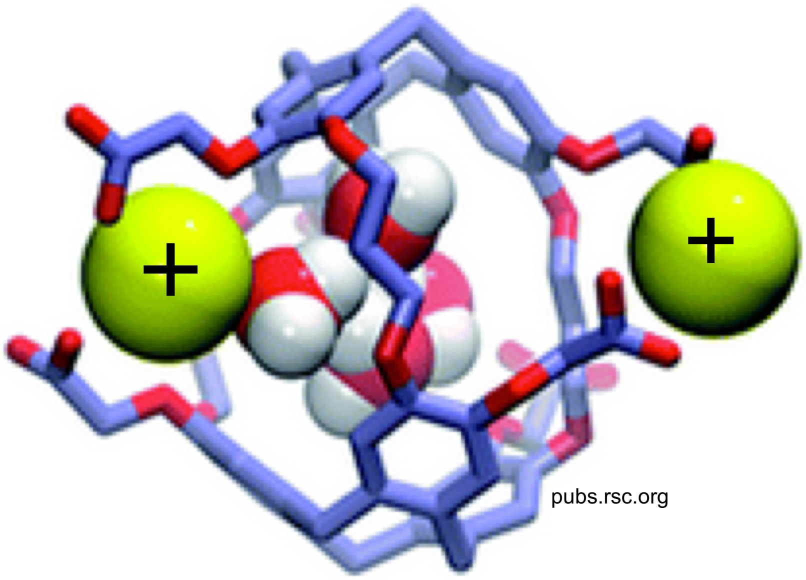
Chapter 2:

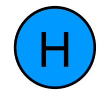
Atoms and the Periodic Table



Atomic Theory of Matter: Dalton (1808)

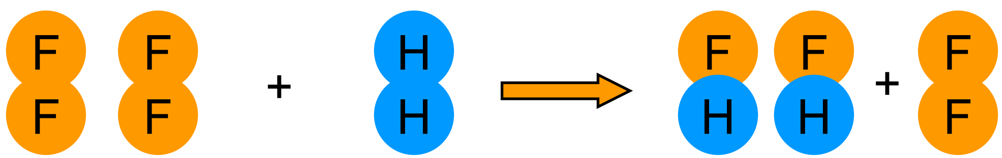
1. All matter is composed of tiny particles called atoms
2. All atoms of a given element are identical, but atoms of different elements differ in size, mass, & chemical properties

Fluorine atom: 18 amu



Hydrogen atom: 1 amu

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



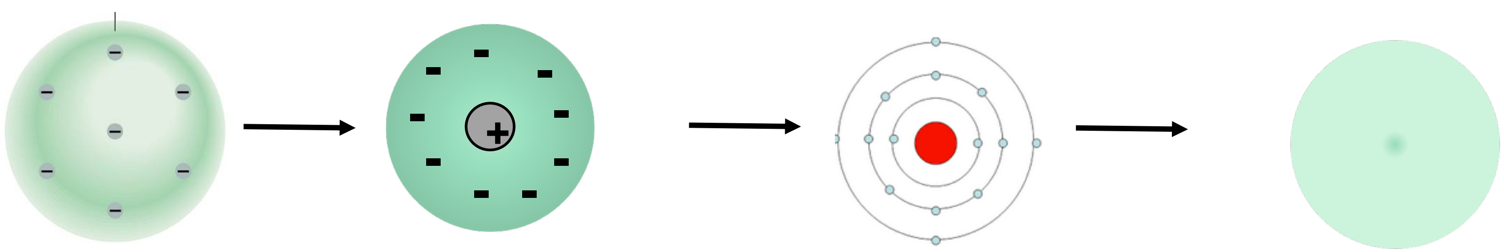
74amu = 72amu + 2amu 38amu + 36amu = 74amu

4. A chemical reaction involves atomic rearrangement.

No atoms are created or destroyed.

Structure of the Atom

What’s on the inside?!?



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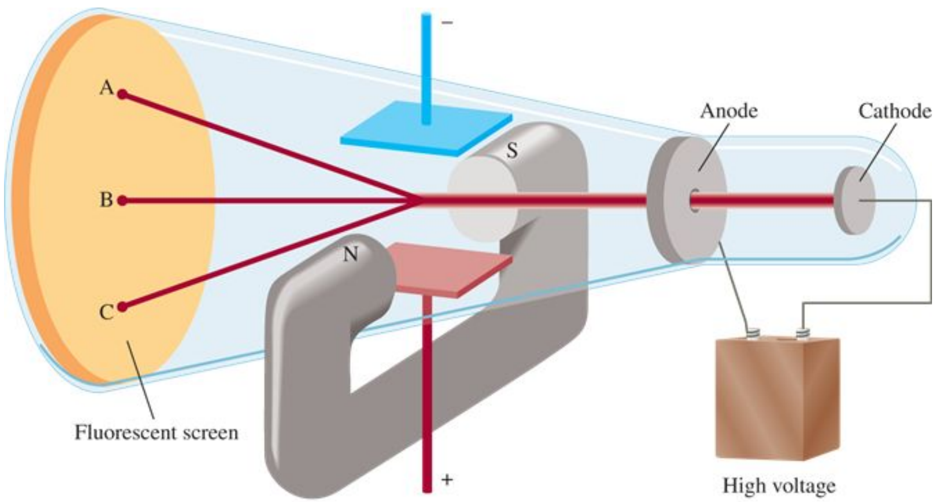
$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + [V_1(x) + iV_2(x)]\Psi$$

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**

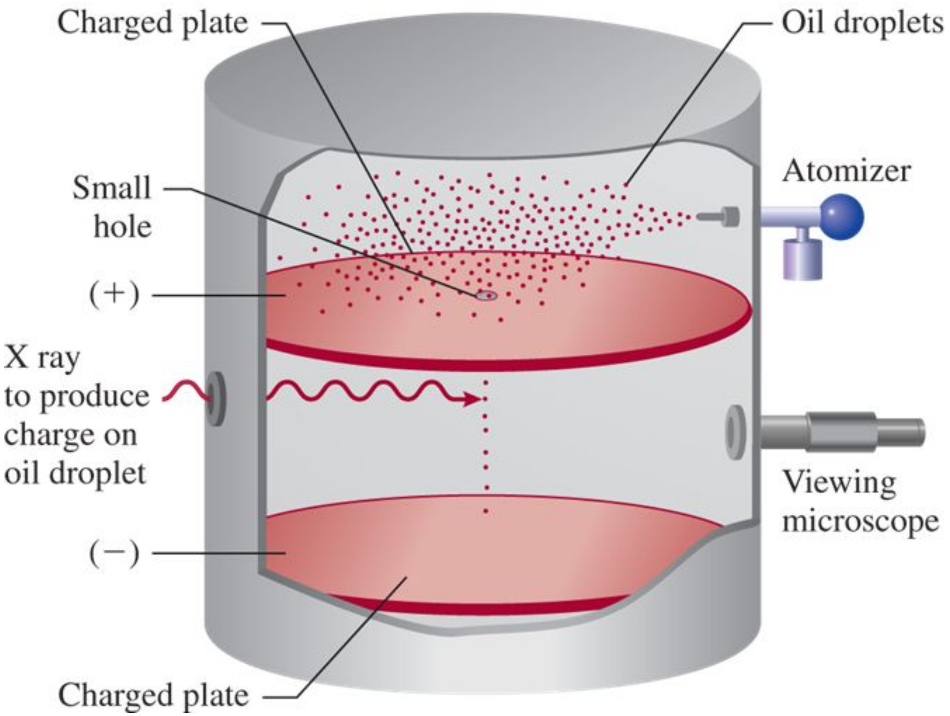
Robert Millikan

Charge on an electron:

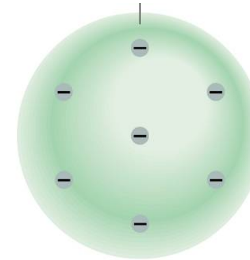
$e = -1.602 \times 10^{-19}$ C

Mass of an electron:

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



Discovery of The Nucleus

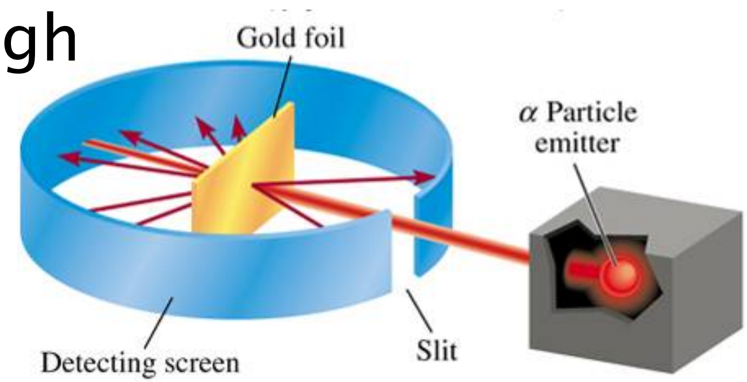


J. J. Thomson’s Raisin (or Plum) Pudding Model

- Positively charged sphere with electrons imbedded inside
- Ball of Chocolate Chip Cookie Dough

Rutherford’s Experiments

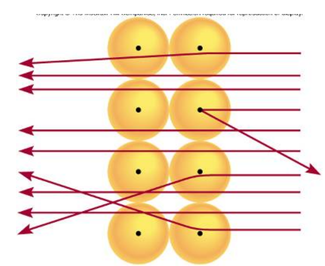
- Shot α particles through gold foil



(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

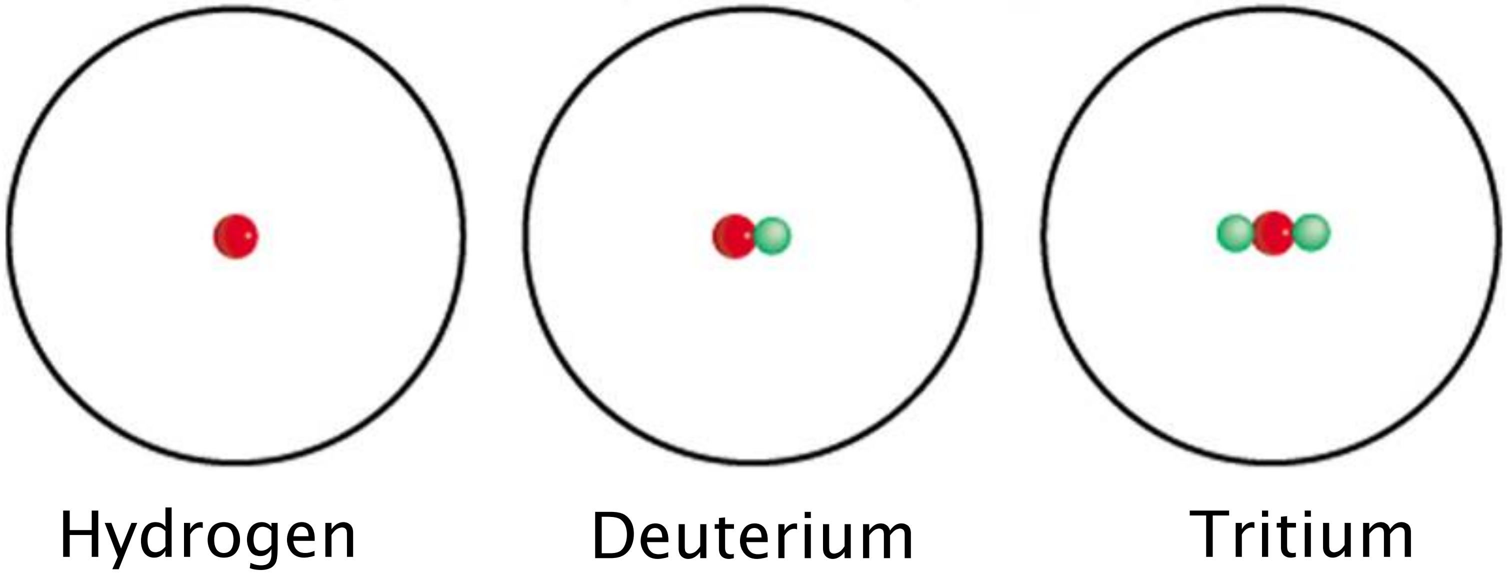


Nucleus!

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
- Needed for stability of nucleus – larger nuclei need more neutrons



The Atom and Sub-Atomic Particles

Protons

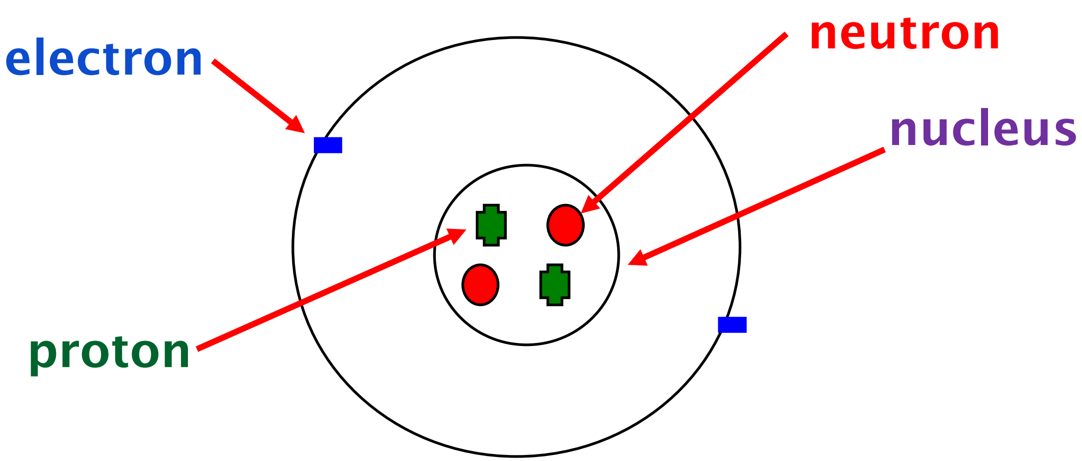
large, positively charged particles in small central nucleus

Electrons

tiny, negatively charged particles in cloud around nucleus

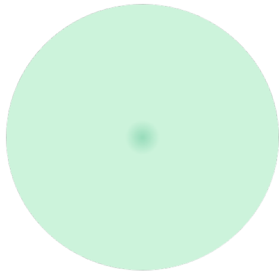
Neutrons

large, neutral particles in nucleus



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

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 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

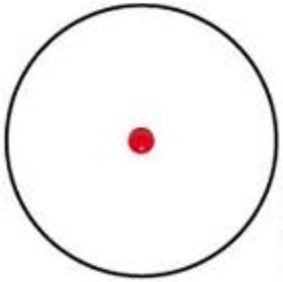
$${}^{35}_{17}\mathrm{Cl}$$

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

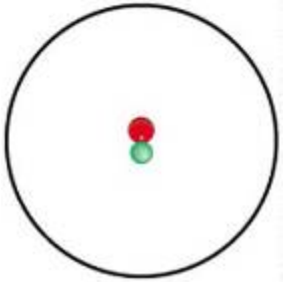


Water, H_2O

H has 1 proton and 0 neutrons

Most abundant

$^{1}_{1}H$



Heavy water, D_2O

D (deuterium) has 1 proton & 1 neutron

Occurs 1/6700 molecules

$^{2}_{1}H$

Average Atomic Mass

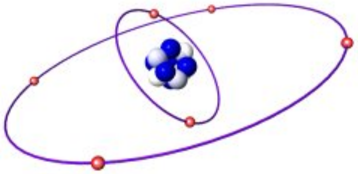
Atomic Mass: Mass of an atom in atomic mass units

1 amu = 1/12 of the mass of 1 C-12 atom

→ The mass of a ^{12}C atom = 12 amu

= 1.661×10^{-24} g

= mass 1 proton or 1 neutron



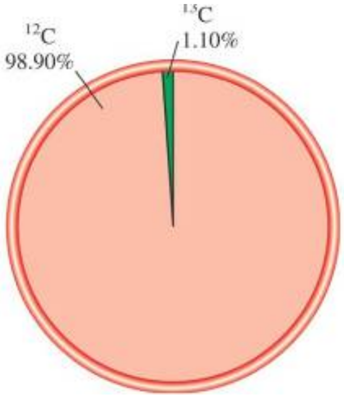
Naturally occurring carbon is a mixture of isotopes

$^{12}_{6}C$ 98.90% 6 protons 6 neutrons 12.000 amu

$^{13}_{6}C$ 1.100% 6 protons 7 neutrons 13.003 amu

$^{14}_{6}C$ ~ 10^{-12} 6 protons 8 neutrons 14.003 amu

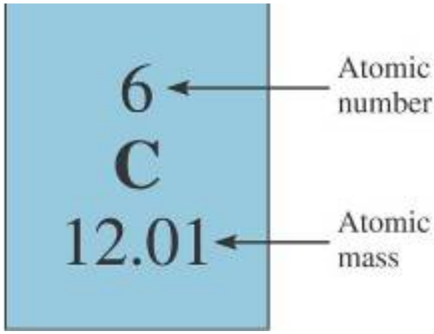
(C-14 is unstable)



Atomic mass of naturally occurring carbon:

(0.9890 x 12.000 amu)+ (0.0110 x 13.003 amu)

= Atomic Mass of C = 12.01 amu



Average Atomic Mass

Calculate the average atomic mass of lead if the isotopes of lead have the following masses and percentages:

^{204}Pb: 203.97043amu, 1.4%

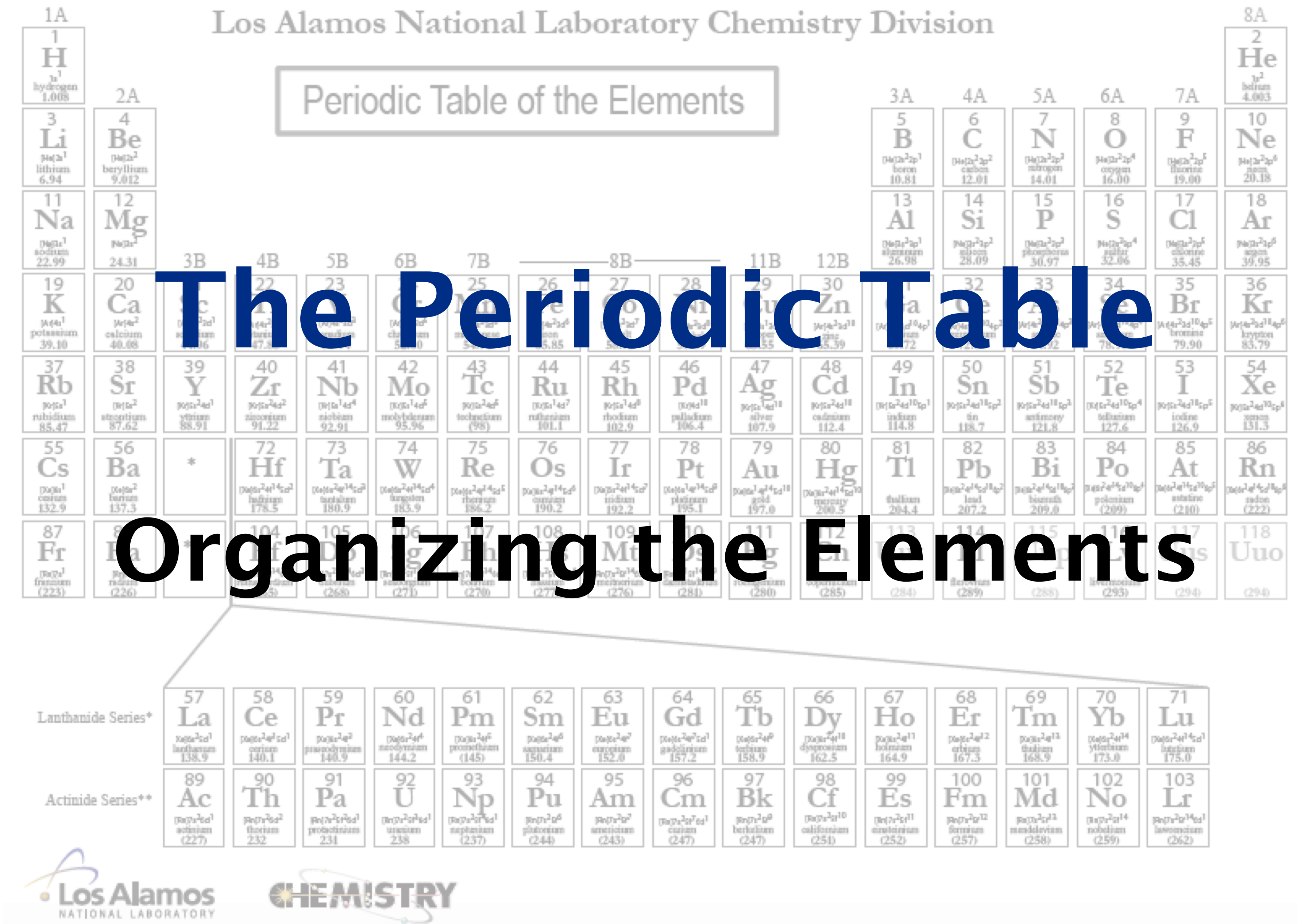
^{206}Pb: 205.947465amu, 24.1%

^{207}Pb: 206.975897amu, 22.1%

^{208}Pb: 207.976652amu, 52.4%

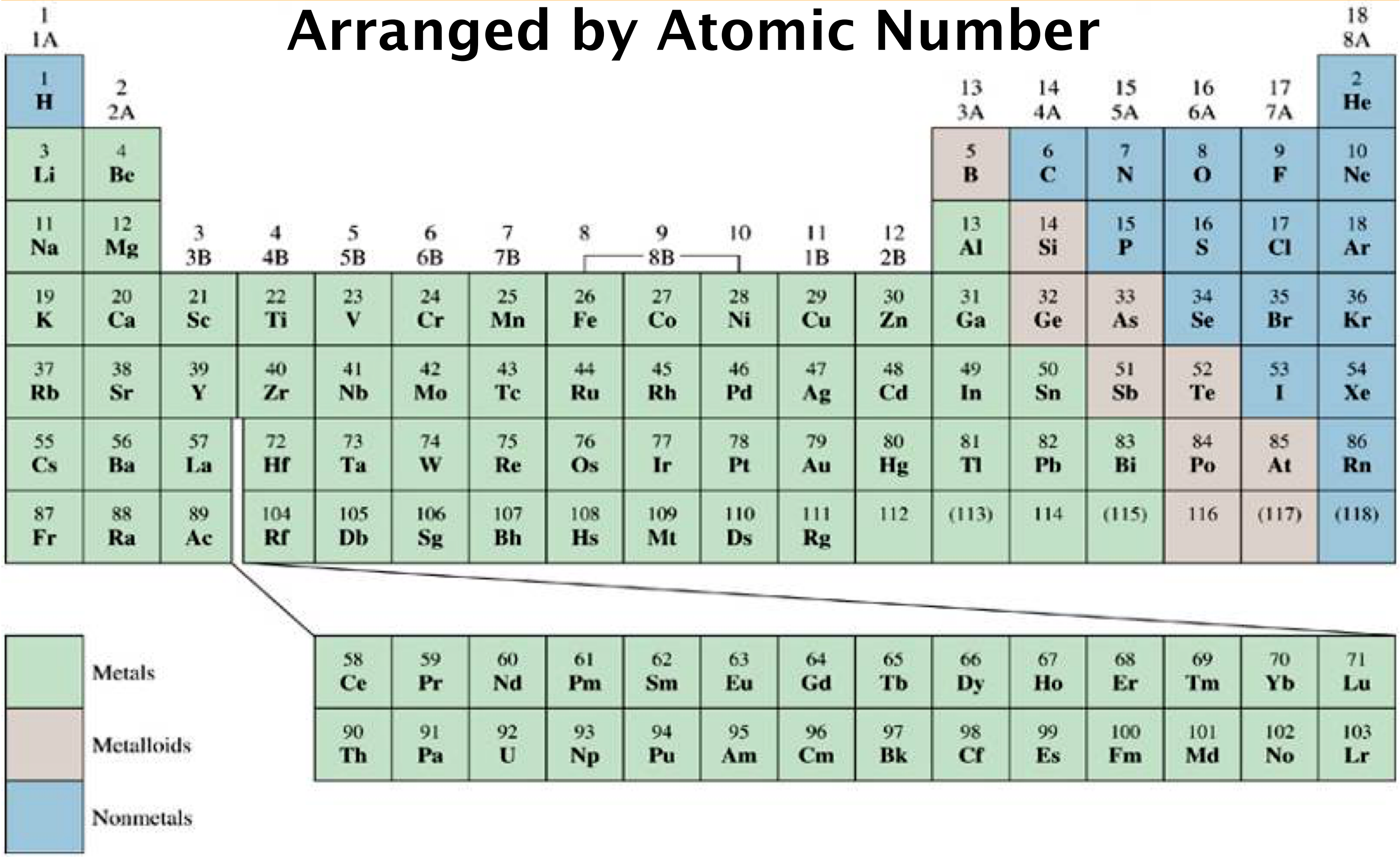
The Periodic Table

Organizing the Elements



The Modern Periodic Table

Arranged by Atomic Number

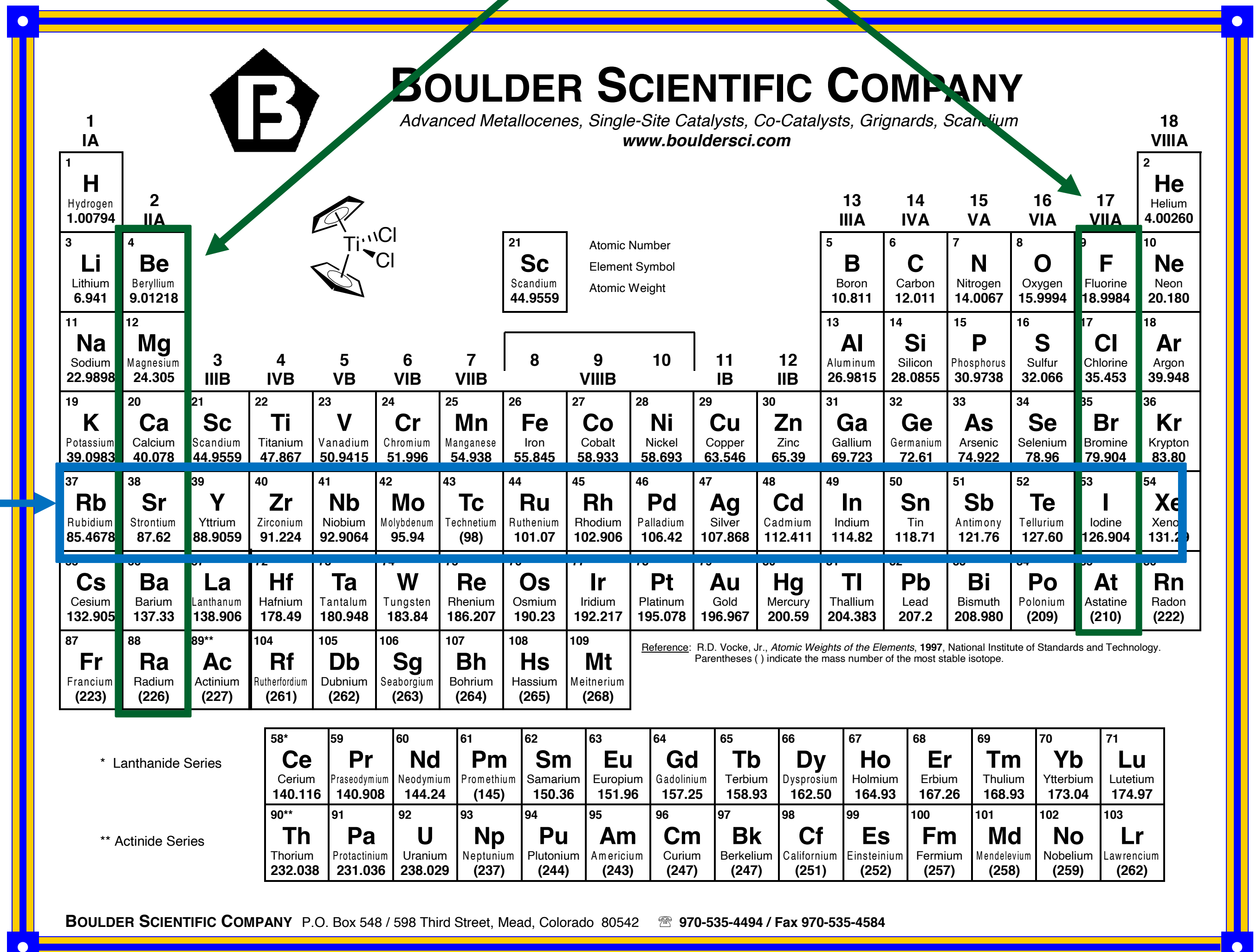


Green	Metals	Ductile, malleable, conductive, positive ionic charge
Blue	Nonmetals	Brittle solids, often gases or liquids, negative charge
Pink	Metalloids	Properties of both metals and nonmetals

The Modern Periodic Table

Columns are called **groups** or **families** – contain elements with similar characteristics

Rows are also called **periods**



Some Groups in the Periodic Table

Alkali Metals

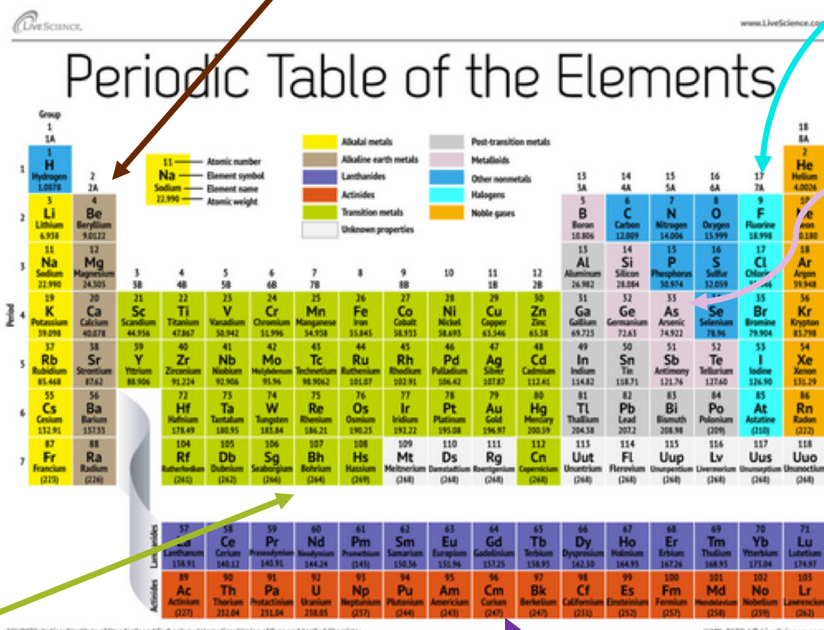
- Group 1A
- +1 charge
- Highly reactive

Alkali Earth Metals

- Group 2A
- +2 charge
- Reactive

Halogens

- Group 7A
- -1 charge
- Highly reactive if single atoms
- Diatomic molecules



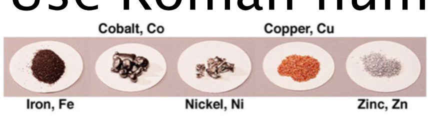
Metalloids

- Some characteristics of metals, some of nonmetals
- semiconductors

Silicon (Si)

Transition metals

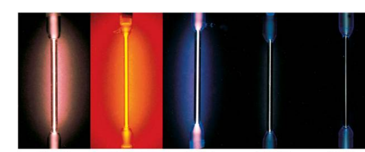
- Center of table
- Varying (+) charge
- Use Roman numerals



Lanthanides & Actinides

- Bottom of table
- Very reactive
- + charge
- Often radioactive

Noble Gases



- Group 8A
- + charge (if charged)
- Inert (least reactive)

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.)

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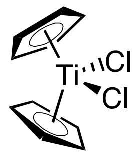

21 Sc Scandium 44.9559	
21	Atomic Number
Sc	Element Symbol
44.9559	Atomic Weight

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 **H** Hydrogen 1.00794																	2 **He** Helium 4.00260
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.01218											5 **B** Boron 10.811	6 **C** Carbon 12.011	7 **N** Nitrogen 14.0067	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984	10 **Ne** Neon 20.180
11 **Na** Sodium 22.9898	12 **Mg** Magnesium 24.305											13 **Al** Aluminum 26.9815	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.9738	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.9559	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933	28 **Ni** Nickel 58.693	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.922	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.9059	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.9064	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.411	49 **In** Indium 114.82	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.76	52 **Te** Tellurium 127.60	53 **I** Iodine 126.904	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.905	56 **Ba** Barium 137.33	57* **La** Lanthanum 138.906	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.967	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.383	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.980	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89** **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (268)									

Reference: R.D. Vocke, Jr., *Atomic Weights of the Elements*, **1997**, National Institute of Standards and Technology. Parentheses ( ) indicate the mass number of the most stable isotope.

* Lanthanide Series	58* **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97
** Actinide Series	90** **Th** Thorium 232.038	91 **Pa** Protactinium 231.036	92 **U** Uranium 238.029	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

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The Mole – like a dozen but a lot more!

Mole

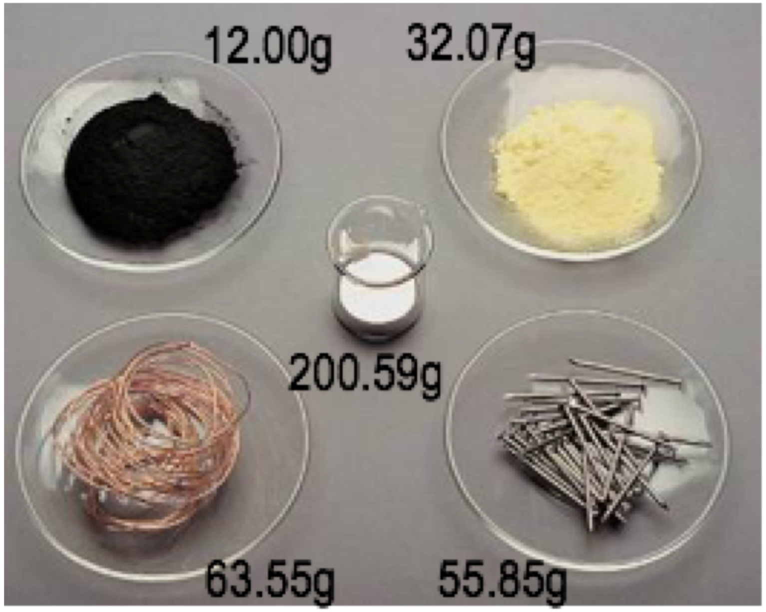
of atoms in 12.00g of C-12

Avogadro's number (N_a)

- # particles in 1 mole
- $N_a = 6.022 \times 10^{23}$ particles/mol
- Determined experimentally

Similar to the word "dozen"

- Makes numbers more manageable



1 Mole of each substance

For most chemicals, a mole is an amount that can be measured in a lab (using a balance, etc.)

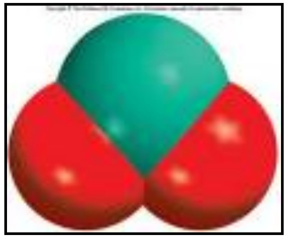
(Atoms are too small to measure on a balance)

C-12: $$\frac{12.00g}{1mole} x \frac{1mole}{6.022x10^{23}\,atoms} = 1.993x10^{-23}\,g/1atom$$

Molar Mass

The mass of one mole of a substance

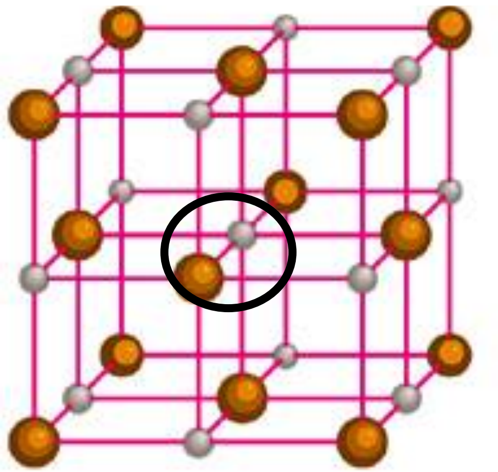
- Equal to AMU, but in units of g/mol



SO_2 - molecule

To calculate for a compound:

- Find atomic mass of each element
  → located on Periodic table (often below symbol)
- Multiply atomic mass of element by subscript, then add all elements together.
- Molecular mass: mass of molecule
  → include every atom
- Formula mass: mass of ions in a salt
  → use smallest ratio



NaCl – ionic compound

Examples:

1 mol Na = 22.99 g/mol

1 mol SO_2 = 64.07g/mol

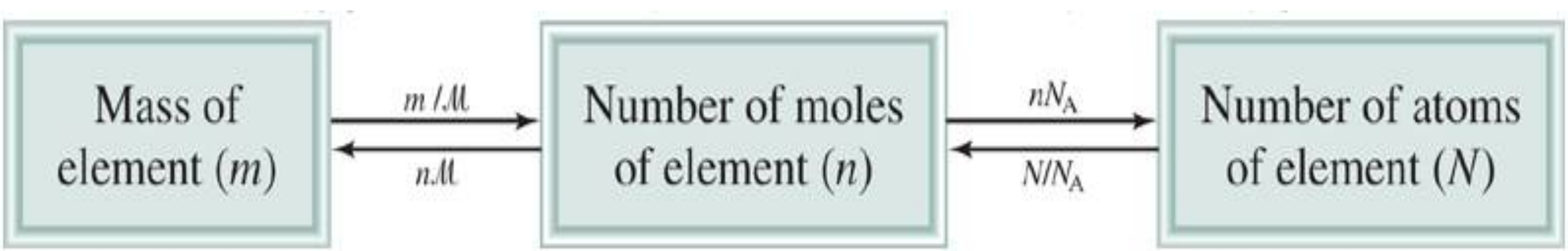
1 mole NaCl = 58.44g/mol

Mole-based Calculations (Mass/Mole/Particle Conversions)

Molar Mass ($\mathcal{M}$): grams/mol – from Periodic Table!

Avogadro's Number N_a: 6.022×10^{23} particles/mol

$$10.0\text{g}_C \text{ x } \frac{1\text{mol}_C}{12.0\text{g}_C} = 0.833\text{mol}_C \text{ x } \frac{6.02\text{x}10^{23}{}_{\text{atoms}}}{1\text{mol}_C} = 5.01\text{x}10^{23}\text{ atoms}$$



$$10.0\text{g}_C = \frac{12.0\text{g}_C}{1\text{mol}_C} \text{ x } 0.833\text{mol}_C = \frac{1\text{mol}_C}{6.02\text{x}10^{23}_{\text{atoms}}} \text{ x } 5.01\text{x}10^{23}\text{ atoms}$$

\# moles → mass

What is the mass, in grams, of 0.287 mol Na? (6.60 g)

mass → # moles

How many moles are there in 38.65 g of Ag? (0.3583 mol)

moles → # particles

How many atoms are in 2.6 moles of Sulfur? (1.6 x 10^{24} atoms)

particles → # moles (→ grams!)

If you have 2.5 x 10^{22} atoms of gold, how many moles do you have? How many grams do you have? (0.042mol, 8.2g)

grams → # particles

If you have 78.56 g of copper, how many atoms do you have?

(1.236mol, 7.445x10^{23}atoms)