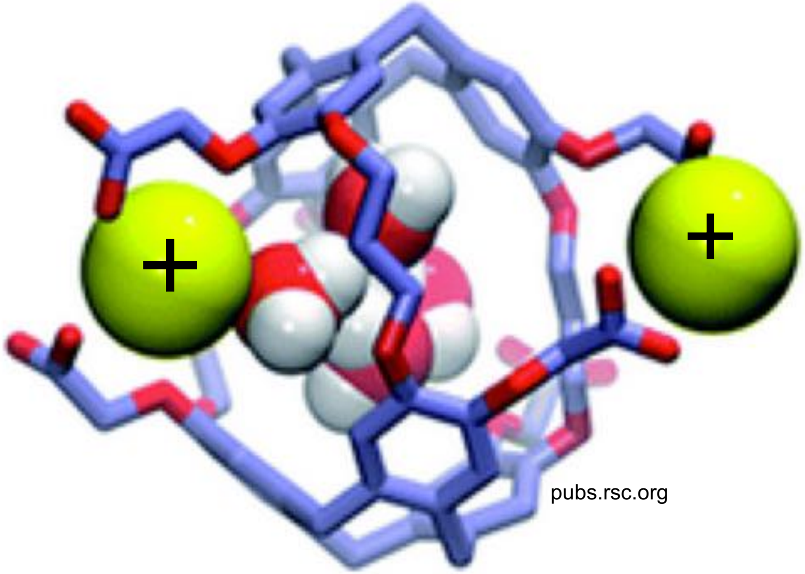
Chapter 2:

Atoms, Molecules, and Ions



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The Atomic Theory

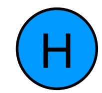
Proof atoms exist
Laws of Chemical Combination

http://clipart-library.com

Atomic Theory of Matter: Dalton (1808)

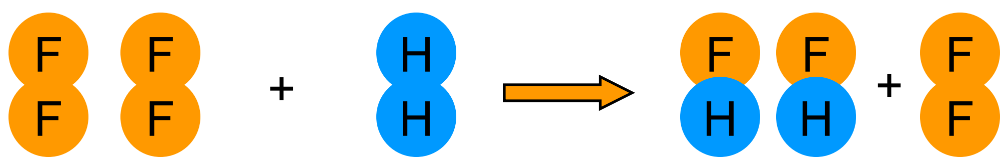
1. All matter is composed of tiny particles called atoms
2. All atoms of a given element are identical, but atoms of different elements differ in size, mass, & chemical properties

Fluorine atom: 18 amu



Hydrogen atom: 1 amu

3. Compounds are formed when atoms of different elements combine in fixed proportions.



74amu = 72amu + 2amu 38amu + 36amu = 74amu

4. A chemical reaction involves atomic rearrangement.

No atoms are created or destroyed.

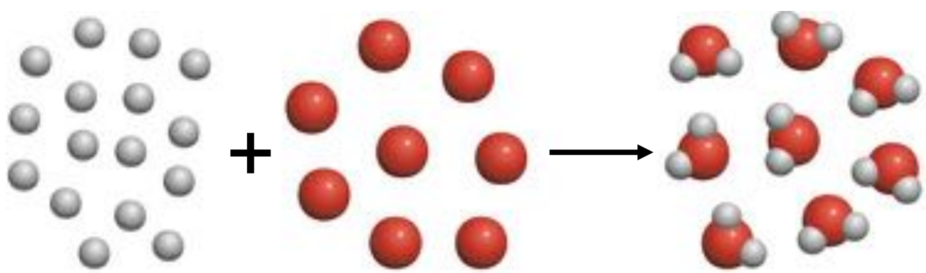
Law of Definite Proportions – Joseph Proust 1799

- Supports Part 3 of Atomic Theory

A compound will always have same chemical composition

- Each product is formed from definite proportions of reactants

3 eggs | 2 cups flour | 1 cake



16 Hydrogen atoms | 8 Oxygen atoms | 8 Water molecules

Water is ALWAYS H_2O

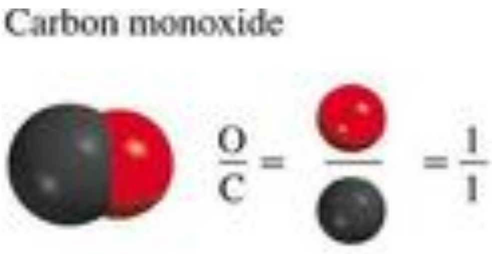
- Same mass proportions & atomic ratios of elements present

Law of Multiple Proportions

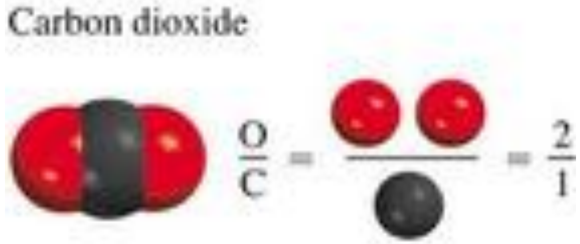
If the same two elements can combine to form more than one compound:

- The **masses** of one element combine with a fixed mass of the second element.
- The combination is in a ratio of **small whole numbers.**

Open face sandwich
1 bread + 1 filling
1:1 ratio



Regular sandwich
2 bread + 1 filling
2:1 ratio



Compounds are formed when atoms of different elements unite in fixed proportions

Law of Conservation of Mass

Total mass is constant during a chemical reaction

Mass of reactants must exactly match mass of products

2lbs potatoes + 3 ounces milk + 1 ounce butter = 2.25 lbs mashed potatoes

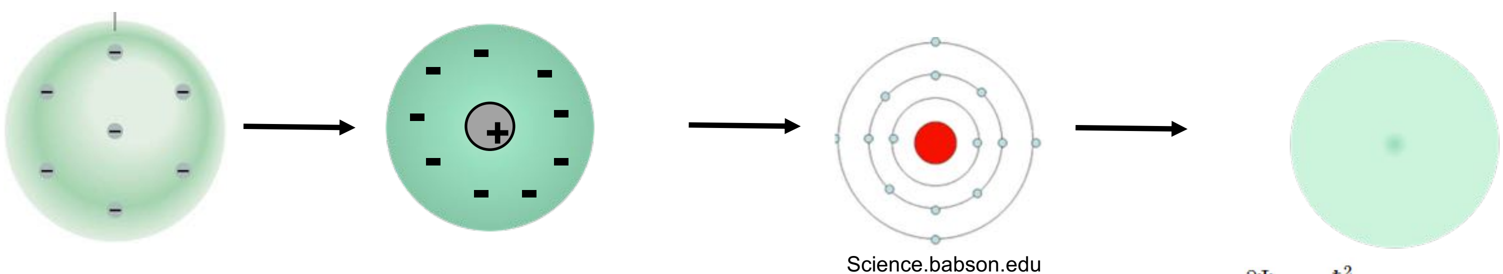
Called mass balance

11.1g H_2 (g) + 88.9g O_2 (g) = 100.0g H_2O (l)

Matter cannot be created or destroyed in chemical reactions!

Structure of the Atom

What's on the inside?!?



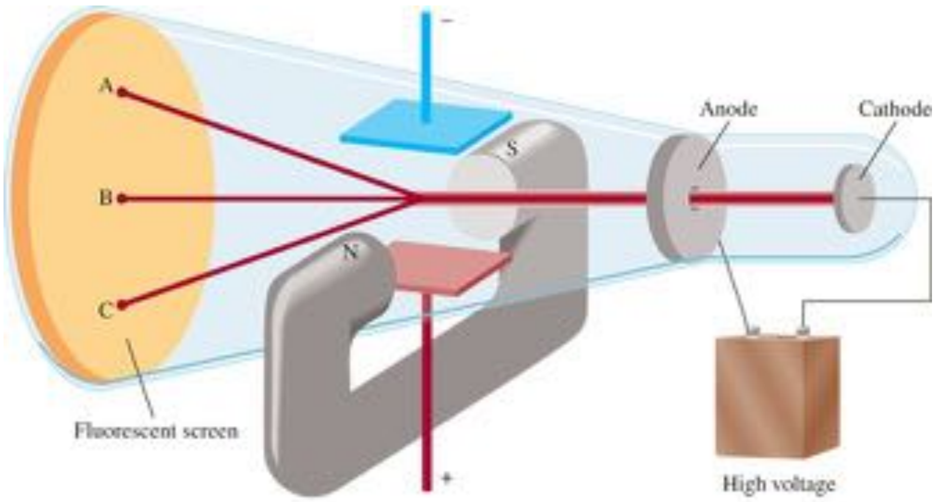
$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + [V_1(x) + iV_2(x)]\Psi$$

The Electron and Cathode Rays (1890's)

Electricity causes ray to be deflected in a vacuum

Few molecules: minimal molecular interference

Applied magnetic field or electric field deflects ray



Ray is attracted to positively (+) charged anode, so it must be made of negatively (-) charged particles

Atom not smallest piece of matter – had charged "things" inside!

Millikan Oil Drop Experiment

Determination of charge and mass of electron

JJ Thompson:

Ratio of cathode ray particle's charge to mass

$= -1.76 \times 10^{8}$ C/g

Negatively charged particle is called an **electron**

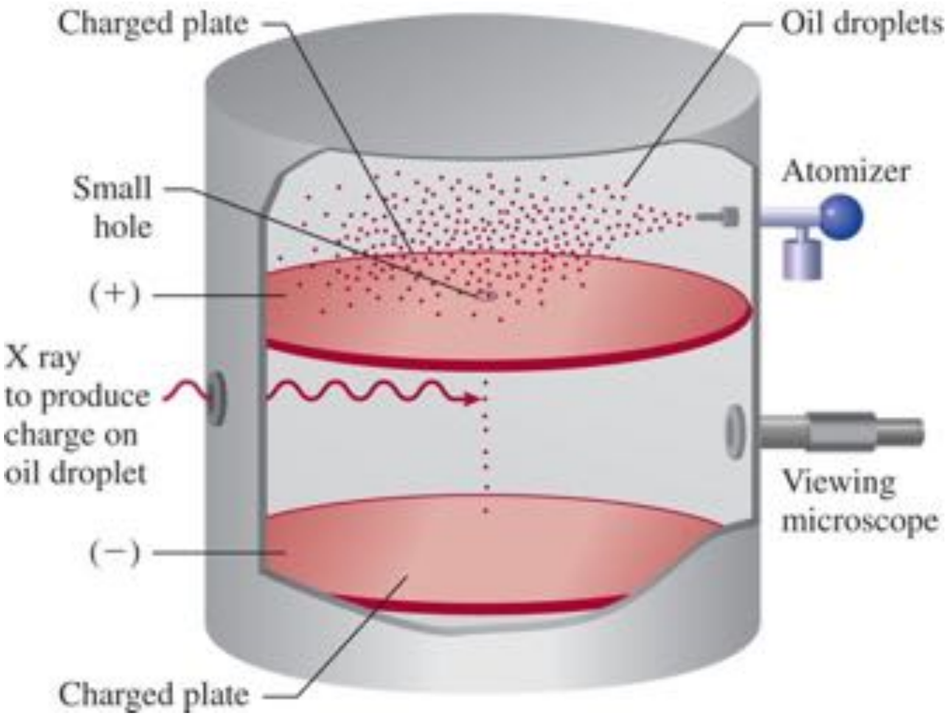
Robert Millikan

Charge on an electron:

$e = -1.602 \times 10^{-19}$ C

Mass of an electron:

$m_e = 9.10 \times 10^{-28}$g



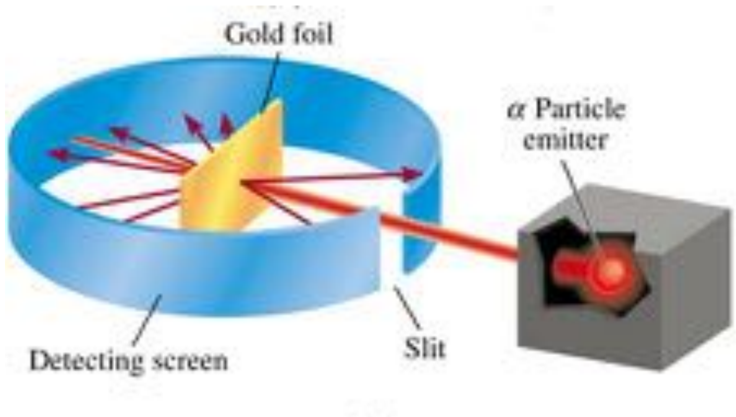
Discovery of The Nucleus

J. J. Thomson's Raisin (or Plum) Pudding Model

- Positively charged sphere with electrons imbedded inside

Rutherford's Experiments

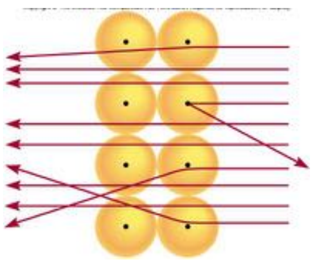
- Shot α particles through gold foil



(a)

Results:

- Most hit detector w/ no interference (empty space!)
- Some deflected from straight line: Charge interference
- A few reflected back toward emitter
  - Hit something small & positive in center



Nucleus!

The Atom and Sub-Atomic Particles

Protons

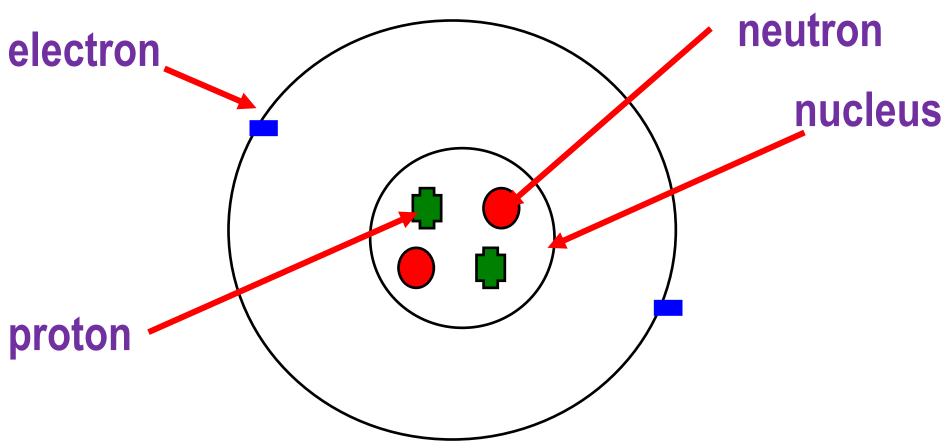
large, positively charged particles in small central nucleus

Electrons

tiny, negatively charged particles in cloud around nucleus

Neutrons

large, neutral particles in nucleus

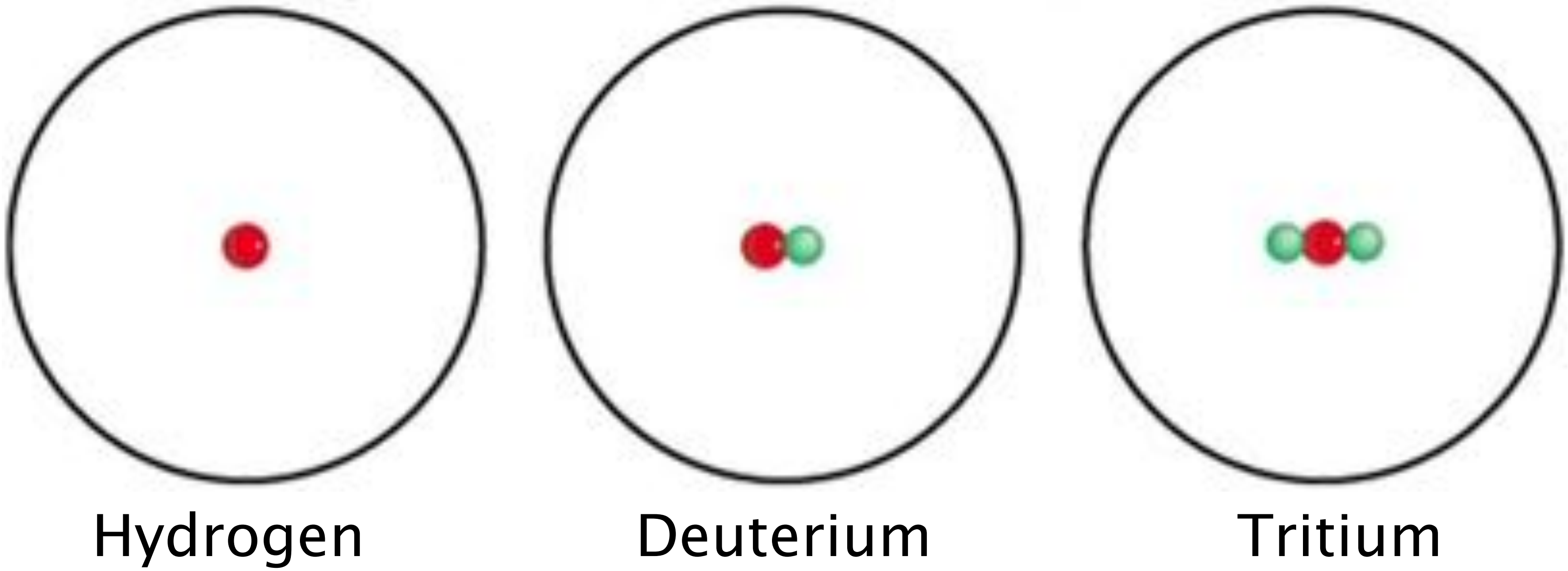


- Elements are not electrically charged
- Must have equal numbers of protons & electrons

Neutrons

Subatomic particle with same mass as proton

- Discovered by James Chadwick
- Located in nucleus
- No charge - accounts for extra mass of isotopes
- Change in mass, no change in chemical properties



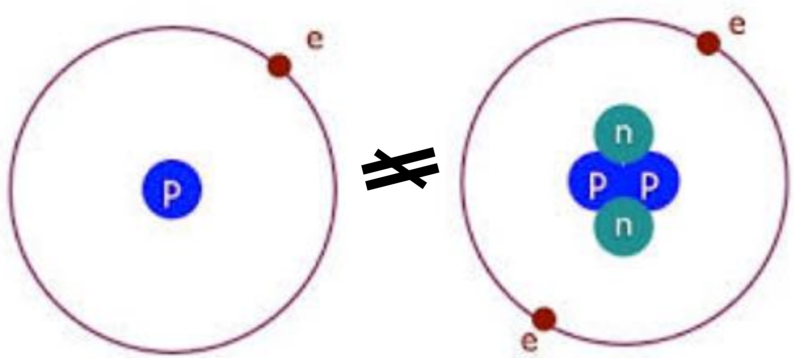
Modern View of the Atom

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + [V_1(x) + iV_2(x)]\Psi$$

- Protons (p^+) & Neutrons (n^o) in nucleus
- Electrons (e^-) in "cloud" around nucleus
  - Exist in mathematically defined energy levels
  - Highest energy level – electrons can travel furthest away from nucleus
  - Electrons in highest energy level are called **valence electrons**
    - Chemical reactions and bonding most often involve valence electrons.
    - Max number of valence electrons is 8 (an octet)
    - 8 valance electrons is stable (don't want to react)

Atomic Number, Mass Number, & Isotopes

Differences between atoms



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Atomic Symbols

Atomic Number (Z)

 # protons in a nucleus

Determines element identity

Located lower left on symbol

- can also be used to determine # electrons in uncharged atom

Mass Number (A)

 # protons + # neutrons

Determines isotope identity

Located upper left on symbol

- use to determine # neutrons!

General Form

$${}^{A}_{Z}\mathrm{E}$$

Actual Element

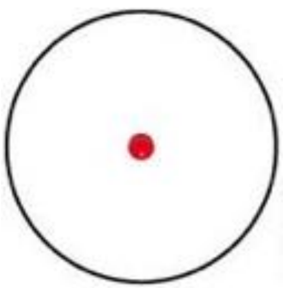
$${}^{35}_{17}\mathrm{Cl}$$

Isotopes

Elements with the same number of protons and electrons, but differing number of **neutrons**

Used in chemistry for structure identification or to follow a particular molecule through a reaction

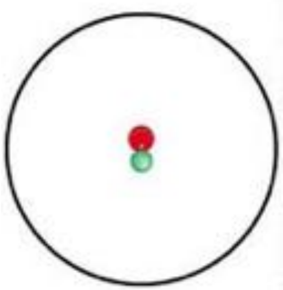
Example: hydrogen and deuterium



Water, H_2O

H has 1 proton and 0 neutrons
Most abundant

$^{1}_{1}\mathrm{H}$



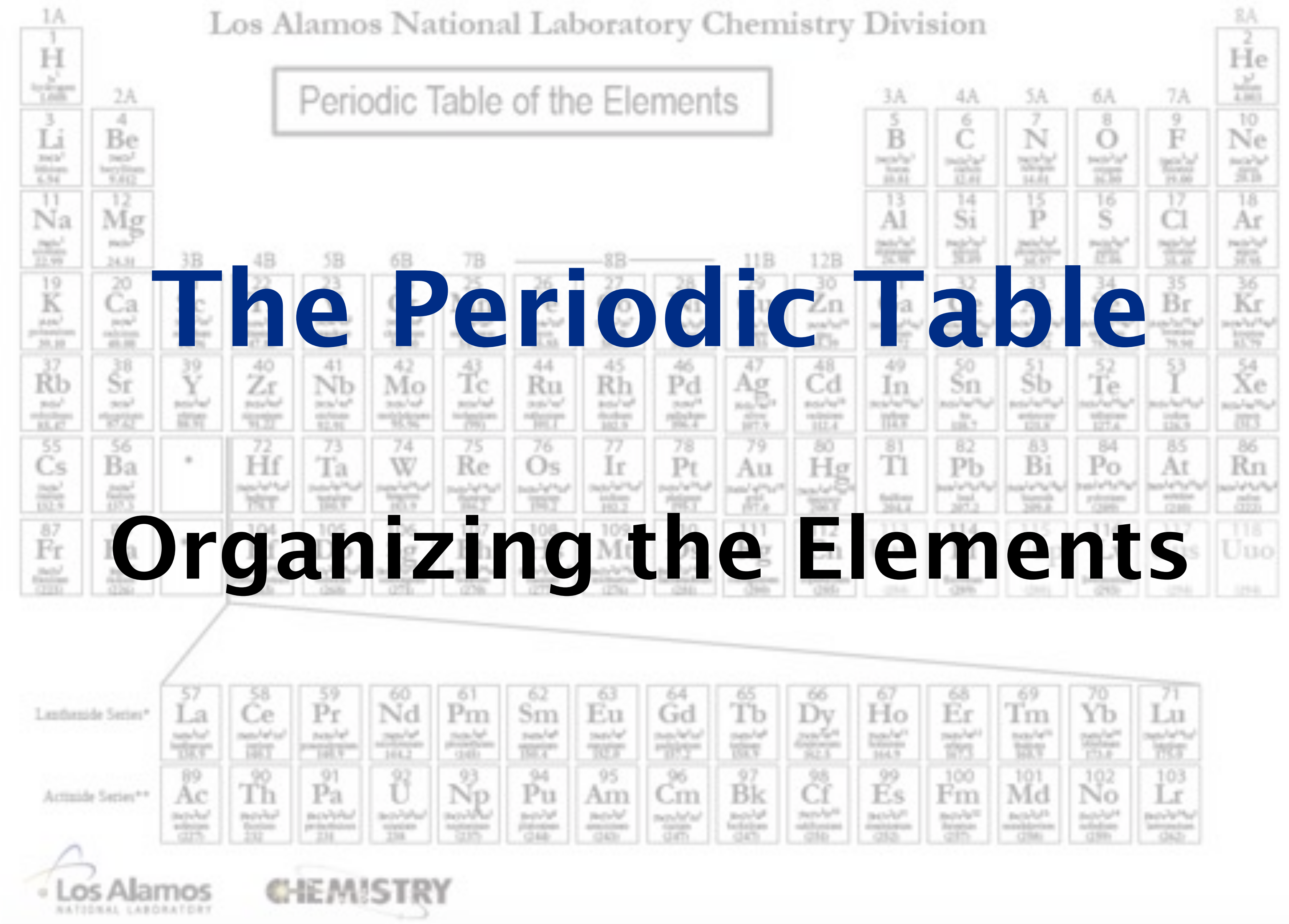
Heavy water, D_2O

D (deuterium) has 1 proton & 1 neutron
Occurs 1/6700 molecules

$^{2}_{1}\mathrm{H}$

The Periodic Table

Organizing the Elements



Mendeleev's Periodic Table 1869

Known elements arranged in order of increasing **atomic mass** from left to right and from top to bottom in groups.

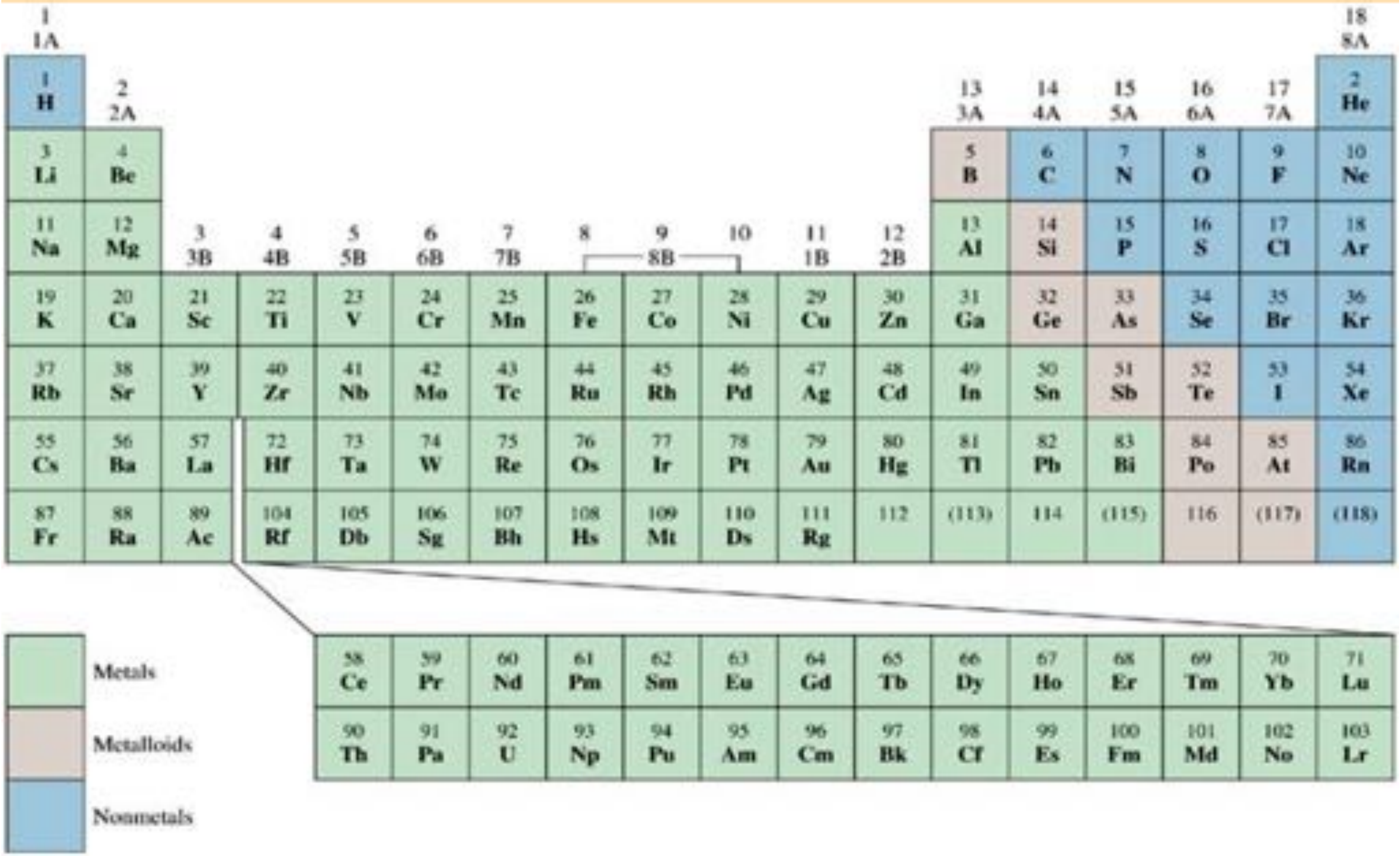
Elements with similar properties are placed in same column.

	H 1						
He 4	Li 7	Be 9	B 11	C 12	N 14	O 16	F 19
Ne 20	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35
Ar 40	K 39	Ca 40		Ge	As 75	Se 79	Br 80
Kr 84	Rb 85	Sr 88	In 115	Sn 119	Sb 122	Te 128	I 127
Xe 131	Cs 133	Ba 137	Tl 204	Pb 207	Bi 209		
Rn (222)							

Used table to predict properties of undiscovered elements!

Eka-Silicon →	Germanium
MM: 72	MM: 72.6
Density: 5.5g/mL	Density: 5.47g/mL
Color: dirty gray	Color: grayish white

The Modern Periodic Table



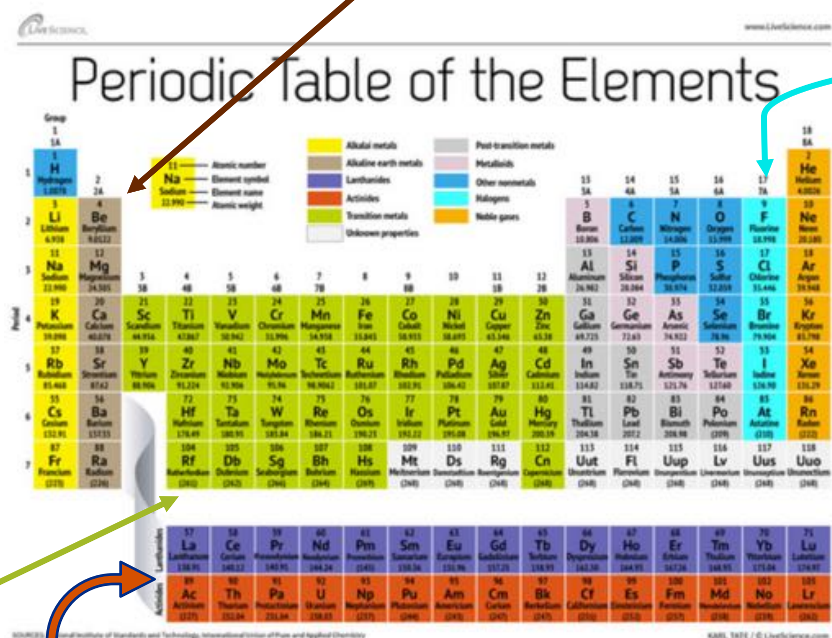
Green	Metals	Ductile, malleable, conductive, positive ionic charge
Blue	Nonmetals	Brittle solids, often gases or liquids, negative charge
Pink	Metalloids	Properties of both metals and nonmetals

Groups in the Periodic Table

Alkali Metals
- Group 1A
- +1 charge
- Highly reactive

Alkali Earth Metals
- Group 2A
- +2 charge
- Reactive

Halogens
- Group 7A
- -1 charge
- Highly reactive
- Diatomic molecules



Transition metals
- Center of table
- Varying (+) charge
- Use Roman numerals

Lanthanides & Actinides
- Bottom of table
- Very reactive
- + charge
- Often radioactive

Noble Gases
- Group 8A
- + charge (if charged)
- Inert

Elements you should be familiar with by the end of this course:

(Name & Symbol)

First 4 rows of periodic table

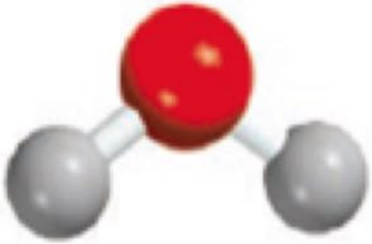
Including 1st row of transition metals

Additional elements

Ag:	Silver	Pb:	Lead
I:	Iodine	Hg:	Mercury

(A Periodic Table with both names & symbols will be provided in this class, but you may be expected to know these in future chemistry courses.)

Chemical Formulas & Names



H_2O

Sodium chloride

Types of Compounds

Ionic:

- Cation + Anion
- Form from transfer of electrons
- Often metal + nonmetal
  - Elements that are very "different"
  - Opposite sides of Periodic Table
- Ex. NaCl (sodium chloride)
- Contain specific ratios of ions but no specific number of ions

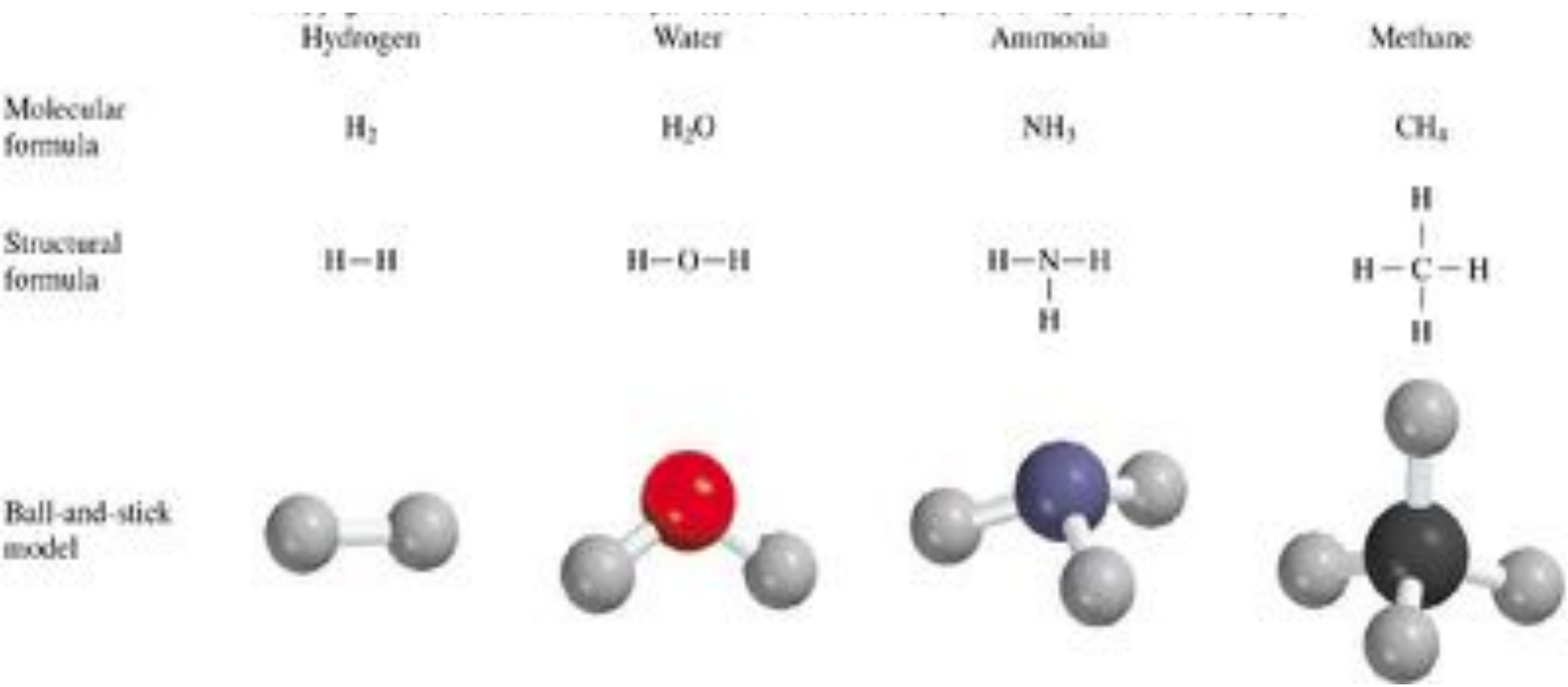
Covalent:

- Form by sharing electrons
- Contain atoms, not ions
- Often nonmetal + nonmetal
  - Elements that are "similar"
  - Same side of Periodic Table
  - Hydrogen is a nonmetal
- Ex. CO_2 (carbon dioxide)
- Molecules contain specific numbers of atoms.

Chemical Formulas

Represent chemical composition (atomic ratios)

- **Empirical**: Ratio of atoms (NH$_2$ instead of N$_2$H$_4$)
  - Can use for ionic or covalent compounds
- **Molecular**: Actual # of atoms (N$_2$H$_4$)
  - Only use for covalent compounds. Molecule = covalent
- **Structural**: Shows how atoms are connected in <u>molecules</u>



Names of Binary Molecules (2 Elements, Covalent)

Names and formulas have 2 parts, 1 for each element:

Dinitrogen tetroxide -------------------- N_2O_4

1st word is 1st element name --------- N = Nitrogen

2nd word is 2nd element name
→ **change ending to "–ide"** ---------- O = Oxygen → Oxide

Formula: Subscripts = # of atoms ------ N_2O_4

Name: Prefix = # of atoms --------------- Dinitrogen tetroxide

Do not include a prefix for the first element if there is only one atom

Ex: CO_2 = Carbon dioxide (not monocarbon dioxide)
CO = Carbon monoxide

Memorize prefixes up to 10

# atoms	prefix	# atoms	prefix
1	mono	6	hexa
2	di	7	hepta
3	tri	8	octa
4	tetra	9	nona
5	penta	10	deca

Note that the o or a at the end of the prefix is often dropped when the element begins with a vowel.

- Monoxide, not monooxide
- Tetroxide, not tetraoxide

Names & Formulas of Binary Molecules

1.) N_2O

2.) SO_3

3.) P_2O_5

4.) nitrogen dioxide

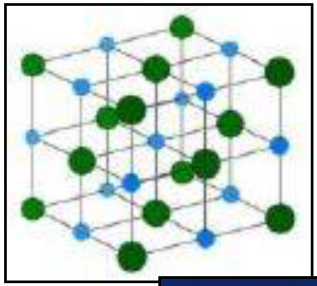
5.) dinitrogen tetroxide

Ionic Compounds (salts)

During a reaction atoms may gain or lose electrons

Both atoms become charged and are called **ions**

- **Anion**: atom gaining the electron is negatively charged
- **Cation**: atom losing the electron is positively charged



Will bind together to form crystals

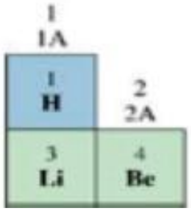
The net charge on the compound is 0

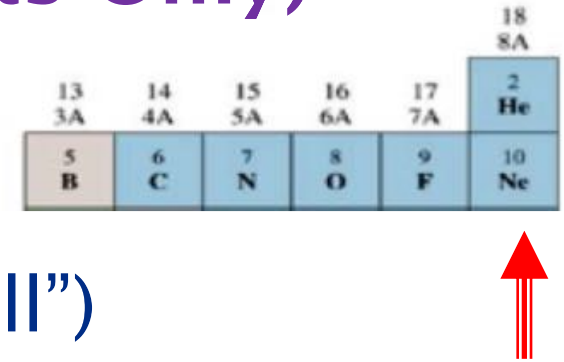
- Cations & anions balance out
- Get charges from periodic table

No distinct molecular units

- Positive charge of cation attracts all nearby anions

Using the Periodic Table to Predict Ionic Charge (**Main Group Elements Only)**





Goal: Get 8 valence electrons ("full")

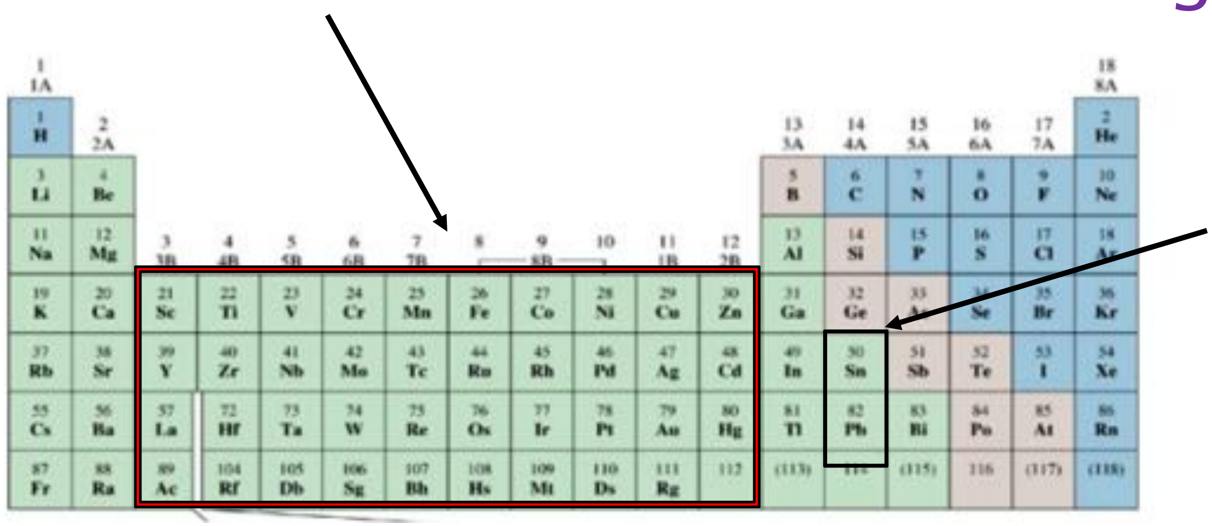
- electrons in "outermost" energy level
- "A" column number tells number of valence electrons
- Noble gases (column 8A/18) already have 8 – generally no charge
- Can gain or lose electrons to get 8 – generally do what is easier
- Electrons are negative → gain electrons = negative charge!

The correct charge is <u>usually</u> the smallest number

Left Side (metals): Li^{1+} or Li^{-7} Mg^{2+} or Mg^{6-}

Right Side (nonmetals): O^{6+} or O^{2-} F^{7+}, or F^{1-}

Charges on Transition & Other Multi-charge Metals



Sn & Pb are the "others" that you will see most often

- Become cations
- Charge is unpredictable
- Often have more than one charge (also possible for some main group elements)
    - Designated with a Roman Numeral
    - Iron (III) = Fe^{3+}; Iron (II) = Fe^{2+}
    - Roman numerals required in names of ionic compounds if cation can have more than one charge
        - Iron (III) oxide
        - Copper (II) chloride

Polyatomic Ions

- Charged molecules
- Lose or gain electrons as a group
- Charge is spread over 2 or more atoms

<u>Memorize the following polyatomic ions!</u>

Ammonium	NH_4^+	Hydronium	H_3O^+
Phosphate	PO_4^{3-}	Acetate	CH_3COO^-
Hydroxide	OH^-	Nitrate	NO_3^-
Cyanide	CN^-	Sulfate	SO_4^{2}
Permanganate	MnO_4^-	Chlorate	ClO_3^-
Carbonate	CO_3^{2-}	Perchlorate	ClO_4^-

Formula of an Ionic Compound must give an overall charge of zero!

Al & O

Ca & Br

Na & CO_3

Names of Ions and Ionic Compounds

Naming Ions:

For cations: add the word ION after element name

Na = sodium

- In col 1A, so loses 1 e^-
- Na^+ =

Al = aluminum

- In col 3A, so loses 3 e^-
- Al^{3+} =

For anions: change the element name ending to –ide first

Cl = chlorine

- In col 7A, so gains 1e^-
- Cl^- =

O = oxygen

- In col 6A, so gains 2 e^-
- O^{2-} =

Naming Ionic Compounds (ie salts):

- Write the name of the cation followed by the name of the anion.
- If the cation can have more than one charge, include a Roman Numeral representing the charge after the name of the cation.

Na & Cl

Net Charge: (+1) + (-1) = 0
Chemical Formula is NaCl

Na = sodium
Cl = chloride
Name = Sodium chloride

Al & O

Net Charge: 2(+3) + 3(-2) = 0
Chemical Formula is Al_2O_3

Al = aluminum
O = oxide
Name = Aluminum oxide

Fe & S

Fe = iron -> 2 possible charges, +2 & +3
S = Sulfide -> charge is -2

If Iron is +2
Net Charge: (+2)+(-2) = 0
Chemical Formula is FeS
Name = Iron (II) sulfide

If Iron is +3
Net Charge: 2(+3)+3(-2) = 0
Chemical Formula is Fe_2S_3
Name = Iron (III) sulfide

Naming Ionic Compounds

1.) K_2O

2.) CaF_2

3.) KF

4.) $Ca(NO_3)_2$

5.) K_3PO_4

If the formula contains a cation that can have more than one charge, you need to determine the charge based on the anion & include it as a Roman Numeral.

6.) $PbCl_2$

7.) Fe_2O_3

Acids and Bases

Acid

- Arrhenius: Compound ionizes in H_2O to form H^+ & anions
  - Name by changing anion –ide ending to –ic acid
  - Add hydro to acids with HX formula (X=halogen; col.17)

    ex: HCl = Hydrochloric acid
- Bronsted acids: H^+ grabs H_2O to form H_3O^+ in water

Base

- Arrhenius: Compound ionizes in H_2O to form OH^- & cations
  - Name as salts: All hydroxide salts are considered bases
- Bronsted base: Pulls H+ from H_2O so NH_3 is a base:

$$H_2O + NH_3 \Rightarrow OH^- + NH_4^+ \Rightarrow NH_4OH$$

Neutralization

- Reaction between acid & base – form water & a salt

$H^+ + OH^- \Rightarrow H_2O$ and cation + anion ⇨ salt

$HCl + NaOH \Rightarrow H_2O + NaCl\ (aq)$

Common acids and bases

Be able to recognize & associate formula with name

Acids

Hydrochloric Acid:	HCl	Carbonic Acid:	H_2CO_3
Sulfuric Acid:	H_2SO_4	Nitric Acid:	HNO_3
Chloric Acid:	$HClO_3$	Phosphoric Acid:	H_3PO_4
Perchloric acid:	$HClO_4$	Acetic Acid:	CH_3COOH

Bases

Sodium hydroxide: NaOH

Potassium hydroxide: KOH

Ammonium hydroxide: NH_4OH (actually ammonia, NH_3 in H_2O)

Lithium hydroxide: LiOH

Hydrates

Compounds associated w/fixed number of water molecules

Presence of water alters properties such as color

Copper(II)sulfate
$CuSO_4$

Copper(II)sulfate pentahydrate
$CuSO_4 \bullet 5H_2O$

Naming Hydrates

- Use numerical prefixes for # of water molecules
  - mono, di, tri, etc.
- Add "hydrate" to the prefix & include at end of name
- A dot shows associated H_2O in formula

Water molecules must be included when calculating mass

Naming Oxoacids and their Anions: Reference Only