
② pick one of the compounds, and multiply by a factor (if necessary) that gives the same number of atoms of a given element on the top and bottom… can be any of the elements
③ cancel-out the element which has the same number of atoms on the top and the bottom
④ the numeric ratio which remains is the multiple proportion

(EX) Law Of Multiple Proportions
¿What is the ratio of the number of chlorine atoms for the materials described by CuxCly, wherein green crystals have a mass ratio of 0.558 gCl/g Cu, and brown crystals have a mass ratio of 1.116 gCl/gCu?

$$\frac{1.116\ \text{Cl} / \cancel{\text{Cu}}}{0.558\ \text{Cl} / \cancel{\text{Cu}}} = \frac{2\ \text{g Cl (brown)}}{1\ \text{g Cl (green)}}$$

This means the brown material has twice as much Cl, per Cu atom, as the green material

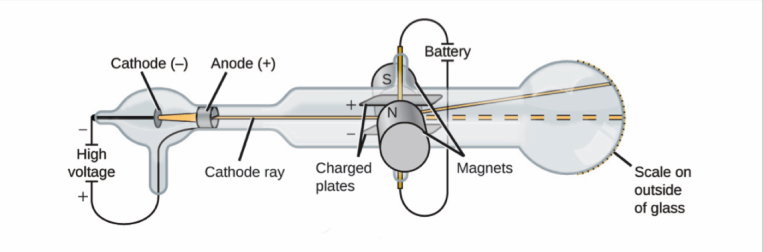
B/C it's the same element, the mass ratio is equal to the atomic ratio

Evolution Of Atomic Theory [2.2]

Atomic Theory After The Nineteenth Century

JJ Thomson – CRT – Discovered The Electron

CRT
↳ invented in 1897 by Ferdinand Brann
↳ precursor of CRT television



OBSERVATIONS
↳ casts shadow, ↛ straight line
↳ magnetic deflection, ↛ (–) charged
↳ turns wheel, ↛ has mass
↳ e/m = 1.8E8 coulomb/gram
- same regardless of gas type
- same regardless of electrode composition
- same regardless of electrical source

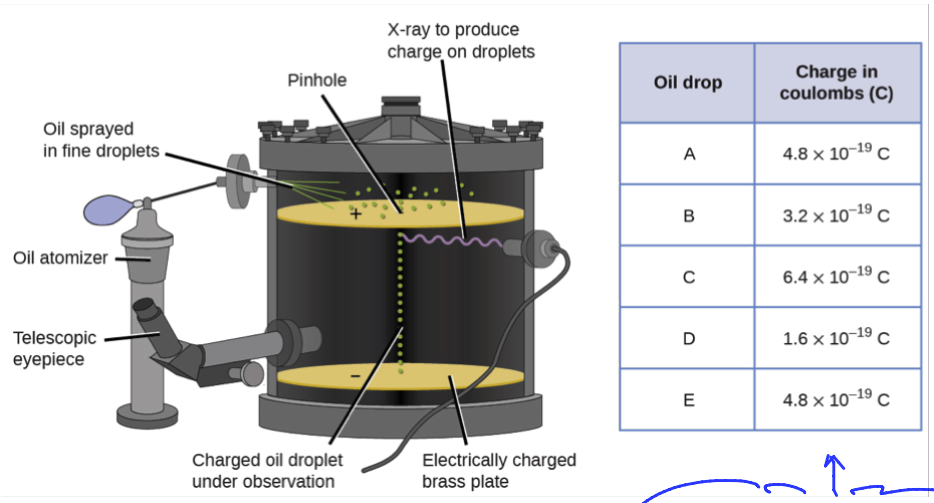
⇓

ELECTRON

↳ named per George Stoney's earlier work in 1891
↳ Thomson's research -> chg/mass = 1.759 E11 C/kg

Robert Milligan – Oil Drop – Discovered Mass Of Electron

A, B, C, E are all multiples of D



Oil drop	Charge in coulombs (C)
A	4.8×10^{-19} C
B	3.2×10^{-19} C
C	6.4×10^{-19} C
D	1.6×10^{-19} C
E	4.8×10^{-19} C

ANALOGY: 2, 8, 6, 16, 12, 10
smallest increment is "2"

⇓

[next page: Observations & Conclusions]

Milligan – Oil Drop Experiment: Observations & Conclusions

↳ The charge of an oil droplet is always a multiple of a specific charge, 1.6 E–19 C.
↳ Thomson's research -> chg/mass = 1.759 E11 C/kg

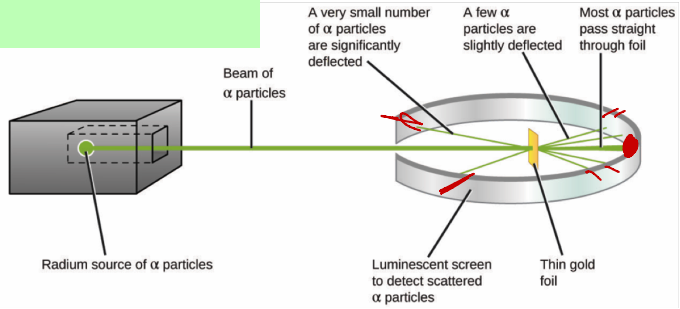
$$\frac{\square}{1} = \frac{1.603E-19\ C}{} \times \frac{1\ Kg}{1.759E11\ C} = 9.107E-31\ Kg$$

Milligan Thompson mass of electron

$$\frac{\square}{1} = \frac{charge}{} \times \frac{mass}{charge} = \frac{mass}{1}$$

Ernest Rutherford – Gold Foil – Discovered Nucleus

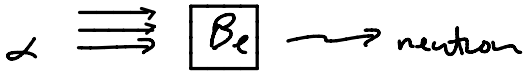
CONCLUSIONS
↳ atom is mostly Empty Space
↳ most mass takes up very little space in the center of the atom
↳ (+) positive charge material is in that central mass



I CAN'T BELIVE YOU SAID THAT…
"It was quite the most incredible event that has ever happened to me in my life. It was almost as if you fired a 15-inch shell into a piece of tissue paper and it came back and hit you."

LECTURE STOP

James Chadwick – Radioactive Bombardment – Discovered Neutron



Summary — Atomic “Parts” Discovered

↳ electron — Thompson — CRT
↳ charge (and hence mass) of electron — Millikan — Oil Drop
↳ nucleus — Rutherford —Gold Foil
↳ neutron — Chadwick — radioactive bombardment of Be

Atomic Structure And Symbolism [2.3]

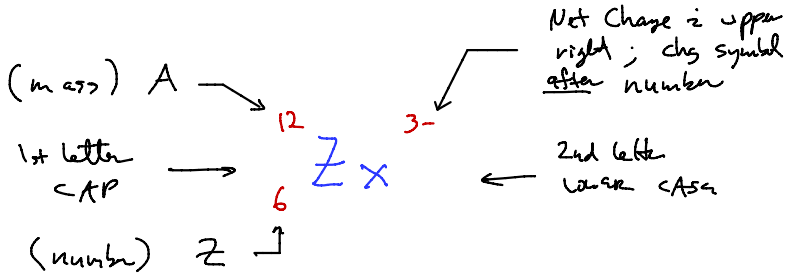
Subatomic Particle Properties

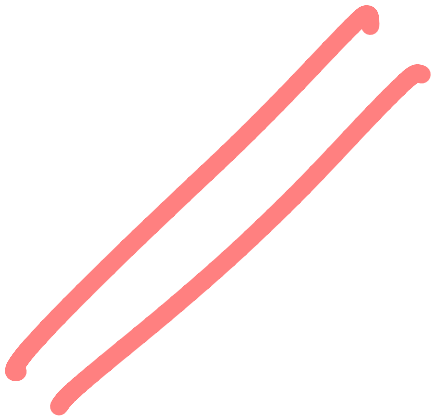
	Mass (amu)	Mass Rel	Mass (g)	Rel chg	Chg (C)
electron	5.5E-4	1	9.1E-28	-1	-1.6E-19
proton	1.0073	1836	1.7E-24	+1	+1.6E-19
neutron	1.0087	1836	1.7E-24	0	0

Atomic Number & Mass Number & Chemical Symbols

p + n = A X CHG
p = Z

A − Z = # neutrons
Z − #e = CHG





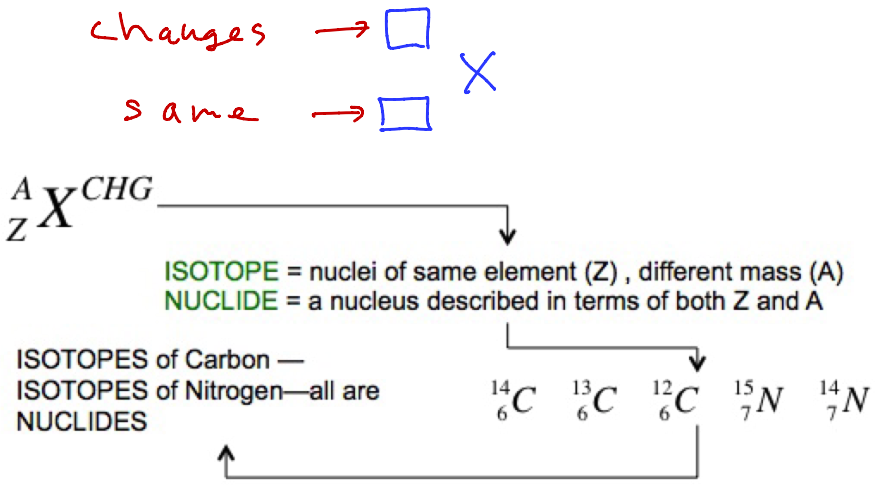
(EX) ¿Who am I?

A = 12; z = 6

A = 15, # neutron = 8

Isotopes and Nuclides

• Frederic Soddy – Radioactive Decay – Discovered Isotopes



Nomenclature of Isotopes

↳ according to Atomic Mass
ex: ^{12}C, ^{13}C, ^{14}C = carbon 12, carbon 13, carbon 14

↳ rarely, isotopes given common name
ex: ^{1}H = protium
^{2}H = deuterium
^{3}H = tritium

(EX) Write the atomic symbol for each of the isotopes described below.

a. Z 26, A 54
b. the isotope of iron with 30 neutrons
c. number of protons-26, number of neutrons-31
d. the isotope of nitrogen with 7 neutrons
e. Z 7, A 15
f. atomic number 7, number of neutrons-8

(a) $^{54}_{26}\text{Fe}$; (b) $^{56}_{26}\text{Fe}$; (c) $^{57}_{26}\text{Fe}$; (d) $^{14}_{7}\text{N}$; (e) $^{15}_{7}\text{N}$; (f) $^{15}_{7}\text{N}$

zum 4.38

(EX) Give the number of protons, electrons, and neutrons in neutral atoms of each of the following isotopes:

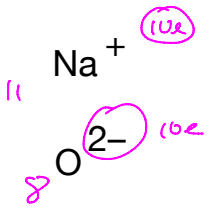
(a) $^{10}_{5}\mathrm{B}$

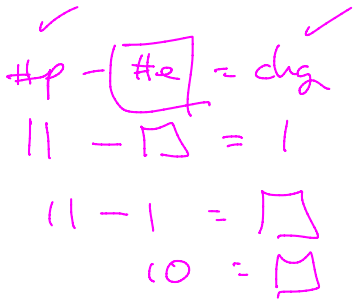
(b) $^{199}_{80}\mathrm{Hg}$

(c) $^{63}_{29}\mathrm{Cu}$

(d) $^{13}_{6}\mathrm{C}$

(e) $^{77}_{34}\mathrm{Se}$





(a) 5 protons, 5 electrons, 5 neutrons;
(b) 80 protons, 80 electrons, 119 neutrons;
(c) 29 protons, 29 electrons, 34 neutrons;
(d) 6 protons, 6 electrons, 7 neutrons;
(e) 34 protons, 34 electrons, 43 neutrons

EOC 2.18

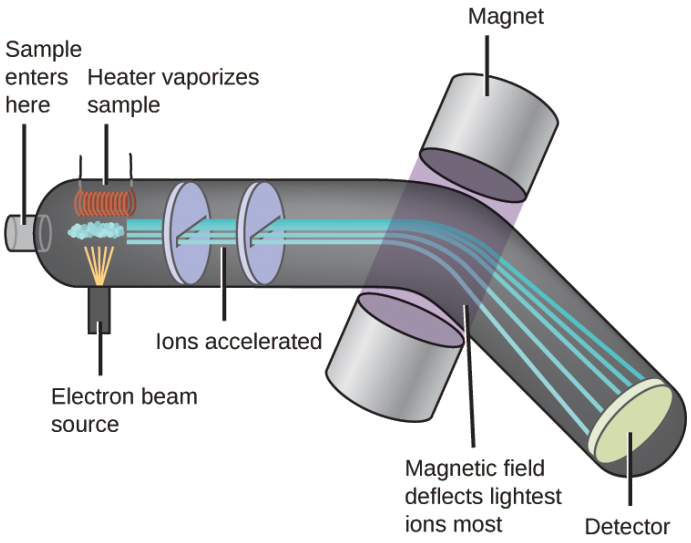
Atomic Mass: A Weighted Averge

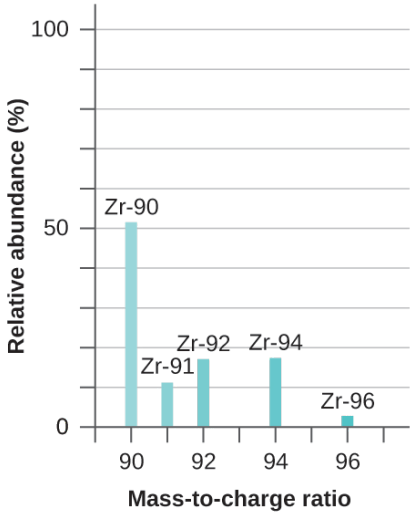
↳ average of isotopes
↳ all averages have fractional values, although all individual isotopes (nuclides) comprising the average are Integers

$^{24}_{12}Mg$ $^{25}_{12}Mg$ $^{26}_{12}Mg$

Wt Avg (Mg) = 0.7899(23.98504) + 0.1000(24.98584) + 0.1101(25.98259)
= 18.95 + 2.4986 + 2.8607
= **24.30 amu**

Mass Spectroscopy





Chemical Formulas [2.4]

Types of Formulas

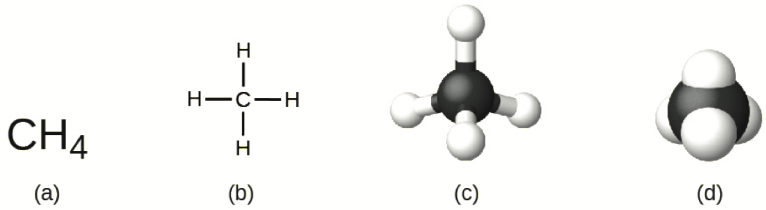
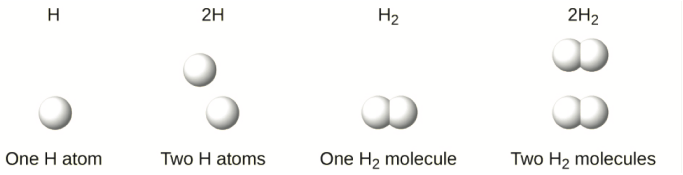
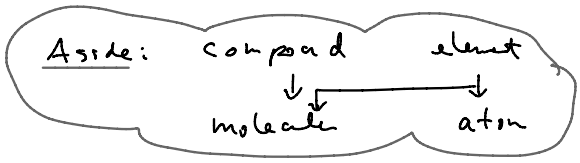


Figure 2.16 Methane (a) a molecular formula, (b) a structural formula, (c) a ball-and-stick model, and (d) a space-filling model.

Atoms & Molecules





9 Molecular Elements

↳ 7 diatomic: $H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2$
(Have No Fear Of Ice Cold Beer)

↳ 2 polyatomic: P_4, S_8

Empirical Vs. Molecular Formula

Molecular – formula for entire molecule
– actual number of atoms
– always COVALENT

$A_xB_yC_z$ eg: $3H_2SO_4$, H_2O, H_2

Empirical – simplest whole-number ratio of of different atoms/ions in a compound.
– COVALENT or IONIC

↳ ex: NaCl, TiO_2, (glucose) $C_6H_{12}O_6$

↳ EF: Repeating Unit

$MF = n(EF)$

"$6(CH_2O)$"

9/10 Tue

(EX) Empirical & Molecular Formulas [ex 2.6b]

¿A molecule of metaldehyde (a pesticide used for snails and slugs) contains 8 carbon atoms, 16 hydrogen atoms, and 4 oxygen atoms. What are the molecular and empirical formulas of metaldehyde?

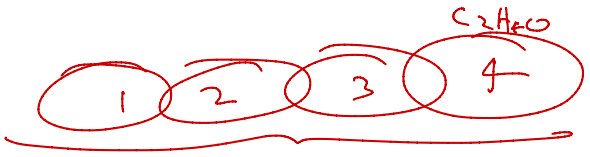
(a) $C_8H_{16}O_4$ = Molecular

(b) (i) All subscripts = even, ∴ ÷ 2 : $C_4H_8O_2$

(ii) still even, ∴ ÷ 2 again : $\boxed{C_2H_4O}$

= or =

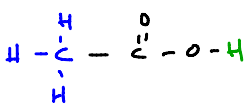
(b) All ÷ 4 (GCD = 4) : $\boxed{C_2H_4O}$



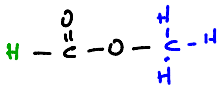
Isomers

$C_2H_4O_2$

isomer — same formula, different molecular structure



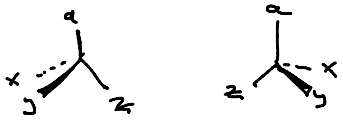
acetic acid



methyl formate

structural isomer — differ in how connected (above)

spatial isomer — differ in 3-D orientation only
↳ analogy — left vs. right hand
↳ ex:



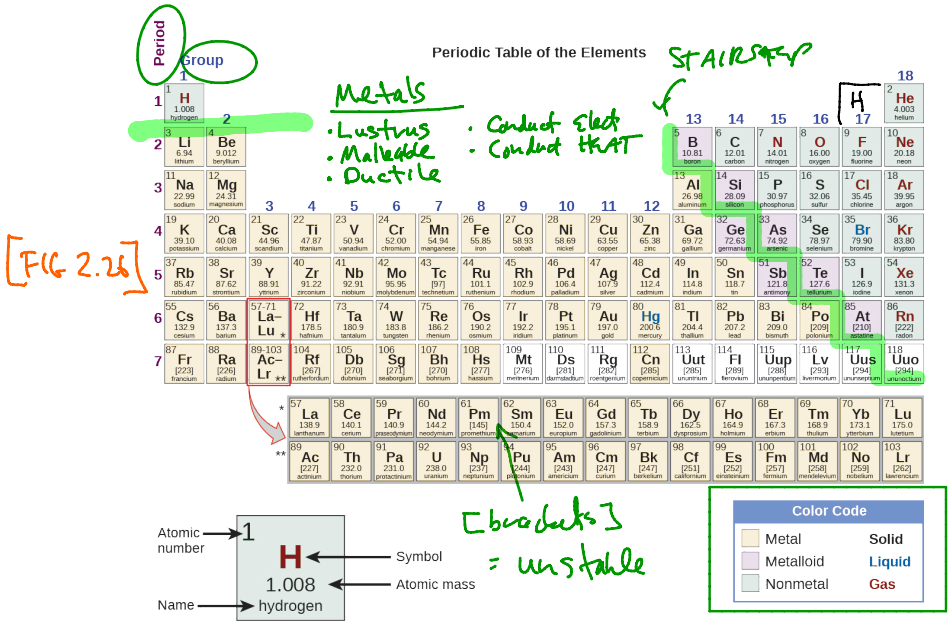
The Periodic Table [2.5]

Dimitri. MENDELEEV

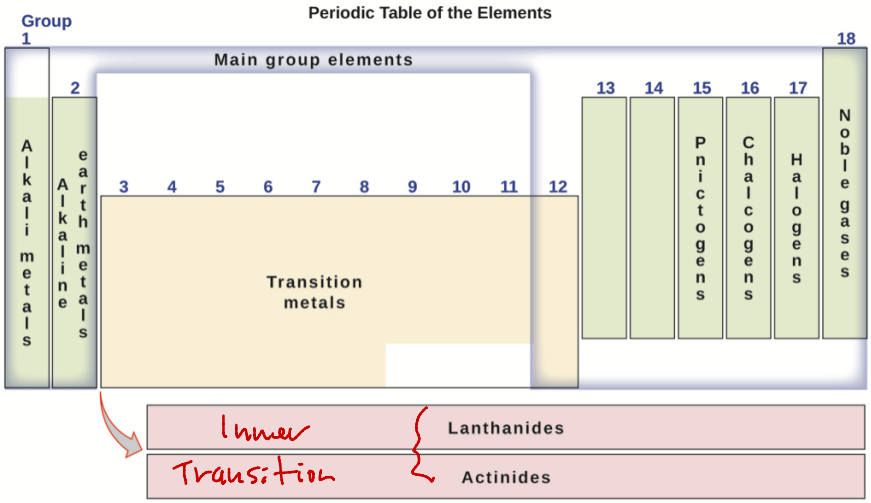
↳ 1869 : Put together the 1st modern PC, accompanied by Predictions

Periodic Law - PATTERN : properties of the elements periodically repeat

[FIG 2.25]



[Fig 2.27]

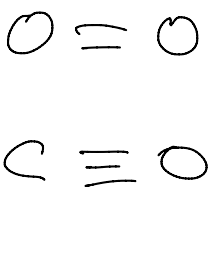

Periodic Table of the Elements
Group
1
18
Main group elements
2
13
14
15
16
17
Alkali metals
Alkaline earth metals
3
4
5
6
7
8
9
10
11
12
Transition metals
Pnictogens
Chalcogens
Halogens
Noble gases
Inner Transition
Lanthanides
Actinides

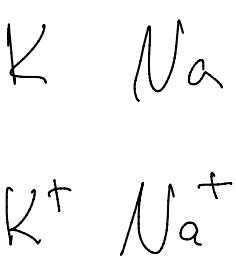
Molecular And Ionic Compounds [2.6]

Elements vs. Atom vs. Compounds vs. Molecules vs. Ions

atom – smallest unit of stable matter
element – subst. made of 1 type of atom
molecule – 2+ atoms joined together
compound – 2+ different elements joined
ion – charged chemical specie
↳ make from atom or molecule, but...
↳ no longer known as atom or molecule – it's and ion

SO_4^{2-}





	El	Compd
atom	mono	never ✗
molecule (2+ atoms)	poly (di + tri +)	always ✓

(EX) Classify Substances

(a) H_2O = compound, molecule

(b) C = monatomic element

(c) $C_6H_{12}O_6$ = compound, molecule

(d) H_2 = diatomic element

(e) SO_4^{2-} = polyatomic ion

(f) Ca^{2+} = monatomic ion ("calcium ion")

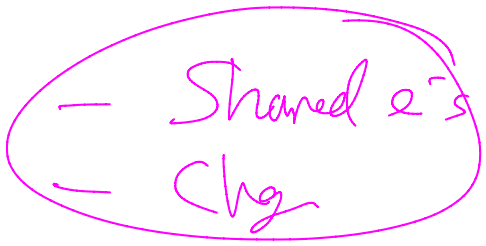
Molecular vs. Ionic Compounds

- Elements & Compounds are CHARGE NEUTRAL, by def.
  If CHARGED, then it's called an Ion

- Ionic – ELECTROSTATIC (opposite charge): $Na^+ Cl^-$

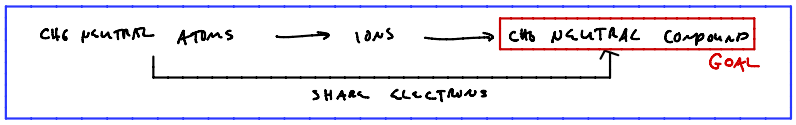
Na = element	Na^+ = ion	NaCl = chg. neut. compd.
Cl = element	Cl^- = ion	

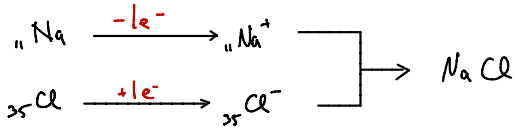
- Molecular – held together by COVALENT BONDS (shared electrons between atoms): H–O–H, , DNA



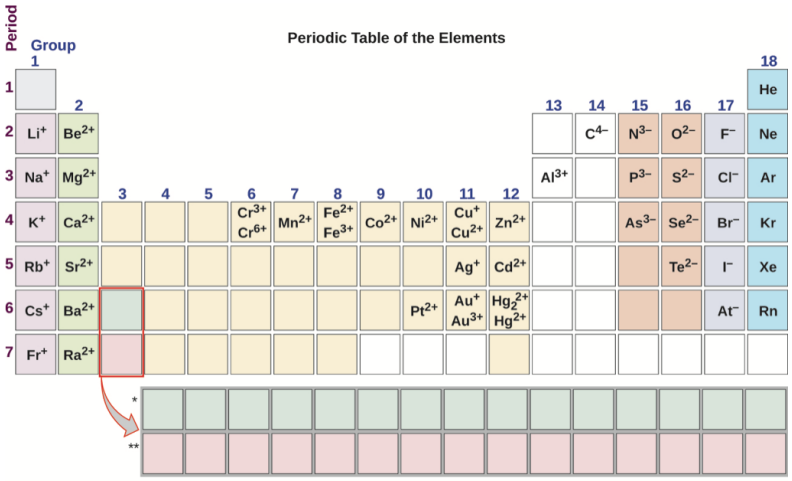
NOTE:
COVALENT Compounds will not be discussed until later in the semester…
…for now, let's focus on IONIC Compounds.

Ions: The Driving Force for Ionic Compound Formation





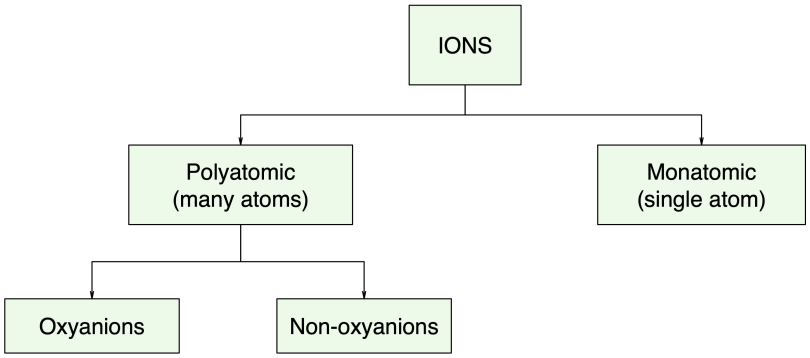
Ionic Compounds are formed from a metal and a non-metal



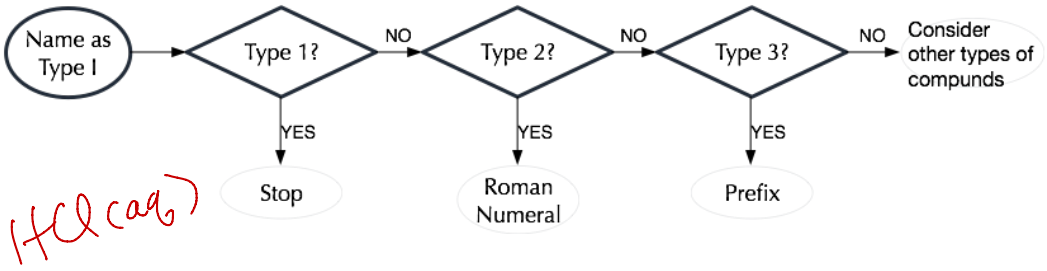
- Know the tell-tale sign for ionic compounds
  ↳ Metal cation + Non-metal anion

- The metal and non-metal combine in a ratio which makes the overall molecule CHARGE NEUTRAL

Classes of Ions

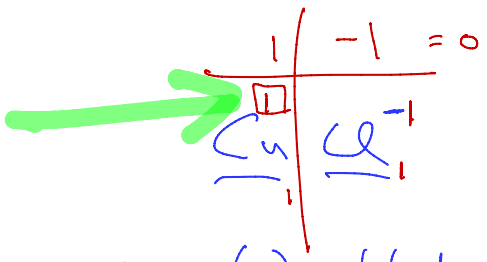


Chemical Nomenclature [2.7]

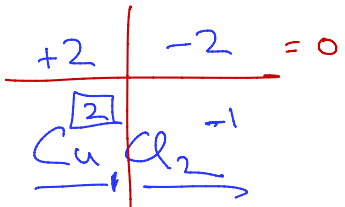


(HCl (aq))

	BINARY	POLYATOMIC
NON-ACID	**Type I** - M + nM - M has only 1 O.N. - Metal named first, anion takes "ide" ending - eg: NaCl = sodium chloride **Type II** - M + nM - M has at least 2 O.N. - utilizes ROMAN NUMERALS - eg: FeO = iron (II) oxide Fe_2O_3 = iron (III) oxide **Type III** - nM + nM - often, element closest to F serves as anion ("ide") - utilizes PREFIXES - eg: CO = carbon monoxide CO_2 = carbon dioxide	**compounds with**: "ate" anions "ite" anions "ium" cations - Typically, named using the rules from the quadrant to the left, and an anion derived from one of the polyatomic acids from the quadrant below. (- ammonium ion is the only polyatomic CATION utilized in this course.) - Often, the formula of the compound's anion 'portion' can be determined if the corresponding POLYATOMIC ACID (quadrant below) is known: SO_4^{-2} = sulfate ion <-- derives from sulfuric acid SO_3^{-2} = sulfite ion <-- derives from sulfurous acid eg: Na_2SO_4 = sodium sulfate $MgSO_3$ = magnesium sulfite
	- For our purpose, these are acids that do not contain oxygen; i.e., they are not OXYacids. • binary acid = H plus 1 other NON-metallic eg: HF = hydrofluoric acid	- Acids in which the corresponding anion is comprised of two or more elements - Some acids can be thought to exist in 'families,' in which the formula of any family member can be derived by application of a few basic rules to any single member of the family for which its formula is known.



copper(I) chloride



copper(II) chloride

CO_4

carbon monoxide

CO_2

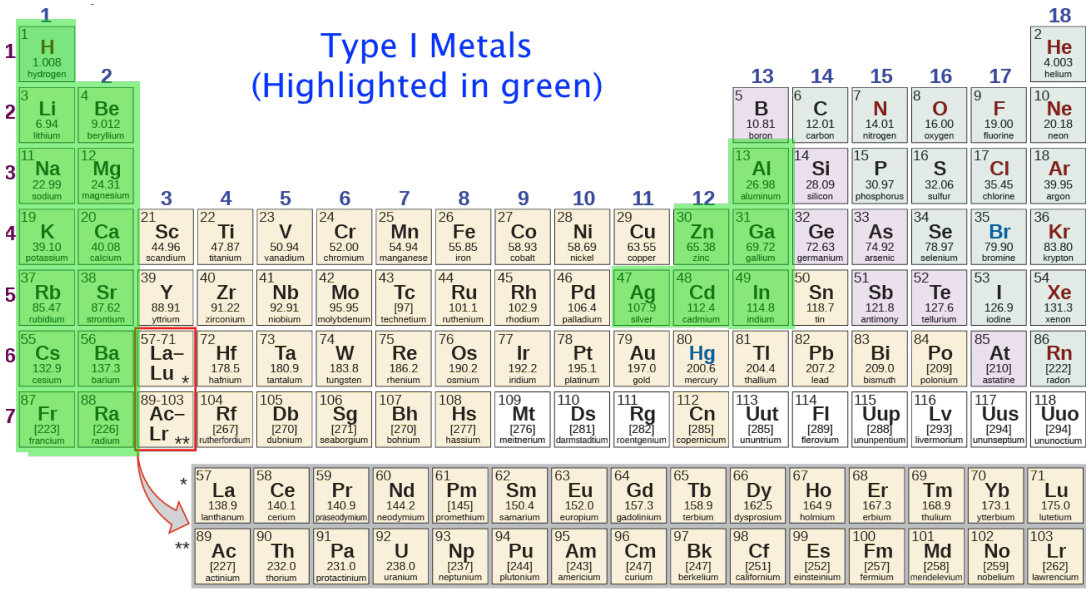
carbon dioxide

N_2O_4

dinitrogen monoxide

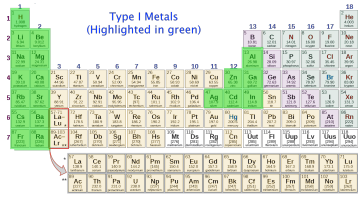
N_2O_5

• The metals highlighted in green are Type I.
• You may assume, for purposes of this class only, that all metals between Group 1–13 that are not green are Type II.



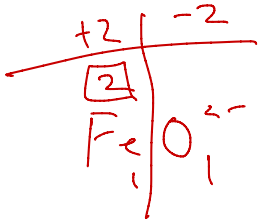
DISCLAIMER:
• some of the non-highlighted metals are, indeed, Type 1 — however, you need not memorize them. If that information is needed, you will be informed.
• as far as memorizing, you only need to memorize that the “6-pack” and the first two Groups are Type I.

Examples of Type I, II, & III Compounds



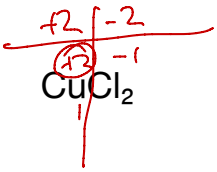
I. M + nM

$CaCl_2$

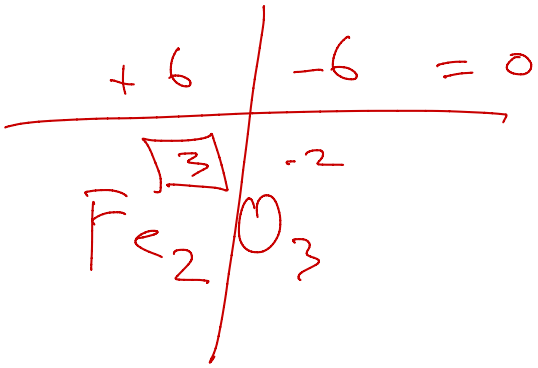


II. M + nM

CuCl



$CuCl_2$



III. nM + nM

NO

N_2O

CO

CO_2

POLYATOMIC ACIDS AND IONS

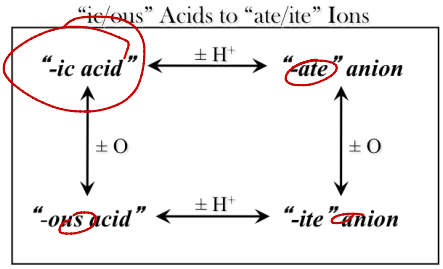
Common Polyatomic Ions

Name	Formula	Related Acid	Formula
ammonium	NH_4^+		
hydronium	H_3O^+		
oxide	O^{2-}		
peroxide	O_2^{2-}		
hydroxide	OH^-		
acetate	CH_3COO^-	acetic acid	CH_3COOH
cyanide	CN^-	hydrocyanic acid	HCN
azide	N_3^-	hydrazoic acid	HN_3
carbonate	CO_3^{2-}	carbonic acid	H_2CO_3
bicarbonate	HCO_3^-		
nitrate	NO_3^-	nitric acid	HNO_3
nitrite	NO_2^-	nitrous acid	HNO_2
sulfate	SO_4^{2-}	sulfiric acid	H_2SO_4
hydrogen sulfate	HSO_4^-		
sulfite	SO_3^{2-}	sulfurous acid	H_2SO_3
hydrogen sulfite	HSO_3^-		
phosphate	PO_4^{3-}	phosphoric acid	H_3PO_4
hydrogen phosphate	HPO_4^{2-}		
dihydrogen phosphate	$H_2PO_4^-$		
perchlorate	ClO_4^-	perchloric acid	$HClO_4$

ic, ous ACIDS — ate, ite ANIONS

H_2SO_4 sulfuric acid ⇌ SO_4^{2-} sulfate ion

H_2SO_3 sulfurous acid ⇌ SO_3^{2-} sulfite ion



H_2CO_3 ⇐ CO_3^{2-} carbonate

H_3PO_4 → PO_4^{3-}

H_3PO_3 → PO_3^{2-}

Na_2PO_3

Memorize These Oxy-acids

- sulfuric acid
- nitric acid
- phosphoric acid
- acetic acid
- chloric acid

The “Extended Family”

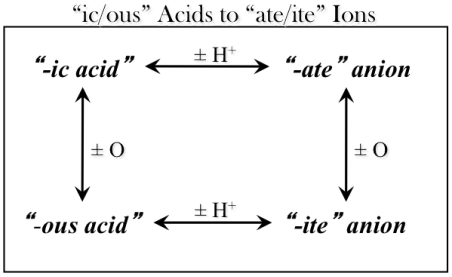
$HClO_4$ perchloric acid → ClO_4^- perchlorate

$HClO_3$ chloric acid → ClO_3^- chlorate → $NaClO_3$

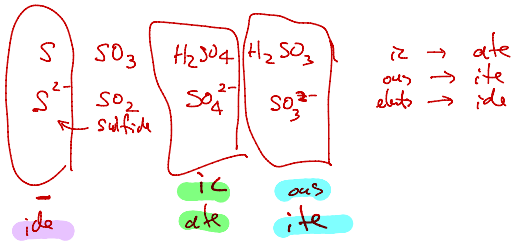
$HClO_2$ chlorous acid → ClO_2^- chlorite → $NaClO_2$

$HClO$ hypochlorous acid → ClO^- hypochlorite → Na^+ClO^-

“ic/ous” Acids to “ate/ite” Ions

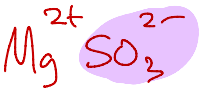


Atoms, Molecules, and their Ions… Don't get them confused



S S^2- SO2 SO3 SO3^2- SO4^2- H2SO3 H2SO4

element —> ide
ic —> ate
ous —> ite



SPECIAL CASE – BINARY ACIDS

↳ "aq" (in water) vs. "g" (pure) Names

Names of Some Simple Acids

Name of Gas	Name of Acid
HF(*g*), hydrogen fluoride	HF(*aq*), hydrofluoric acid
HCl(*g*), hydrogen chloride	HCl(*aq*), hydrochloric acid
HBr(*g*), hydrogen bromide	HBr(*aq*), hydrobromic acid
HI(*g*), hydrogen iodide	HI(*aq*), hydroiodic acid
$H_2S(g)$, hydrogen sulfide	$H_2S(aq)$, hydrosulfuric acid

Table 2.12

COMMON NAMES – "The Resistant Ones"

H_2O = water (not dihydrogen monoxide)

NH_3 = ammonia (not nitrogen trihydride)

↓ H^+

NH_4^+

ammonium

NH_4Cl

(EX) IONIC VS. MOLECULAR (COVALENT)
¿Are the following Ionic or Covalent/Molecular? Why? [ex 2.12b]

ⓐ SO_2 = molecular ; diatomic $nM + nM$

ⓑ CaF_2 = ionic ; $M+nM$, $Ca^{2+} + 2F^-$

ⓒ N_2H_4 = molecular ; diatomic $nM + nM$

ⓓ $Al_2(SO_4)_3$ = ionic ; $M+nM$ (polyatomic) ; $2Al^{3+} + 3\ SO_4^{2-}$

(EX) NOMENCLATURE: NAME —> FORMULA

ⓐ chromium (III) phosphide

Cr^{3+} P^{3-}

ⓑ manganese (II) phosphate

$Mn_3^{2+}(PO_4)_2^{3-}$

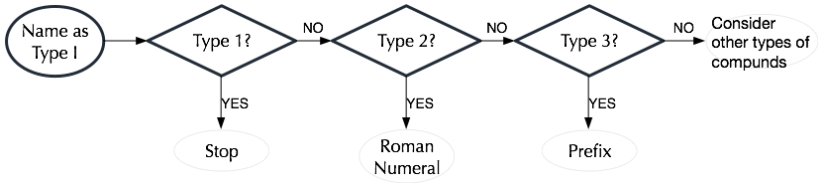
ⓒ calcium chloride

ⓓ ammonium sulfate

$(NH_4^+)_2SO_4^{2-}$

ⓔ calcium oxide

$Ca^{2+}O^{2-}$



ⓕ nitric acid

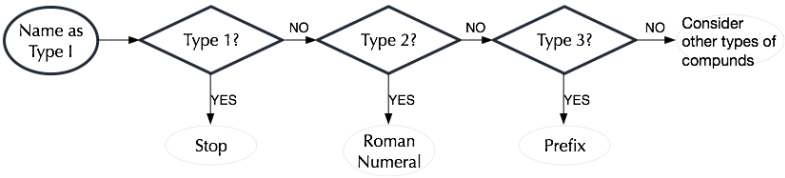
ⓖ nitrate ion HNO_3

NO_3^-

ⓗ phosphite ion

[answers next page]

(EX) NOMENCLATURE: NAME —> FORMULA



ⓐ chromium(III) phosphide

Cr^{3+} P^{3-}

⇒ Cr P (cfg naht)

ⓑ manganese (II) phosphate

Mn_3^{2+} $(PO_4^{3-})_2$ ⇒ $Mn_3(PO_4)_2$

ⓒ calcium chloride :

Ca_1^{2+} Cl_2^- → $CaCl_2$

ⓓ ammonium sulfate :

$NH_{4\,3}^{+}$ $SO_{4\,1}^{3-}$ → $(NH_4)_3SO_4$

ⓔ calcium oxide :

Ca^{2+} O^{2-} → CaO

ⓕ nitric acid :

HNO_3 (memory)

ⓖ nitrate ion :

ic → te

HNO_3 → NO_3^-

ic ate

ⓗ phosphite ion :

ous → ite

H_3PO_3 → PO_3^{3-}

(EX) NOMENCLATURE: FORMULA —> NAME

(a) KNO_3 <T1>

Type I name

no II, no III

(b) NO <T3>

Type I name

no II, yes III --> prefixes

(c) Al_2O_3 <T1>

Type I name

no II, no III

(d) $Ni_2(SO_4)_3$ <T2>

Type I name

yes II --> RN
(around the bend)

(EX) NOMENCLATURE: FORMULA —> NAME

ⓐ KNO_3 <T1>

↓ Type I name

potassium nitrate

↑↓ no II, no III

(stop)

ⓑ NO <T3>

↓ Type I name

nitrogen monoxide

↓ no II, yes III --> prefixes

nitrogen monoxide

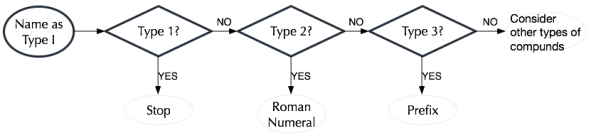
ⓒ Al_2O_3 <T1>

↓ Type I name

aluminum oxide

↓ no II, no III

(stop)



ⓓ $Ni_2(SO_4)_3$ <T2>

↓ Type I name

nickel sulfate

↓ yes II --> RN (around the bend)

RN Source → 3

+6 −6 = 0

$Ni_2(SO_4)_3^{2-}$

↓

nickel (II) sulfate