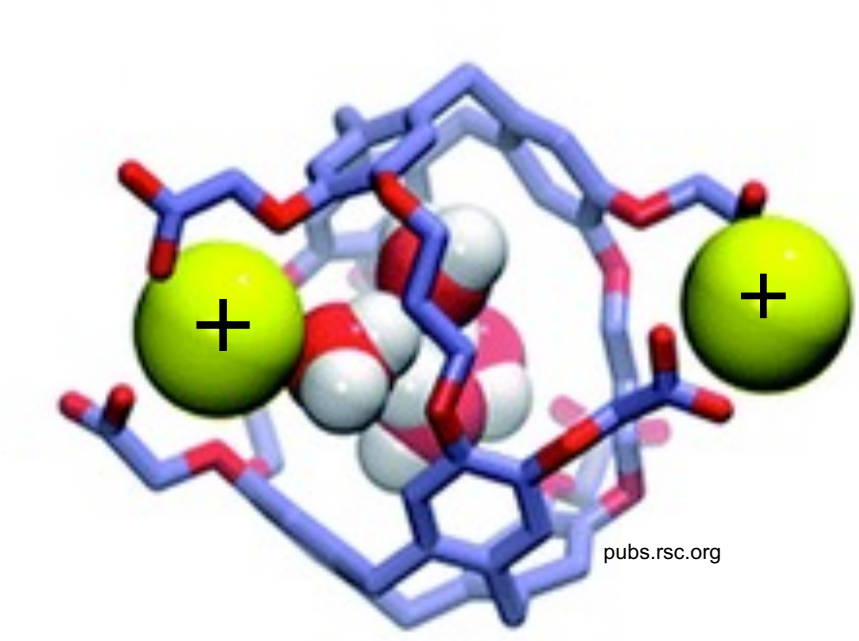
Chapter 2:

Atoms and the Periodic Table



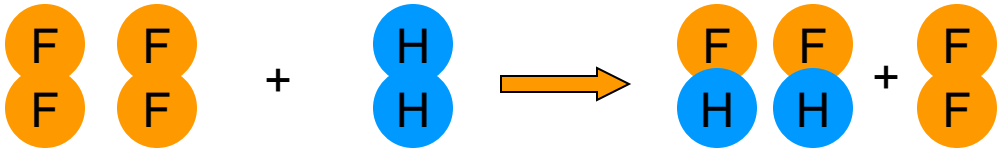
Atomic Theory of Matter: Dalton (1808)

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.



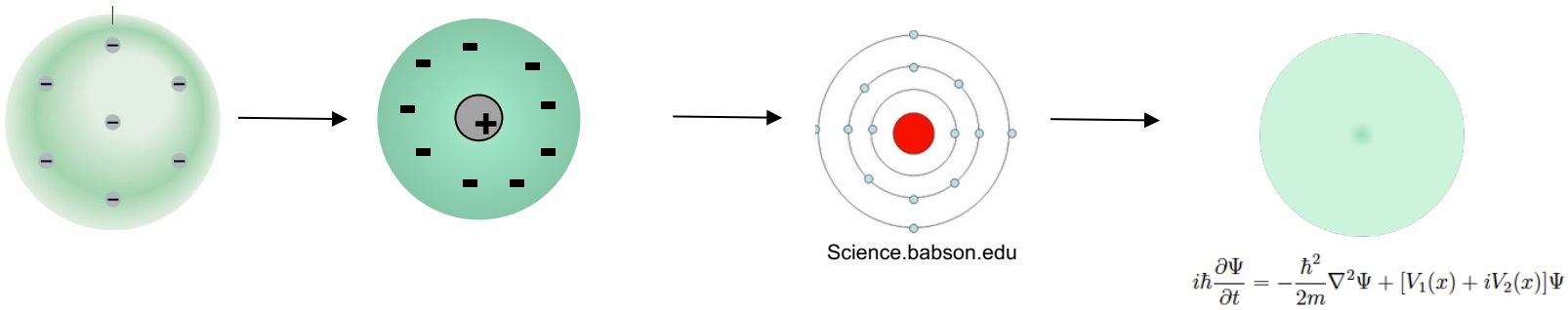
74amu = 72amu + 2amu 38amu + 36amu = 74amu

4. A chemical reaction involves atomic rearrangement.

No atoms are created or destroyed!!!

Structure of the Atom

What's on the inside?!?

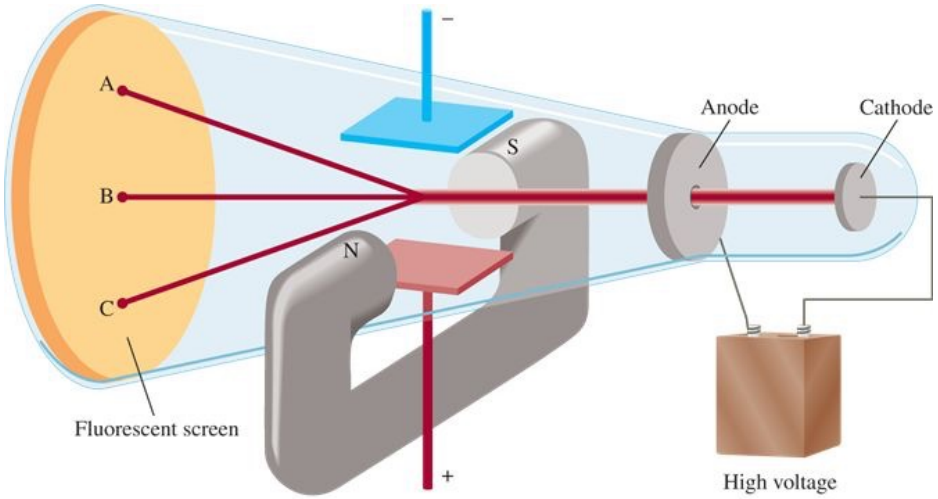


The Electron and Cathode Rays (1890's)

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**

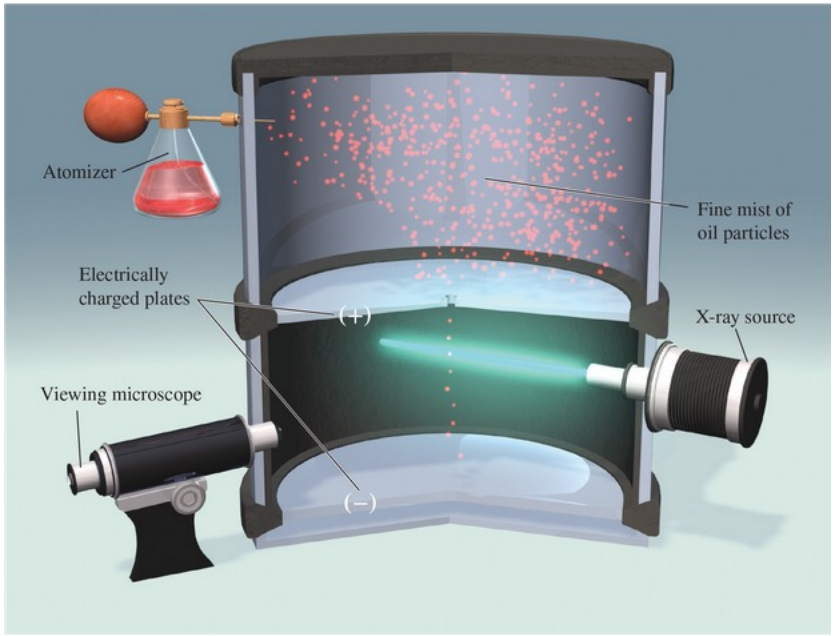
Robert Millikan

Charge on an electron:

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

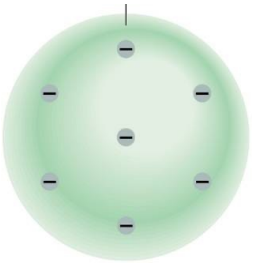
Mass of an electron:

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



Amount of electricity needed to suspend particle = charge on particle

Discovery of The Nucleus

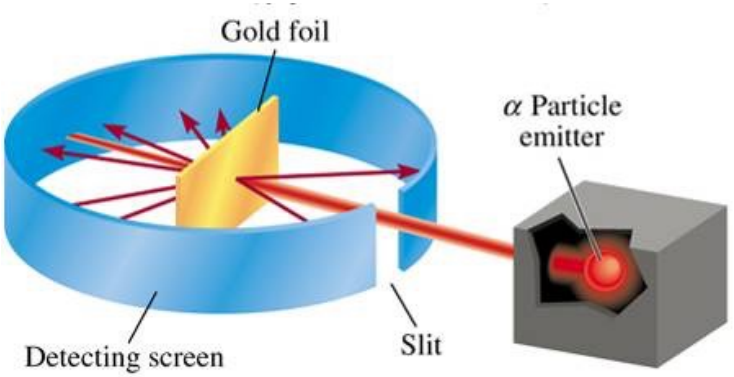


J. J. Thomson's Plum Pudding Model

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

Rutherford's Experiments

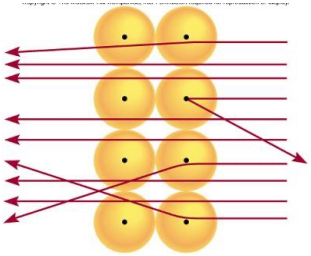
- Shot α particles through gold foil



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

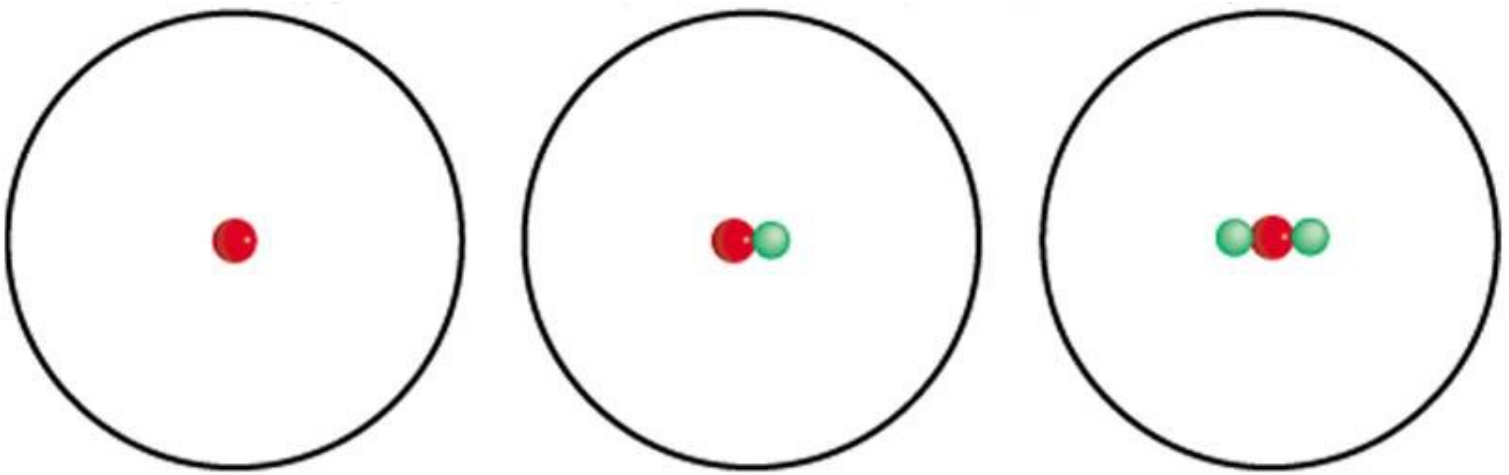
Nucleus!



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



Hydrogen Deuterium Tritium

The Atom and Sub-Atomic Particles

Protons

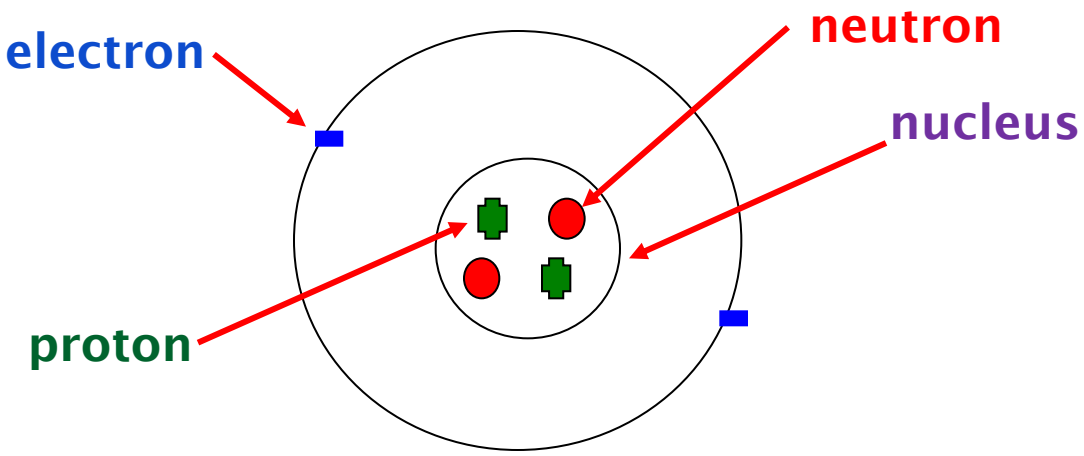
large, positively charged particles in small central nucleus

Electrons

tiny, negatively charged particles in cloud around nucleus

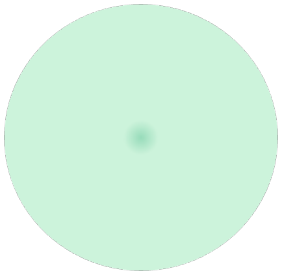
Neutrons

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

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

Actual Element

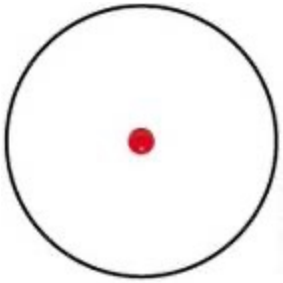
$${}^{35}_{17}Cl$$

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

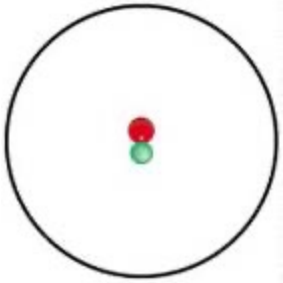
Example: hydrogen and deuterium



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

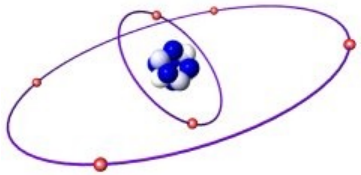
Atomic Mass: Mass of an atom in atomic mass units

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

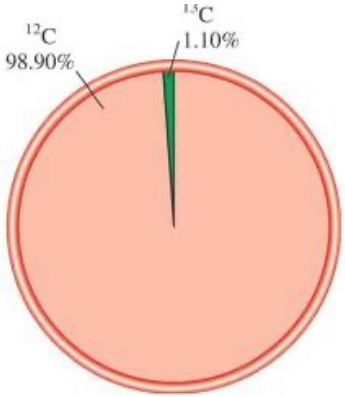
→ The mass of a ^{12}C atom = 12 amu

= 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

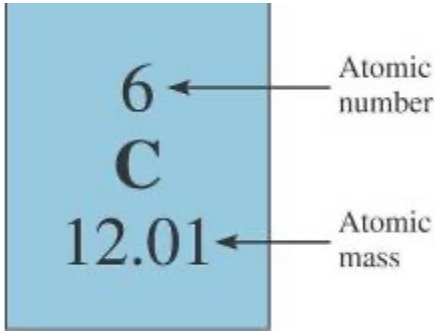
$^{14}_{6}C$ ~ 10^{-12} 6 protons 8 neutrons 14.003 amu

(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

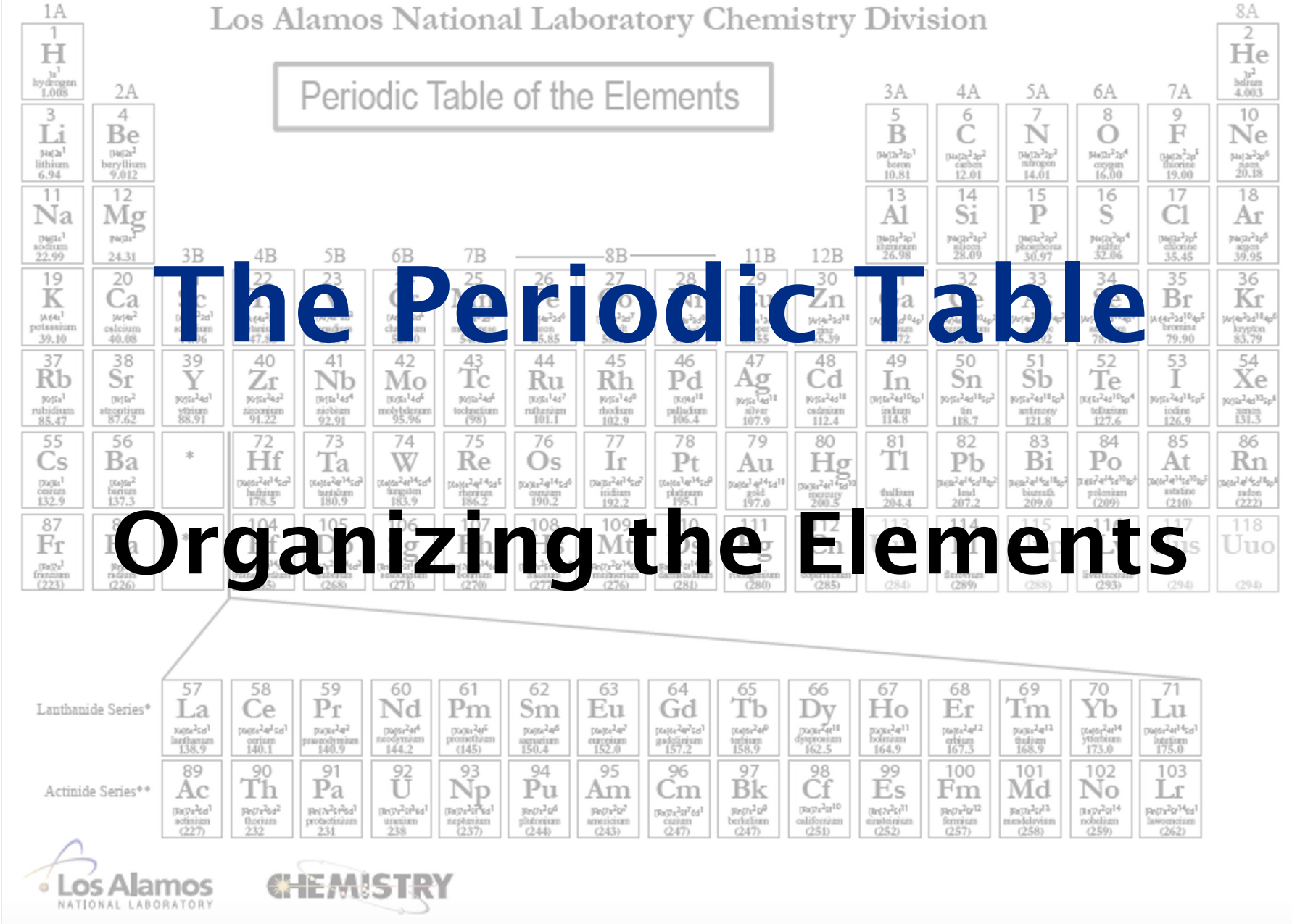
Calculate the average atomic mass of lead if the isotopes of lead have the following masses and percentages:

^{204}Pb: 203.97043amu, 1.4%

^{206}Pb: 205.947465amu, 24.1%

^{207}Pb: 206.975897amu, 22.1%

^{208}Pb: 207.976652amu, 52.4%


Los Alamos National Laboratory Chemistry Division
Periodic Table of the Elements
The Periodic Table
Organizing the Elements
Lanthanide Series*
Actinide Series**
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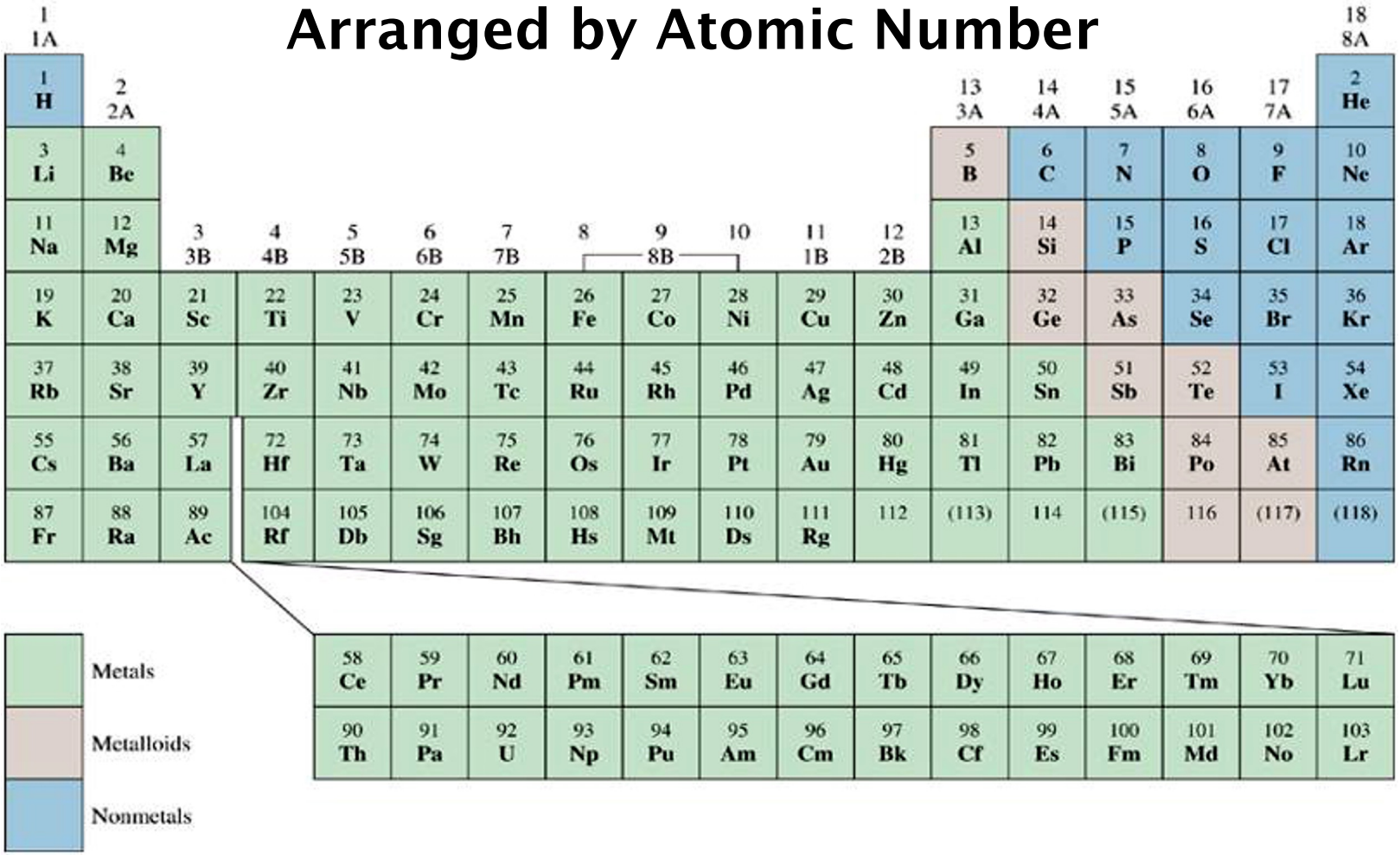
The Modern Periodic Table

Arranged by Atomic Number

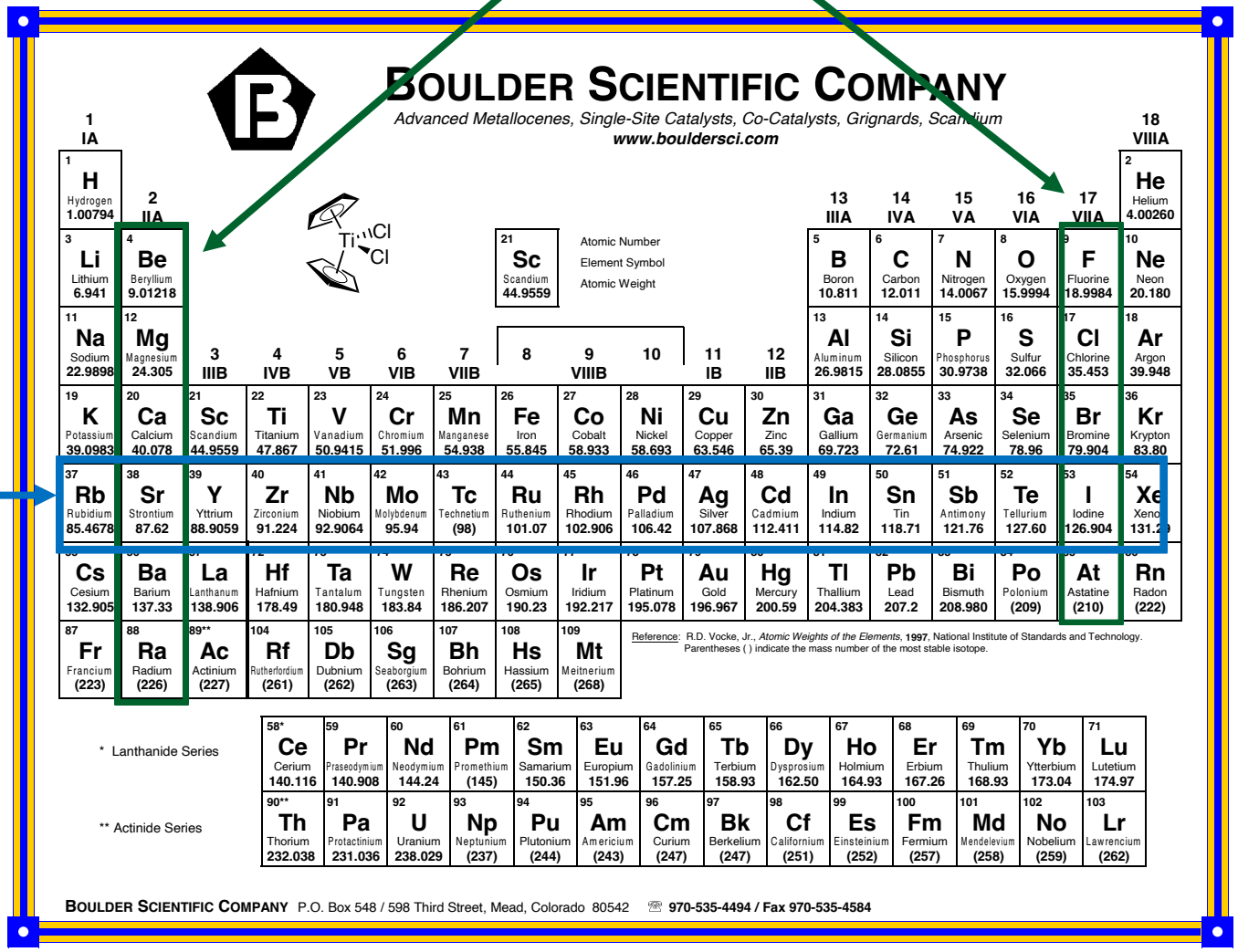


Green	Metals	Ductile, malleable, conductive, positive ionic charge
Blue	Nonmetals	Brittle solids, often gases or liquids, negative charge
Pink	Metalloids	Properties of both metals and nonmetals

The Modern Periodic Table

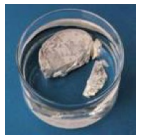
Columns are called **groups** or **families** – contain elements with similar characteristics

Rows are also called **periods**



Some Groups in the Periodic Table

Alkali Metals

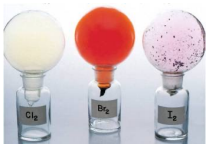


- Group 1A
- +1 charge
- Highly reactive

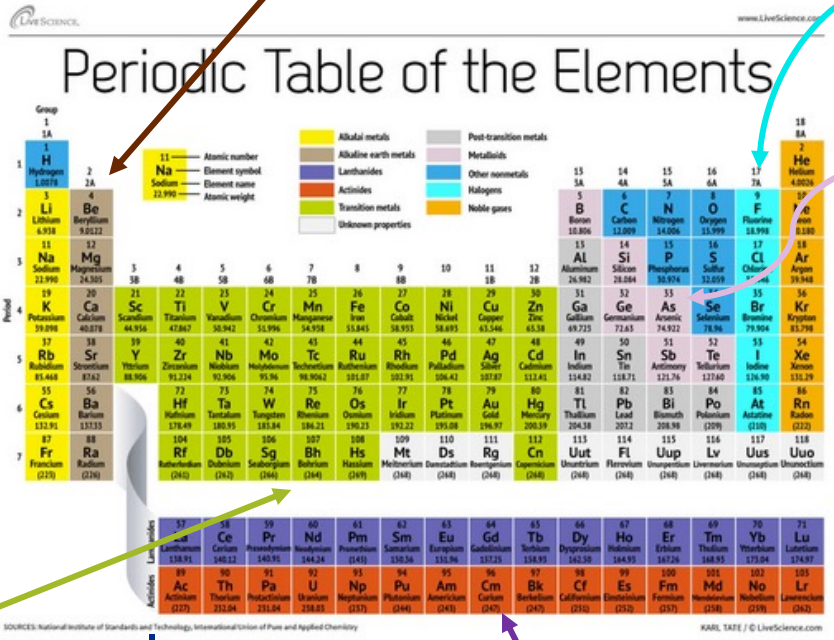
Alkali Earth Metals

- Group 2A
- +2 charge
- Reactive

Halogens



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

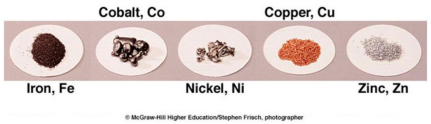


Metalloids

- Some characteristics of metals, some of nonmetals
- semiconductors

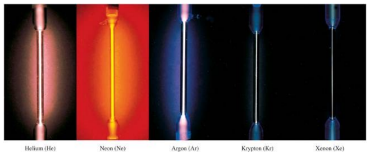
Transition metals

- 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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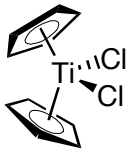

Atomic Number
Element Symbol
Atomic Weight

1 IA												2 IIA	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	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB		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 – so does impact sig figs!

1 Mole of each substance

Similar to the word "dozen"

- Makes numbers more manageable

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

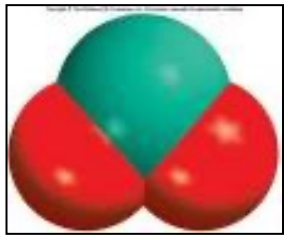
(Atoms are too small to measure on a balance)

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

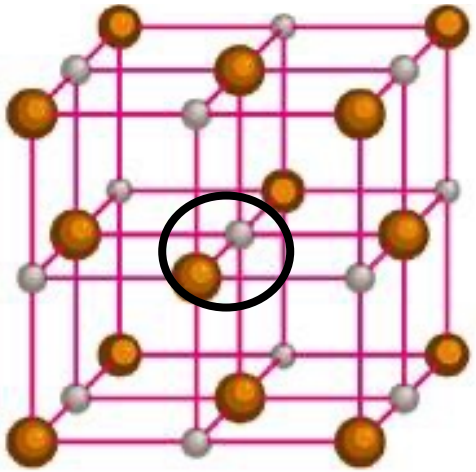
- Equal to AMU, but in units of g/mol



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:

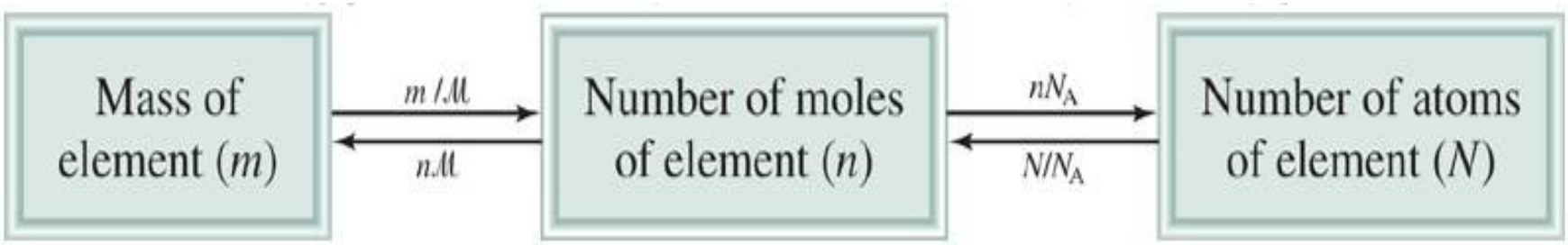
1 mol Na = 22.99 g/mol
1 mol SO_2 = 64.07g/mol
1 mole NaCl = 58.44g/mol

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

Molar Mass (*M*): grams/mol – from Periodic Table!

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

$$10.0\text{g}_{\text{C}} \times \frac{1\text{mol}_{\text{C}}}{12.0\text{g}_{\text{C}}} = 0.833\text{mol}_{\text{C}} \times \frac{6.02\times10^{23}\text{ atoms}}{1\text{mol}_{\text{C}}} = 5.01\times10^{23}\text{ atoms}$$



$$10.0\text{g}_{\text{C}} = \frac{12.0\text{g}_{\text{C}}}{1\text{mol}_{\text{C}}} \times 0.833\text{mol}_{\text{C}} = \frac{1\text{mol}_{\text{C}}}{6.02\times10^{23}\text{ atoms}} \times 5.01\times10^{23}\text{ atoms}$$

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)