NATIONAL MATH + SCIENCE INITIATIVE

AP* Chemistry
ATOMS, MOLECULES & IONS

This is the highest honor given by the American Chemical Society. Priestly discovered oxygen. Ben Franklin got him interested in electricity and he observed graphite conducts an electric current. Politics forced him out of England and he died in the US in 1804. The back side, pictured below was given to Linus Pauling in 1984. Pauling was the only person to win Nobel Prizes in TWO Different fields: Chemistry and Peace.

THE EARLY HISTORY OF CHEMISTRY

- 1,000 B.C.—processing of ores to produce metals for weapons and ornaments; use of embalming fluids
- 400 B.C.—Greeks—proposed all matter was make up of 4 “elements”: fire, earth, water and air
- Democritus—first to use the term *atomos* to describe the ultimate, smallest particles of matter
- Next 2,000 years—*alchemy*—a pseudoscience where people sought to turn metals into gold. Much was learned from the plethora of mistakes alchemists made.
- 16^{th} century—Georg Bauer, German , refined the process of extracting metals from ores & Paracelsus, Swiss, used minerals for medicinal applications
- Robert Boyle, English—first “chemist” to perform **quantitative** experiments of pressure versus volume. Developed a working definition for “elements”.
- 17^{th} & 18^{th} Centuries—Georg Stahl, German—suggested “phlogiston” flowed OUT of burning material. An object stopped burning in a closed container since the air was “saturated with phlogiston”
- Joseph Priestley, English—discovered oxygen which was originally called “dephlogisticated air”

FUNDAMENTAL CHEMICAL LAWS

- late 18^{th} Century—Combustion studied extensively
- CO_2, N_2, H_2 and O_2 discovered
- list of elements continued to grow
- Antione Lavoisier, French—explained the true nature of combustion—published the first modern chemistry textbook AND stated the Law of Conservation of Mass. The French Revolution broke out the same year his text was published. He once collected taxes for the government and was executed with a guillotine as an enemy of the people in 1794. He was the first to insist on *quantitative* experimentation.

THE LAW OF CONSERVATION OF MASS:

Mass is neither created nor destroyed.

- 1808--John Dalton stated the Law of Definite proportions.
  He later went on to develop the Atomic Theory of Matter.

THE LAW OF DEFINITE PROPORTIONS:

A given compound always contains exactly the same proportions of elements by mass.

THE LAW OF MULTIPLE PROPORTIONS:

When two elements combine to form a series of compounds, the ratios of the masses of the second element that combine with 1 gram of the first element can always be reduced to small whole numbers.

Dalton considered compounds of carbon and oxygen and determined:

	Mass of Oxygen that combines with 1 gram of C
Compound I	1.33 g
Compound II	2.66 g

Therefore, Compound I may be CO while Compound II may be CO_2.

Exercise 1 Illustrating the Law of Multiple Proportions

The following data were collected for several compounds of nitrogen and oxygen:

Mass of Nitrogen That Combines With 1 g of Oxygen

Compound A	1.7500 g
Compound B	0.8750 g
Compound C	0.4375 g

Show how these data illustrate the law of multiple proportions.

$$\frac{A}{B} = \frac{1.7500}{0.8750} = \frac{2}{1}$$

$$\frac{B}{C} = \frac{0.8750}{0.4375} = \frac{2}{1}$$

$$\frac{A}{C} = \frac{1.750}{0.4375} = \frac{4}{1}$$

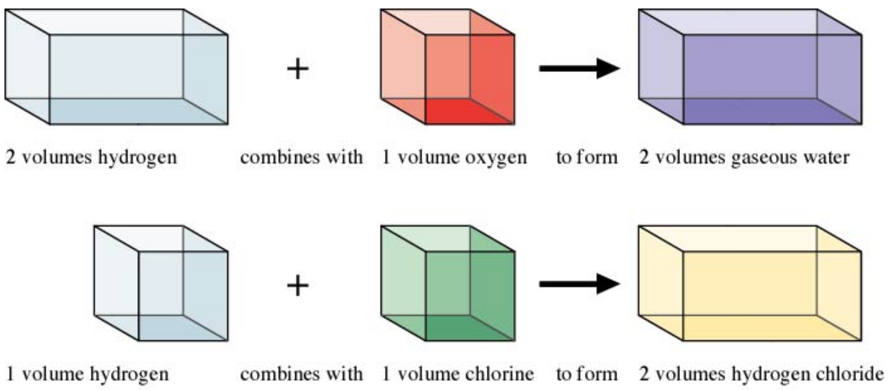
DALTON’S ATOMIC THEORY

Postulates of Dalton’s ATOMIC THEORY OF MATTER: (based on knowledge *at that time)*

1. All matter is made of **atoms**. These *indivisible and indestructible objects* are the ultimate chemical particles.
2. All the atoms of a given element are identical, in both weight and chemical properties. However, atoms of different elements have different weights and different chemical properties.
3. **Compounds** are formed by the combination of different atoms in the ratio of small whole numbers.
4. A **chemical reaction** involves only the combination, separation, or rearrangement of atoms; atoms are neither created nor destroyed in the course of ordinary chemical reactions.

**TWO MODIFICATIONS HAVE BEEN MADE TO DALTON’S THEORY:
1. *Subatomic particles were discovered. Bet you can name them!*
2. *Isotopes were discovered. Bet you can define “isotope” as well!*

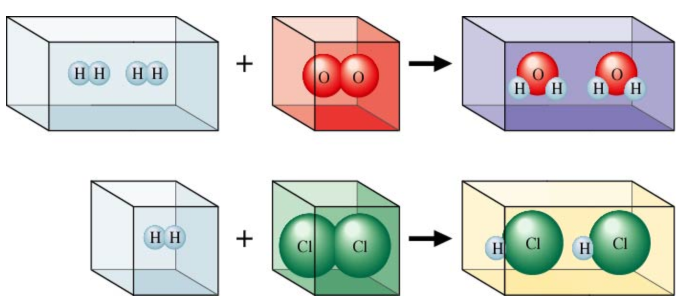
- 1809 Joseph Gay-Lussac, French—performed experiments [at constant temperature and pressure] and measured volumes of gases that reacted with each other.



- 1811 Avogadro, Italian—proposed his hypothesis regarding Gay-Lussac’s work [and you thought he was just famous for 6.02×10^{23}] He was basically ignored, so 50 years of confusion followed.

AVOGADRO’S HYPOTHESIS:

At the same temperature and pressure, equal volumes of <u>different</u> gases contain the same number of particles.

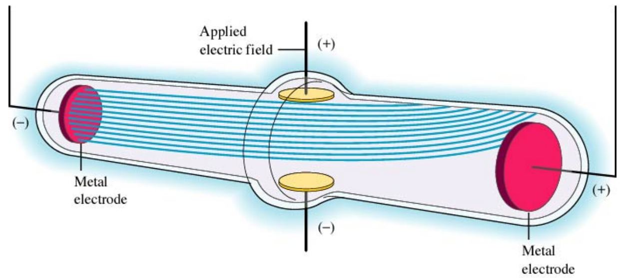


EARLY EXPERIMENTS TO CHARATERIZE THE ATOM

Based on the work of Dalton, Gay-Lussac, Avogadro, & others, chemistry was beginning to make sense [even if YOU disagree!] and the concept of the atom was clearly a good idea!

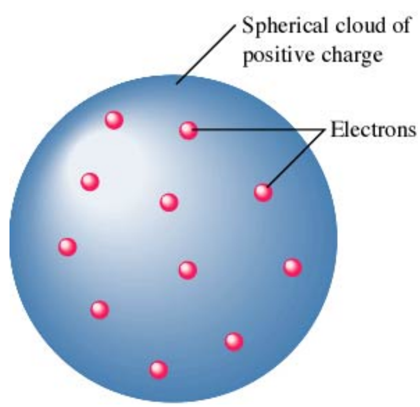
THE ELECTRON

- J.J. Thomson, English (1898-1903)—found that when high voltage was applied to an evacuated tube, a "ray" he called a cathode ray [since it emanated from the (–) electrode or cathode when YOU apply a voltage across it] was produced.
    - The ray was produced at the (–) electrode
    - Repelled by the (–) pole of an applied electric field, **E**
    - He postulated the ray was a stream of NEGATIVE particles now called electrons, e^-

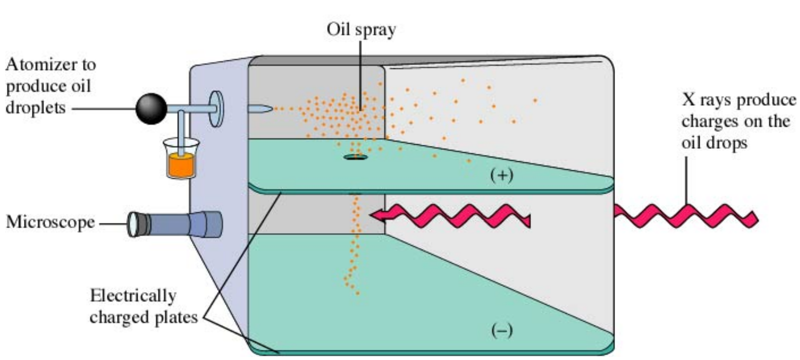


- He then measured the deflection of beams of e^- to determine the **charge-to-mass ratio**

$$\frac{e}{m} = -1.76 \times 10^8 \frac{C}{g}$$



- *e* is charge on electron in Coulombs, (C) and *m* is its mass.
- Thomson discovered that he could repeat this deflection and calculation using electrodes of different metals ∴ all metals contained electrons and ALL ATOMS contained electrons
- Furthermore, all atoms were neutral ∴ there must be some (+) charge within the atom and the "plum pudding" model was born. Lord Kelvin may have played a role in the development of this model. [The British call *every* dessert "pudding"—we'd call it raisin bread where the raisins were the electrons randomly distributed throughout the + bread]



- 1909 Robert Millikan, American—University of Chicago, sprayed charged oil drops into a chamber. Next, he halted their fall due to gravity by adjusting the voltage across 2 charged plates. Now the voltage needed to halt the fall and the mass of the oil drop can be used to calculate the charge on the oil drop which is a whole number multiple of the electron charge.
Mass of $e^- = 9.11 \times 10^{-31}$ kg.

RADIOACTIVITY

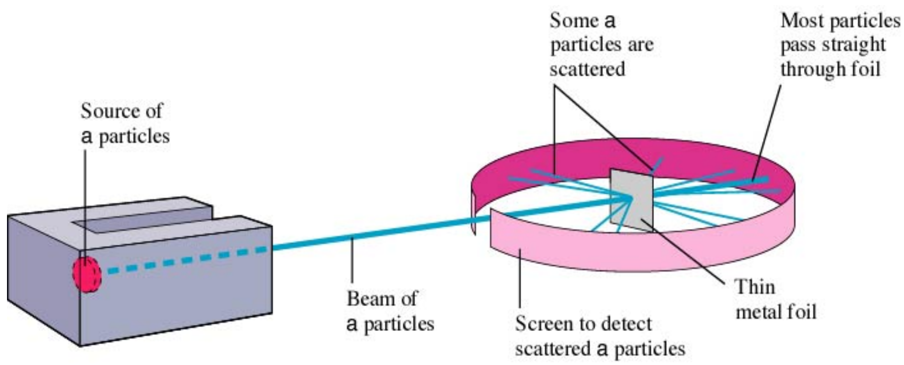
- Henri Becquerel, French—found out quite by accident [serendipity] that a piece of mineral containing uranium could produce its image on a photographic plate in the *absence* of light. He called this **radioactivity** and attributed it to a spontaneous emission of radiation by the uranium in the mineral sample.

- THREE types of radioactive emission:
  - **alpha, α--**equivalent to a helium nucleus; the largest particle radioactive particle emitted; 7300 times the mass of an electron. ${}^{4}_{2}He$ Since these are larger that the rest, early atomic studies often involved them.
  - **beta, β**--a high speed electron. ${}^{0}_{-1}\beta$ OR ${}^{0}_{-1}e$
  - **gamma, γ**--pure energy, no particles at all! Most penetrating, therefore, most dangerous.

THE NUCLEAR ATOM

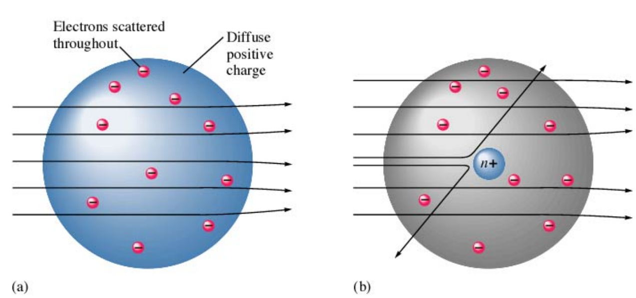
- 1911 Ernest Rutherford, England—A pioneer in radioactive studies, he carried out experiments to test Thomson's plum pudding model.
  - Directed α particles at a thin sheet of gold foil. He thought that if Thomson was correct, then the massive α particles would blast through the thin foil like "cannonballs through gauze". [He actually had a pair of graduate students Geiger & Marsden do the first rounds of experiments.] He expected the α particles to pass through with minor and occasional deflections.

  - The results were astounding [poor Geiger and Marsden first suffered Rutherford's wrath and were told to try again—since this couldn't be!].



    - Most of the α particles did pass straight through, BUT many were deflected at LARGE angles and some even REFLECTED!
    - Rutherford stated that was like "shooting a howitzer at a piece of tissue paper and having the shell reflected back"
    - He knew the plum pudding model could not be correct!

    - Those particles with large deflection angles had a "close encounter" with the dense positive center of the atom
    - Those that were reflected had a "direct hit"
    - He conceived the **nuclear atom**; that with a dense (+) core or **nucleus.**
    - This center contains most of the mass of the atom while the remainder of the atom is empty space!



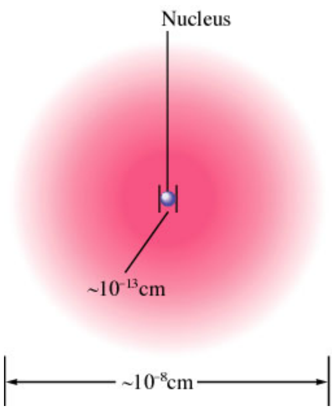
THE MODERN VIEW OF ATOMIC STRUCTURE: AN INTRODUCTION

ELEMENTS

All matter composed of only one type of atom is an element. There are 92 naturally occurring, all others are *man*made.

ATOMS

atom--the smallest particle of an element that retains the chemical properties of that element.



- **nucleus**--contains the protons and the neutrons; the electrons are located outside the nucleus. Diameter = 10^{-13} cm. The electrons are located 10^{-8}cm from the nucleus. A mass of nuclear material the size of a pea would weigh 250 million tons! Very dense!
  - **proton**--positive charge, responsible for the identity of the element, defines *atomic number*
  - **neutron**--no charge, same size & mass as a proton, responsible for *isotopes*, alters *atomic mass number*
  - **electron**--negative charge, same size as a proton or neutron, BUT 1/2,000 the mass of a proton or neutron, responsible for bonding, hence reactions and ionizations, easily added or removed.
- **atomic number(Z)**--The number of p+ in an atom. All atoms of the *same* element have the *same number* of p+.
- **mass number(A)**--The sum of the number of neutrons and p+ for an atom. A different mass number *does not* mean a different element--just signifies an isotope.

Particle	Mass	Charge
e^-	9.11×10^{-31}	1–
p^+	1.67×10^{-27}	1+
n^0	1.67×10^{-27}	None

$$\text{mass number} \rightarrow \quad {}^{A}_{Z}\mathrm{X} \quad \leftarrow \text{element symbol}$$
$$\text{atomic number} \rightarrow$$

- The actual mass is not an integral number! **mass defect**--causes this and is related to the energy binding the particles of the nucleus together.

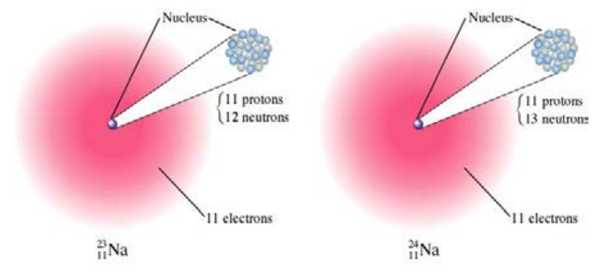
Exercise 2 Writing the Symbols for Atoms

Write the symbol for the atom that has an atomic number of 9 and a mass number of 19. How many electrons and how many neutrons does this atom have?

F; **9 electrons and 10 neutrons**

ISOTOPES

- **isotopes**--atoms having the same atomic number (# of *p*+) but a different number of neutrons
  - most elements have at least two stable isotopes, there are very few with only one stable isotope (Al, F, P)
  - Hydrogen's isotopes are so important they have special names:
    - 0 neutrons ☞ hydrogen
    - 1 neutron ☞ deuterium
    - 2 neutrons ☞ tritium

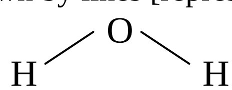


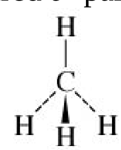
MOLECULES AND IONS

Electrons are the only subatomic particles involved in bonding and chemical reactivity.

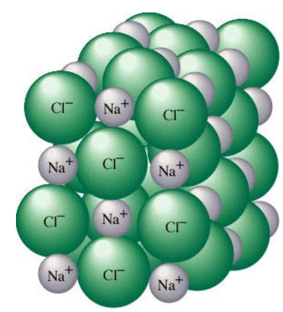
- **Chemical bonds**—forces that hold atoms together
- **Covalent bonds**—atoms share electrons and make molecules [independent units]; H_2, CO_2, H_2O, NH_3, O_2, CH_4 to name a few.
- **molecule**--smallest unit of a compound that retains the chem. characteristics of the compound; characteristics of the constituent elements are lost.
- **molecular formula**--uses symbols and subscripts to represent the composition of the molecule. (Strictest sense--covalently bonded)
- **structural formula**—bonds are shown by lines [representing shared e^- pairs]; may NOT indicate shape

H—O—H



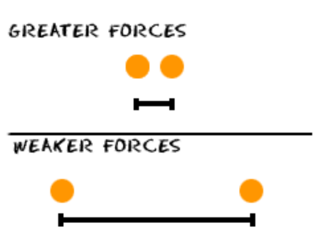


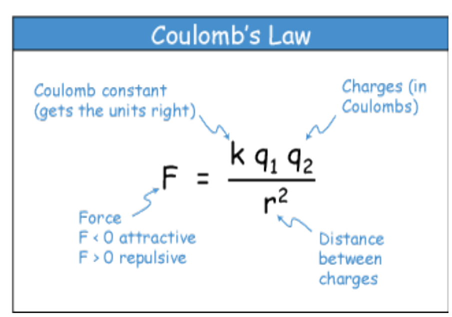
Methane



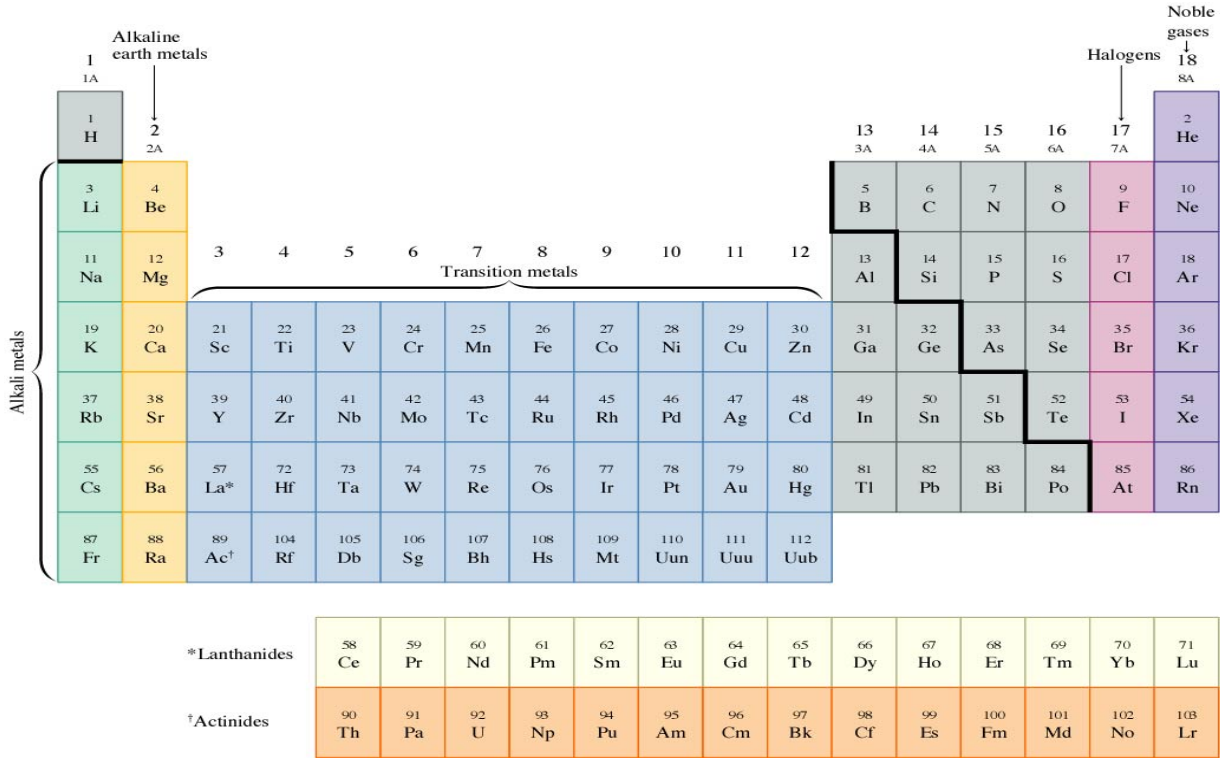
- **ions**--formed when electrons are lost or gained in ordinary chem. reactions; dramatic change in size (more about that shortly)
  - **cations**--(+) ions; often metals since metals *lose* electrons to become *positively* charged
  - **anions**--(–) ions; often nonmetals since nonmetals *gain* electrons to become *negatively* charged
  - **polyatomic ions**--units of atoms behaving as one entity ☞ It's worth memorizing 9 polyatomic ions + 3 patterns. (separate handout)
  - **ionic solids**—Electrostatic forces hold ions together. We can calculate the magnitude of them using Coulomb's Law. When these electrostatic attractions are strong, the ions are held together tightly and are close together ∴ solids. Additionally, the stronger the Coulombic force, F_c, the higher the melting point.

Coulomb's Law: $F_c \propto \frac{q_1 q_2}{d^2}$ or $F_c = k\frac{q_1 q_2}{d^2}$





AN INTRODUCTION TO THE PERIODIC TABLE



Current Name	Original Name (often Latin)	Symbol
Antimony	Stibium	Sb
Copper	Cuprum	Cu
Iron	Ferrum	Fe
Lead	Plumbum	Pb
Mercury	Hydrargyrum	Hg
Potassium	Kalium	K
Silver	Argentum	Ag
Sodium	Natrium	Na
Tin	Stannum	Sn
Tungsten	Wolfram	W

- Atomic number = number of protons and is written above each symbol
- **metals**—malleable, ductile & have luster; most of the elements are metals—exist as cations in a "sea of electrons" which accounts for their excellent conductive properties; form oxides [tarnish] readily and form POSITIVE ions [cations]. Why must some have such goofy symbols?

- **groups or families**--vertical columns; have similar physical and chemical properties (based on similar electron configurations!!)
    - **group A—**Representative elements
    - **group B**--transition elements; all metals; have numerous oxidation/valence states
- **periods**--horizontal rows; progress from metals to metalloids [either side of the black "stair step" line above that separates metals from nonmetals] to nonmetals
- **MEMORIZE:**
    1. ALKALI METALS—1A or IA
    2. ALKALINE EARTH METALS—2A or IIA
    3. HALOGENS—7A or VIIA
    4. NOBLE (RARE) GASSES—8A or VIIIA

NAMING SIMPLE COMPOUNDS

BINARY IONIC COMPOUNDS

<u>Naming (+) ions</u>: usually metals

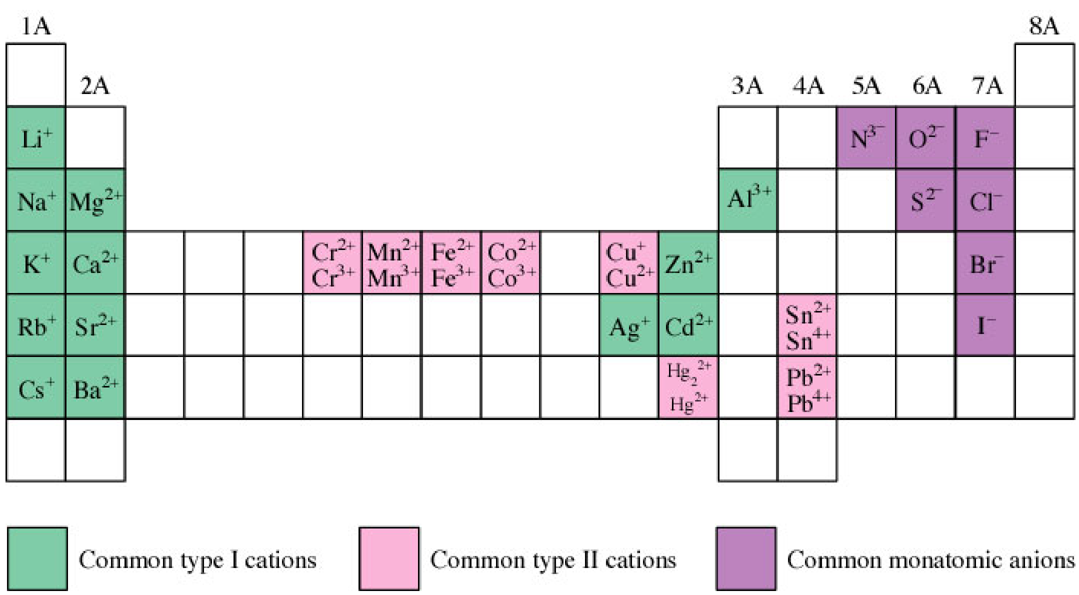
- monatomic, metal, cation → simply the name of the metal from which it is derived. **Al^{3+} is the aluminum ion;** transition metals form *more than one* ion; Roman Numerals (in) follow the ion's name, they are your friend—they tell you which charge is on that particular ion **Cu^{2+} is copper(II); Mercury(I)** ***is an exception*** ☞ ***it is Hg_2^{2+} ∴ two Hg^+ associated together*** also, remember Hg is a metal that is a liquid at room temperature. (Yeah, the no space thing between the ion's name and (Roman Numeral) looks strange, but it is the correct way to do it. It's called the Stock system developed by the German chemist Alfred Stock and first published in 1916.)
- NH_4^+ is ammonium
- NO ROMAN NUMERAL IS USED WITH silver, cadmium and zinc. Why not? They only make one valence state.
  [Arrange their SYMBOLS in alphabetical order—first one is 1+ and the other two are 2+]

<u>Naming (–) ions</u>: monatomic and polyatomic

- **MONATOMIC**--add the suffix ***-ide*** to the stem of the nonmetal's name. Halogens are called the ***halides***.
- **POLYATOMIC**--quite common; *oxyanions* are the PA's containing oxygen (Go, figure!)
  - *hypo*--"ate" the least oxygen
  - *-ite*--"ate" 1 more oxygen than hypo-
  - *-ate*--"ate" 1 more oxygen than -ite
  - *hy**per***---ate--"ate" the most oxygen (often the "hy" is left off to read simply "per")

Example: hypochlorite ClO^-
Chlorite ClO_2^-
Chlorate ClO_3^-
Hyper or more commonly Perchlorate ClO_4^-
You can substitute any halogen in for the Cl.

<u>NAMING IONIC COMPOUNDS</u>: The + ion name is given *first* followed by the name of the negative ion.



Exercise 3 **Naming Type I Binary Compounds**

Name each binary compound.

a. CsF b. $A1C1_3$ c. LiH

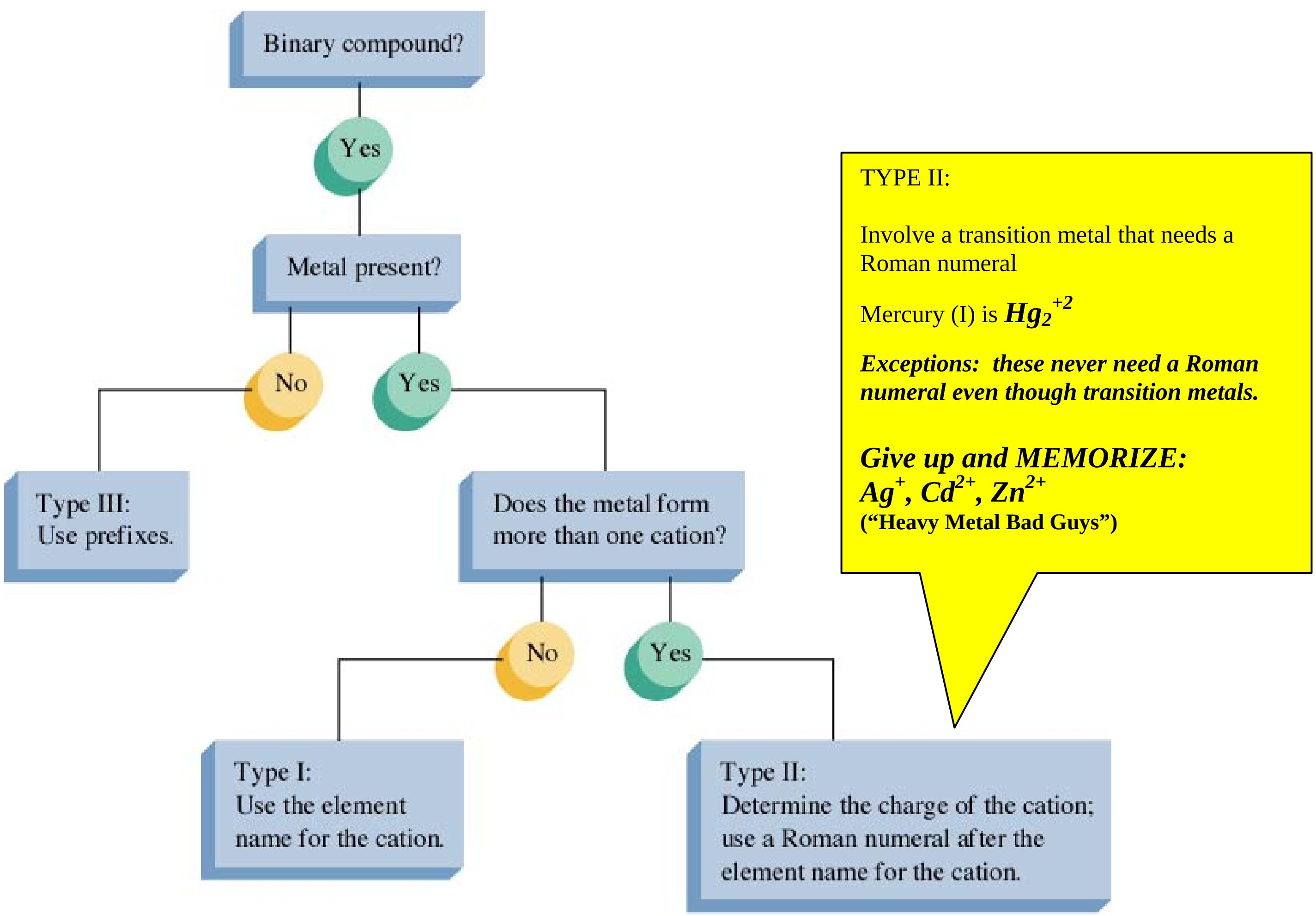
a. cesium fluoride
b. aluminum chloride
c. lithium hydride

Exercise 4 **Naming Type II Binary Compounds**

Give the systematic name of each of the following compounds.

a. CuC1 b. HgO c. Fe_2O_3 d. MnO_2 e. $PbC1_2$

a. copper(I) chloride
b. mercury(II) oxide
c. iron(III) oxide
d. manganese(IV) oxide
e. lead(II) chloride



Exercise 5 **Naming Binary Compounds**

Give the systematic name of each of the following compounds.

a. $CoBr_2$ b. $CaC1_2$ c. $A1_2O_3$ d. $CrC1_3$

a. Cobalt(II) bromide; b. Calcium chloride; c. Aluminum oxide; d. Chromium(III) chloride

Exercise 6 **Naming Compounds Containing Polyatomic Ions**

Give the systematic name of each of the following compounds.

a. Na_2SO_4 b. KH_2PO_4 c. $Fe(NO_3)_3$ d. $Mn(OH)_2$
e. Na_2SO_3 f. Na_2CO_3 g. $NaHCO_3$ h. $CsC1O_4$
i. NaOC1 j. Na_2SeO_4 k. $KBrO_3$

a. Sodium sulfate; b. Potassium dihydrogen phosphate; c. Iron(III) nitrate; d. Manganese(II) hydroxide; e. Sodium sulfite; f. Sodium carbonate; g. Sodium hydrogen carbonate; h. Cesium perchlorate; i. Sodium hypochlorite; j. Sodium selenite; k. Potassium bromate

NAMING BINARY COVALENT COMPOUNDS: (covalently bonded)

- Use prefixes!!! Don't forget the –ide ending as well.

Exercise 7 **Naming Type III Binary Compounds**

Name each of the following compounds.

a. $PC1_5$ b. $PC1_3$ c. SF_6 d. SO_3 e. SO_2 f. CO_2

a. Phosphorus pentachloride; b. Phosphorus trichloride; c. Sulfur hexafluoride; d. Sulfur trioxide; e. Sulfur dioxide; f. Carbon dioxide

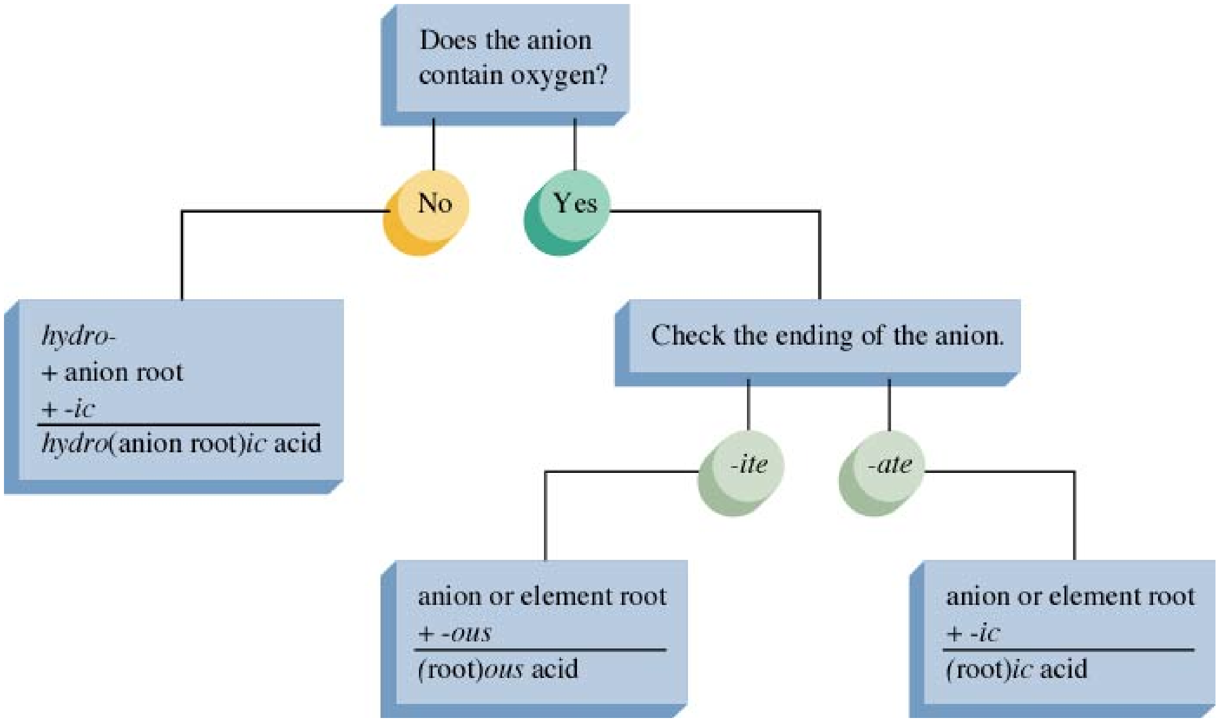
ACIDS

Naming acids is actually easy. The nomenclature follows quite an elegant pattern:

Hydrogen, if present, is listed first followed by a suffix and finally the word "acid".

If the negative ion's name ends in:

-ide $\rightarrow$□*hydro*[negative ion root]*ic* acid Ex: hydrosulfuric acid, H_2S
-ate $\rightarrow$ *-ic* acid Ex: sulfuric acid, H_2SO_4
-ite $\rightarrow$ *-ous* acid Ex: chlorous acid, H_2SO_3



PAINS IN THE GLUTEUS MAXIMUS: these lovely "critters" have been around longer than the naming system and no one wanted to adapt!! With the exception of the first 2 on this list, the AP exam either avoids them altogether or gives you the formula. Ex: phosphine (PH_3—ammonia's cousin), etc.

- water
- ammonia
- hydrazine
- phosphine
- nitric oxide
- nitrous oxide ("laughing gas")

Exercise 8 **Naming Acids**

Name each of the following acids.

a. HBr b. HBrO c. $HBrO_2$ d. $HBrO_3$ e. $HBrO_4$ f. HNO_2 g. HNO_3

a. hydrobromus acid; b. hypobromous acid; c. bromous acid; d. bromic acid; e. perbromic acid; f. nitrous acid; g. nitric acid

Exercise 9 Naming Various Types of Compounds

Give the systematic name for each of the following compounds.

a. P_4O_{10} b. Nb_2O_5 c. Li_2O_2 d. $Ti(NO_3)_4$

a. Tetraphosphorus decoxide; b. Niobium(V) oxide; c. Lithium peroxide; d. Titanium(IV) nitrate

Exercise 10 Writing Compound Formulas from Names

Given the following systematic names, write the formula for each compound.

a. Vanadium(V) fluoride b. Dioxygen difluoride
c. Rubidium peroxide d. Gallium oxide

a. VF_5; b. O_2F_2; c. Rb_2O_2 d. Ga_2O_3

For the visual learners among you, here's a "Cheat Sheet". Practice, practice, practice!