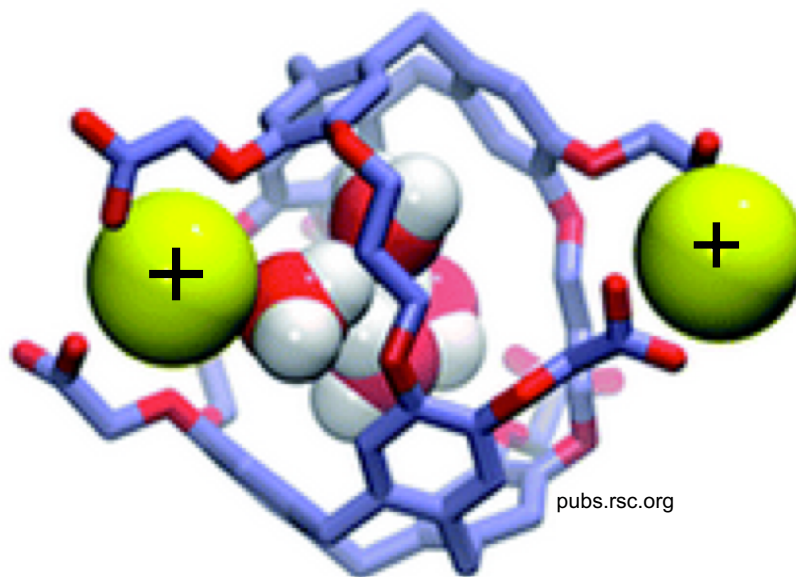


Chapter 2:

Atoms and the Periodic Table



Atomic Theory of Matter: Dalton (1808)²

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

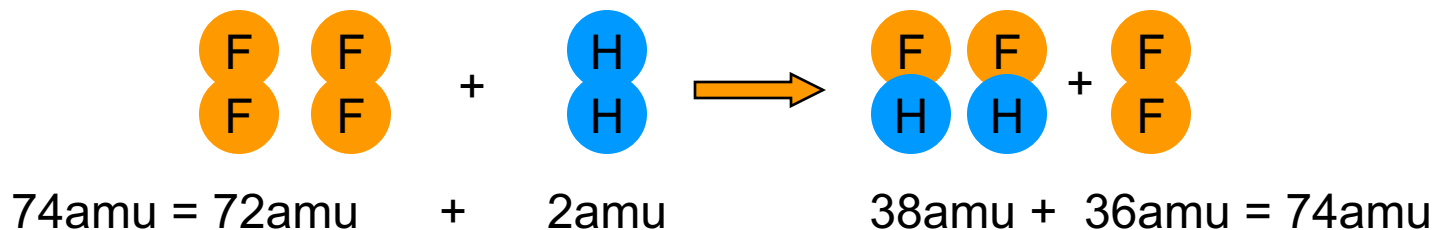


Fluorine atom: 18 amu



Hydrogen atom: 1 amu

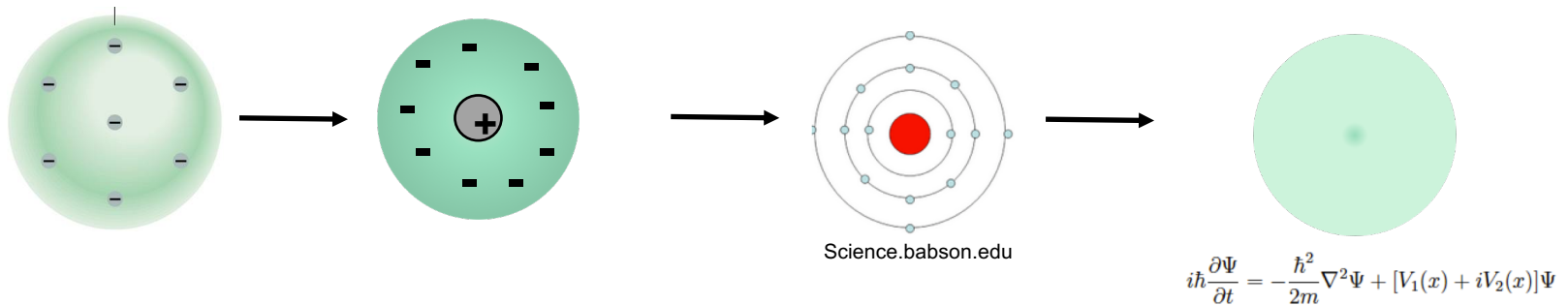
3. Compounds are formed when atoms of different elements combine in fixed proportions.



4. A chemical reaction involves atomic rearrangement.
No atoms are created or destroyed.

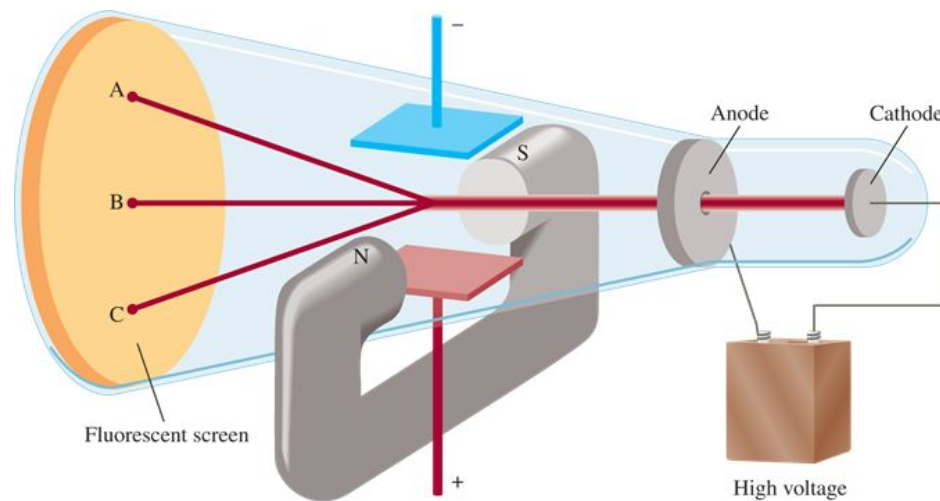
Structure of the Atom

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

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

Negatively charged particle is called an **electron**

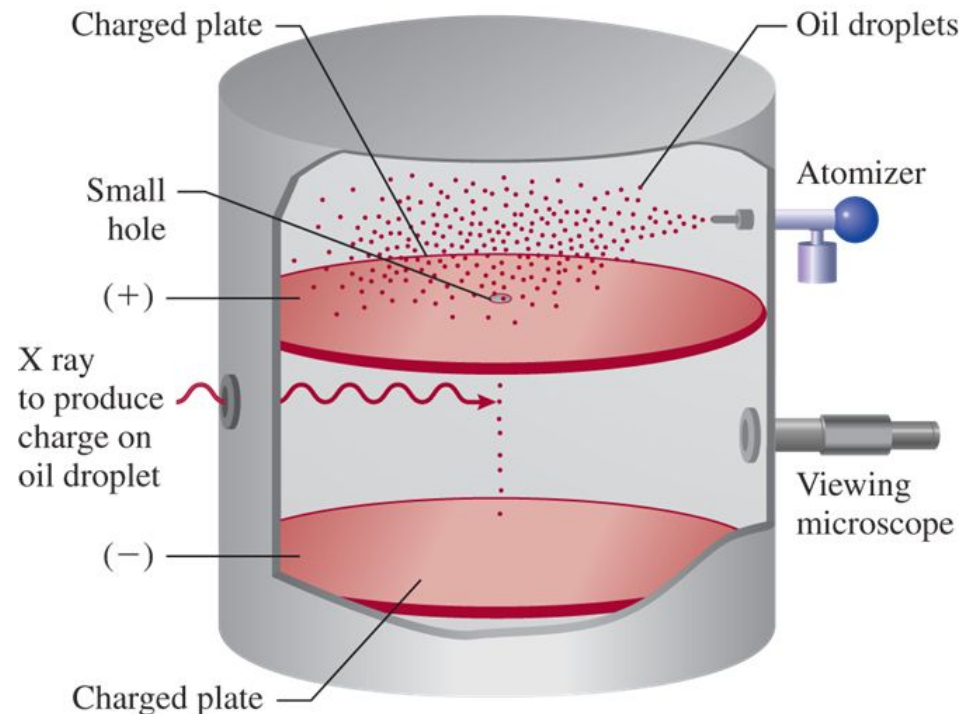
Robert Millikan

Charge on an electron:

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

Mass of an electron:

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



Discovery of The Nucleus

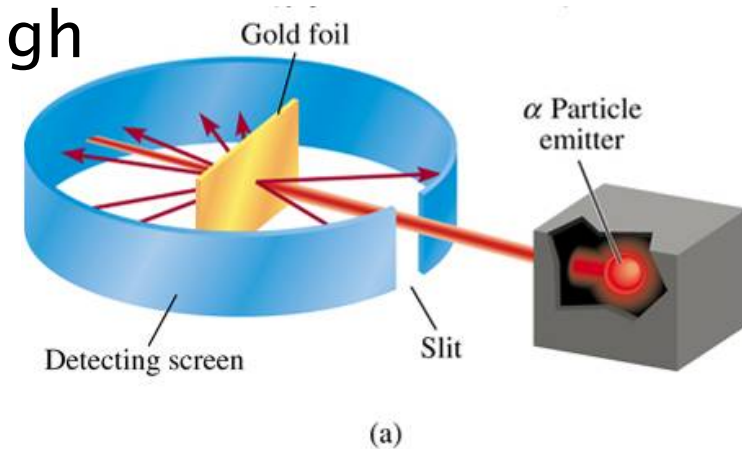


J. J. Thomson's Raisin (or Plum) Pudding Model

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

Rutherford's Experiments

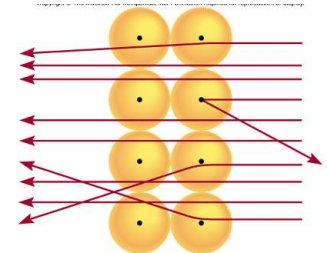
- Shot α particles through gold foil



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

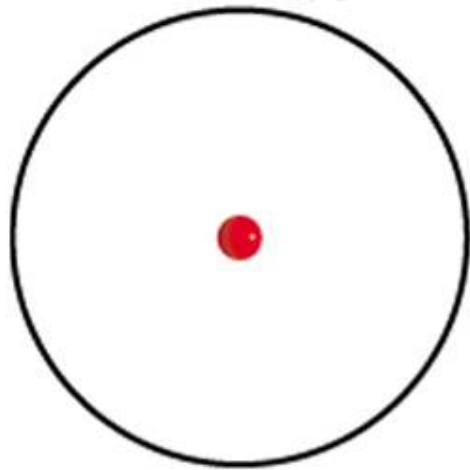
Nucleus!



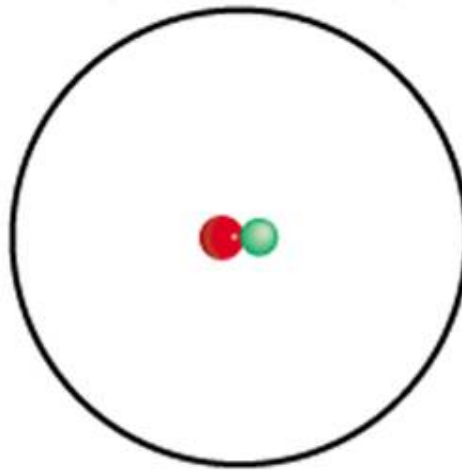
Neutrons

Subatomic particle with same mass as proton

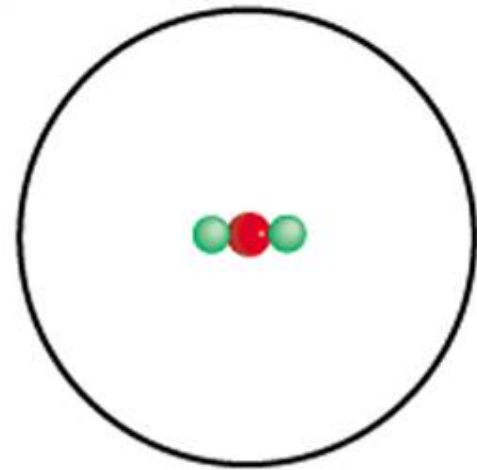
- Discovered by James Chadwick
- Located in nucleus
- No charge – accounts for extra mass of isotopes
- Change in mass, no change in chemical properties
- Needed for stability of nucleus – larger nuclei need more neutrons



Hydrogen



Deuterium



Tritium

The Atom and Sub-Atomic Particles

✚ Protons ✚

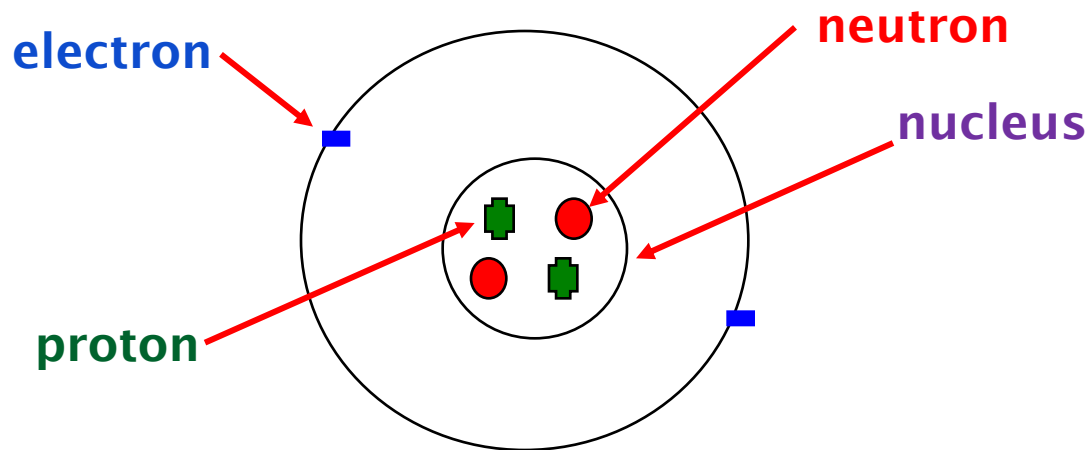
large, positively charged particles in small central nucleus

- Electrons -

tiny, negatively charged particles in cloud around nucleus

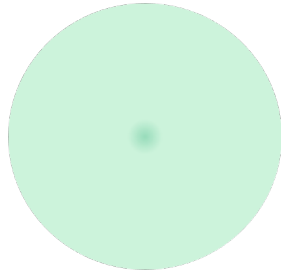
● Neutrons ●

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 (n⁰) 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 valence 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



Actual Element

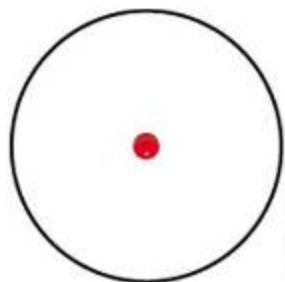


Isotopes

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

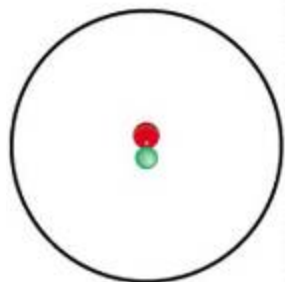
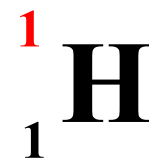
Used in chemistry for structure identification or to follow a particular molecule through a reaction

Example: hydrogen and deuterium



Water, H₂O

H has 1 proton and 0 neutrons
Most abundant



Heavy water, D₂O

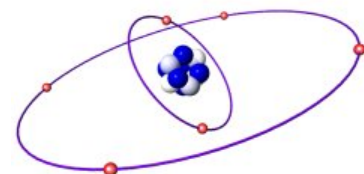
D (deuterium) has 1 proton & 1 neutron
Occurs 1/6700 molecules



Average Atomic Mass

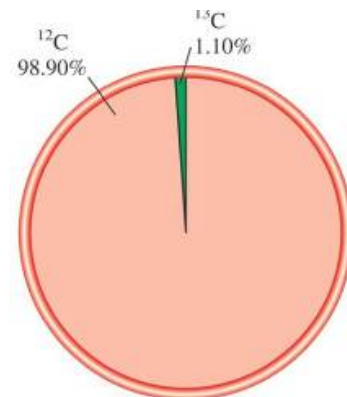
Atomic Mass: Mass of an atom in atomic mass units

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



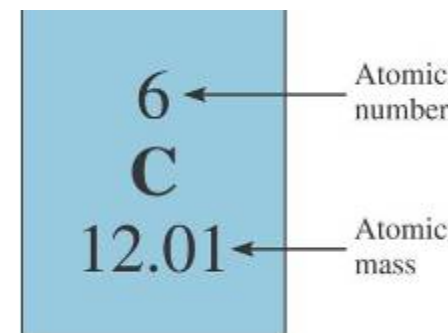
Naturally occurring carbon is a mixture of isotopes

$^{12}_6\text{C}$	98.90%	6 protons	6 neutrons	12.000 amu
$^{13}_6\text{C}$	1.100%	6 protons	7 neutrons	13.003 amu
$^{14}_6\text{C}$	$\sim 10^{-12}$	6 protons	8 neutrons	14.003 amu
(C-14 is unstable)				



Atomic mass of naturally occurring carbon:

$(0.9890 \times 12.000 \text{ amu}) + (0.0110 \times 13.003 \text{ amu})$
 = Atomic Mass of C = 12.01 amu



Los Alamos National Laboratory Chemistry Division

Periodic Table of the Elements

Los Alamos National Laboratory Chemistry Division																	
Periodic Table of the Elements																	
1A																	2
1 H ¹ ₁ hydrogen 1.008																	2 He ² ₂ helium 4.003
3	2A																
3 Li ³ ₃ lithium 6.94	4 Be ⁴ ₄ beryllium 9.012																
11	12																
11 Na ¹¹ ₁₁ sodium 22.99	12 Mg ¹² ₁₂																
19	20	3B	4B	5B	6B	7B	8B		11B	12B	13	14	15	16	17	18	
19 K ¹⁹ ₁₉ potassium 39.10	20 Ca ²⁰ ₂₀ calcium 40.08	21 Sc ²¹ ₂₁ scandium 44.96	22 Ti ²² ₂₂ titanium 47.88	23 V ²³ ₂₃ vanadium 50.94	24 Cr ²⁴ ₂₄ chromium 52.00	25 Mn ²⁵ ₂₅ manganese 54.94	26 Fe ²⁶ ₂₆ iron 55.85	27 Co ²⁷ ₂₇ cobalt 58.93	28 Ni ²⁸ ₂₈ nickel 58.69	29 Cu ²⁹ ₂₉ copper 63.55	30 Zn ³⁰ ₃₀ zinc 65.39	31 Ga ³¹ ₃₁ gallium 69.72	32 Ge ³² ₃₂ germanium 72.64	33 As ³³ ₃₃ arsenic 74.92	34 Se ³⁴ ₃₄ selenium 78.96	35 Br ³⁵ ₃₅ bromine 79.90	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
37 Rb ³⁷ ₃₇ rubidium 85.47	38 Sr ³⁸ ₃₈ strontium 87.62	39 Y ³⁹ ₃₉ yttrium 88.91	40 Zr ⁴⁰ ₄₀ zirconium 91.22	41 Nb ⁴¹ ₄₁ niobium 92.91	42 Mo ⁴² ₄₂ molybdenum 95.96	43 Tc ⁴³ ₄₃ technetium (98)	44 Ru ⁴⁴ ₄₄ ruthenium 101.1	45 Rh ⁴⁵ ₄₅ rhodium 102.9	46 Pd ⁴⁶ ₄₆ palladium 106.4	47 Ag ⁴⁷ ₄₇ silver 107.9	48 Cd ⁴⁸ ₄₈ cadmium 112.4	49 In ⁴⁹ ₄₉ indium 114.8	50 Sn ⁵⁰ ₅₀ tin 118.7	51 Sb ⁵¹ ₅₁ antimony 121.8	52 Te ⁵² ₅₂ tellurium 127.6	53 I ⁵³ ₅₃ iodine 126.9	54 Xe ⁵⁴ ₅₄ xenon 131.3
55	56	*	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
55 Cs ⁵⁵ ₅₅ cesium 132.9	56 Ba ⁵⁶ ₅₆ barium 137.3		72 Hf ⁷² ₇₂ hafnium 178.5	73 Ta ⁷³ ₇₃ tantalum 180.9	74 W ⁷⁴ ₇₄ tungsten 183.9	75 Re ⁷⁵ ₇₅ rhenium 186.2	76 Os ⁷⁶ ₇₆ osmium 190.2	77 Ir ⁷⁷ ₇₇ iridium 192.2	78 Pt ⁷⁸ ₇₈ platinum 195.1	79 Au ⁷⁹ ₇₉ gold 197.0	80 Hg ⁸⁰ ₈₀ mercury 200.5	81 Tl ⁸¹ ₈₁ thallium 204.4	82 Pb ⁸² ₈₂ lead 207.2	83 Bi ⁸³ ₈₃ bismuth 209.0	84 Po ⁸⁴ ₈₄ polonium (209)	85 At ⁸⁵ ₈₅ astatine (210)	86 Rn ⁸⁶ ₈₆ radon (222)
87	88	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	
87 Fr ⁸⁷ ₈₇ francium (223)	88 Ra ⁸⁸ ₈₈ radium (226)	104 Ru ¹⁰⁴ ₁₀₄ rutherfordium (261)	105 Db ¹⁰⁵ ₁₀₅ dubnium (268)	106 Sg ¹⁰⁶ ₁₀₆ seaborgium (271)	107 Bh ¹⁰⁷ ₁₀₇ bohrium (270)	108 Hs ¹⁰⁸ ₁₀₈ hassium (277)	109 Mt ¹⁰⁹ ₁₀₉ meitnerium (276)	110 Ds ¹¹⁰ ₁₁₀ darmstadtium (281)	111 Rg ¹¹¹ ₁₁₁ roentgenium (280)	112 Cn ¹¹² ₁₁₂ copernicium (285)	113 Nh ¹¹³ ₁₁₃ nihonium (284)	114 Fl ¹¹⁴ ₁₁₄ flerovium (289)	115 Mc ¹¹⁵ ₁₁₅ moscovium (288)	116 Lv ¹¹⁶ ₁₁₆ livermorium (293)	117 Ts ¹¹⁷ ₁₁₇ tennessine (294)	118 Uuo ¹¹⁸ ₁₁₈	

The Periodic Table

Organizing the Elements

Lanthanide Series*

57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.2	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
89 Ac actinium (227)	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	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)

The Modern Periodic Table

Arranged by Atomic Number

Arranged by Atomic Number																	
1 1A H	2 2A He											13 3A B	14 4A C	15 5A N	16 6A O	17 7A F	18 8A Ne
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112	(113)	114	(115)	116	(117)	(118)

	Metals
	Metalloids
	Nonmetals

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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

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)

Periodic Table of the Elements

Legend:

- Alkali metals
- Alkaline earth metals
- Lanthanides
- Actinides
- Transition metals
- Post-transition metals
- Metalloids
- Other nonmetals
- Halogens
- Noble gases
- Unknown properties

SOURCES: National Institute of Standards and Technology, International Union of Pure and Applied Chemistry

Transition metals

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

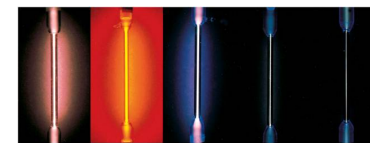


Lanthanides & Actinides

- 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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1 IA																	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., <i>Atomic Weights of the Elements</i> , 1997, National Institute of Standards and Technology. Parentheses () indicate the mass number of the most stable isotope.								

* Lanthanide Series

** Actinide 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
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)

The Mole – like a dozen but a lot more!

19

Mole

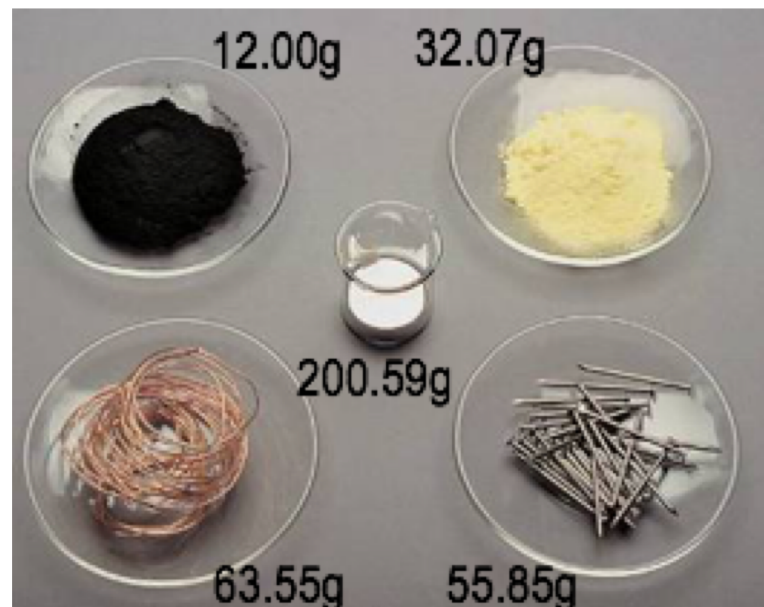
of atoms in 12.00g of C-12

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.)

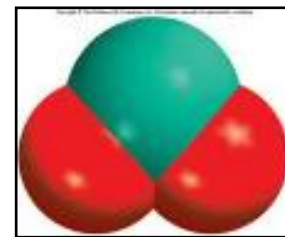
(Atoms are too small to measure on a balance)

$$\text{C-12: } \frac{12.00\text{g}}{1\text{mole}} \times \frac{1\text{mole}}{6.022 \times 10^{23} \text{ atoms}} = 1.993 \times 10^{-23} \text{ g / 1 atom}$$

Molar Mass

The mass of one mole of a substance

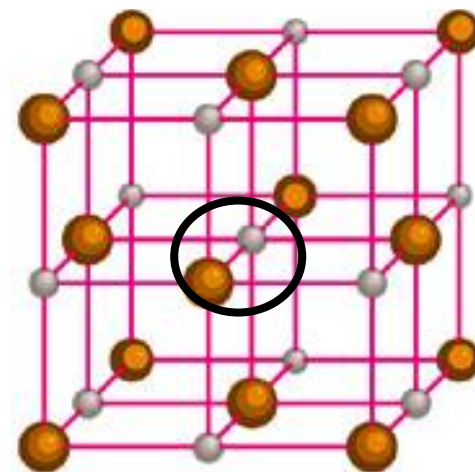
- Equal to AMU, but in units of g/mol



SO₂ - 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:

$$1 \text{ mol Na} = 22.99 \text{ g/mol}$$

$$1 \text{ mol SO}_2 = 64.07 \text{ g/mol}$$

$$1 \text{ mole NaCl} = 58.44 \text{ g/mol}$$

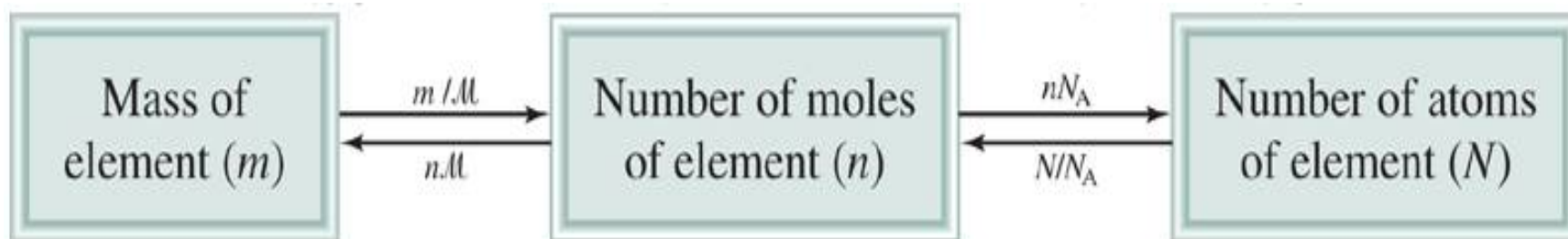
Mole-based Calculations

(Mass/Mole/Particle Conversions)

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

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

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



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

moles $\rightarrow$ mass

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

mass $\rightarrow$ # moles

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

moles $\rightarrow$ # particles

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

particles $\rightarrow$ # moles ($\rightarrow$ grams!)

If you have 2.5×10^{22} atoms of gold, how many moles do you have?

How many grams do you have? (0.042mol, 8.2g)

grams $\rightarrow$ # particles

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

(1.236mol, 7.445×10^{23} atoms)