Measurement and Units

- SI – similar to (but not exactly the same as) the metric system

Measurement and Units

Physical Quantity	Name of unit	Symbol of Unit
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Temperature	Kelvin	K
Amount of substance	Mole	mol
Electric current	Ampere	A
Luminous intensity	Candela	cd

Prefix	Multiple
Tera (T)	10^{12}
Giga (G)	10^{9}
Mega (M)	10^{6}
Kilo (k)	10^{3}
Centi (c)	10^{-2}
Milli (m)	10^{-3}
Micro (u or μ)	10^{-6}
Nano (n)	10^{-9}
Pico (p)	10^{-12}
Femto (f)	10^{-15}

More on measurement

- *Precision* – how “close” experimental values are to each other (consistency)
- *Accuracy* – how “close” experimental values are to a “true” or “accepted” value
- “closeness” can be measured by a variety of statistical techniques – mean, median, mode, standard deviation, etc.

Significant figures

- We live in the real world, not in theory!
- Aid in reporting experimentally measured quantities
  - Any instrument used for measurement will have a specified precision (+/-)
  - We are allowed to report <u>all</u> *known* digits and <u>one</u> *unknown* digit

Significant figures

- Any non-zero digit is significant (Ex. 1234)
- Zeros sandwiched between digits are significant (Ex. 1023)
- Zeros to the left of a decimal are NOT significant (Ex. 0.123)
- Zeros to the left of the first non-zero digit are NOT significant (Ex. 0.0000123)
- Zeros to the right of the last non-zero digit are significant (Ex. 0.123000)
- If there is no decimal point, zeros are NOT significant (Ex. 100 vs 100.)

Calculations involving significant figures

- “A chain is only as strong as its weakest link”
- Addition and Subtraction – use the number with the least number of significant figures AFTER the decimal (or least number if there is no decimal)
- Multiplication and Division – use the number with the least number of TOTAL significant figures
- Propagation of error – round only at the last step of a multi-step calculation (but keep track of how many sig figs there should be at each point)

Dimensional Analysis and Unit Conversion

- Can be used as a problem-solving tool
- It is always a good idea to include units, not just numbers!
- Ex. How many seconds are in one year?

$$1\,year\left(\frac{365\,days}{1\,year}\right)\left(\frac{24\,hours}{1\,day}\right)\left(\frac{60\,minutes}{1\,hour}\right)\left(\frac{60\,seconds}{1\,minute}\right)$$

Chemical Reactions (Equations)

- Note: In this course the phases for each chemical reaction are omitted
- Example
  - $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$ will be written as
  - $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Neutralizations

- Reaction of an acid with a base
  - Acid + Base → Salt + Water
- Overall/Complete formula/Molecular reaction:
  - $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
- However, we should really show this reaction as it would "look" in solution

Neutralizations

- Ionic equation:
  - $H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$

  (water only dissociates about every 1 in 10^7 molecules)
- Net ionic equation:
  - $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
  - *Spectator ions* – identity is irrelevant, however they are necessary for charge neutrality

Naming compounds

- Usually put metal first, then nonmetal (go from left to right from the periodic table)
- Exceptions – N, H, O
- Name = firstelement secondelement(-ide)
- Prefixes
  - Ionic substances generally have no prefixes
  - Covalent substances – prefixes are always used for the 2nd element (even if it only has one of them) but are only used for the 1st element if >1

Number	Prefix
1	Mono
2	Di
3	Tri
4	Tetra
5	Penta
6	Hexa
7	Hepta
8	Octa
9	Nona
10	Deca

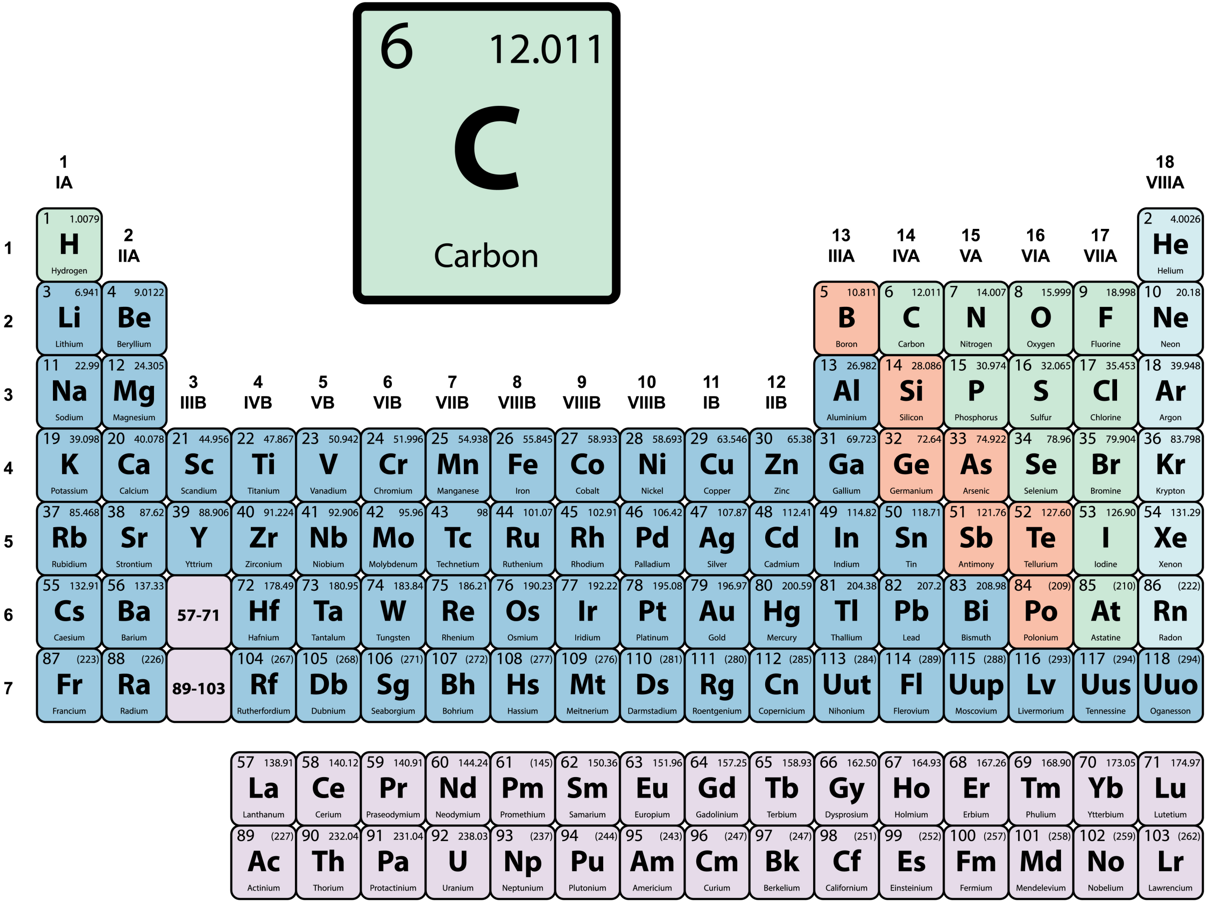
Ionic Compounds

- Ions – atoms that have gained or lost electrons (have + or – charge)
  - Can have very different properties than their corresponding elements
- Cations - + charge (lost electrons)
  - Usually originate from metals
- Anions - - charge (gained electrons)
  - Usually originate from nonmetals
- Ions can also be *polyatomic* (composed of more than one atom)

Determining the charge for an ion

- For Groups IA-VIIIA the “usual” charge of an ion is based on its position
  - +1, +2, +3, +/-4, -3, -2, -1, 0
- For Group B (transition metals), use the Stock system
  - Roman numerals represent charges
  - Ex. Fe(II) ion = Fe^{2+}

Periodic Table of the Elements



6 12.011
C
Carbon

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H Hydrogen																	2 4.0026 He Helium
2	3 6.941 Li Lithium	4 9.0122 Be Beryllium											5 10.811 B Boron	6 12.011 C Carbon	7 14.007 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.18 Ne Neon
3	11 22.99 Na Sodium	12 24.305 Mg Magnesium											13 26.982 Al Aluminium	14 28.086 Si Silicon	15 30.974 P Phosphorus	16 32.065 S Sulfur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
4	19 39.098 K Potassium	20 40.078 Ca Calcium	21 44.956 Sc Scandium	22 47.867 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.845 Fe Iron	27 58.933 Co Cobalt	28 58.693 Ni Nickel	29 63.546 Cu Copper	30 65.38 Zn Zinc	31 69.723 Ga Gallium	32 72.64 Ge Germanium	33 74.922 As Arsenic	34 78.96 Se Selenium	35 79.904 Br Bromine	36 83.798 Kr Krypton
5	37 85.468 Rb Rubidium	38 87.62 Sr Strontium	39 88.906 Y Yttrium	40 91.224 Zr Zirconium	41 92.906 Nb Niobium	42 95.96 Mo Molybdenum	43 98 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.71 Sn Tin	51 121.76 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.29 Xe Xenon
6	55 132.91 Cs Caesium	56 137.33 Ba Barium	57-71	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.84 W Tungsten	75 186.21 Re Rhenium	76 190.23 Os Osmium	77 192.22 Ir Iridium	78 195.08 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.38 Tl Thallium	82 207.2 Pb Lead	83 208.98 Bi Bismuth	84 (209) Po Polonium	85 (210) At Astatine	86 (222) Rn Radon
7	87 (223) Fr Francium	88 (226) Ra Radium	89-103	104 (267) Rf Rutherfordium	105 (268) Db Dubnium	106 (271) Sg Seaborgium	107 (272) Bh Bohrium	108 (277) Hs Hassium	109 (276) Mt Meitnerium	110 (281) Ds Darmstadium	111 (280) Rg Roentgenium	112 (285) Cn Copernicium	113 (284) Uut Nihonium	114 (289) Fl Flerovium	115 (288) Uup Moscovium	116 (293) Lv Livermorium	117 (294) Uus Tennessine	118 (294) Uuo Oganesson

57 138.91 La Lanthanum	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.36 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Gy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.90 Tm Phulium	70 173.05 Yb Ytterbium	71 174.97 Lu Lutetium
89 (227) Ac Actinium	90 232.04 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 (237) Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (258) Md Mendelevium	102 (259) No Nobelium	103 (262) Lr Lawrencium

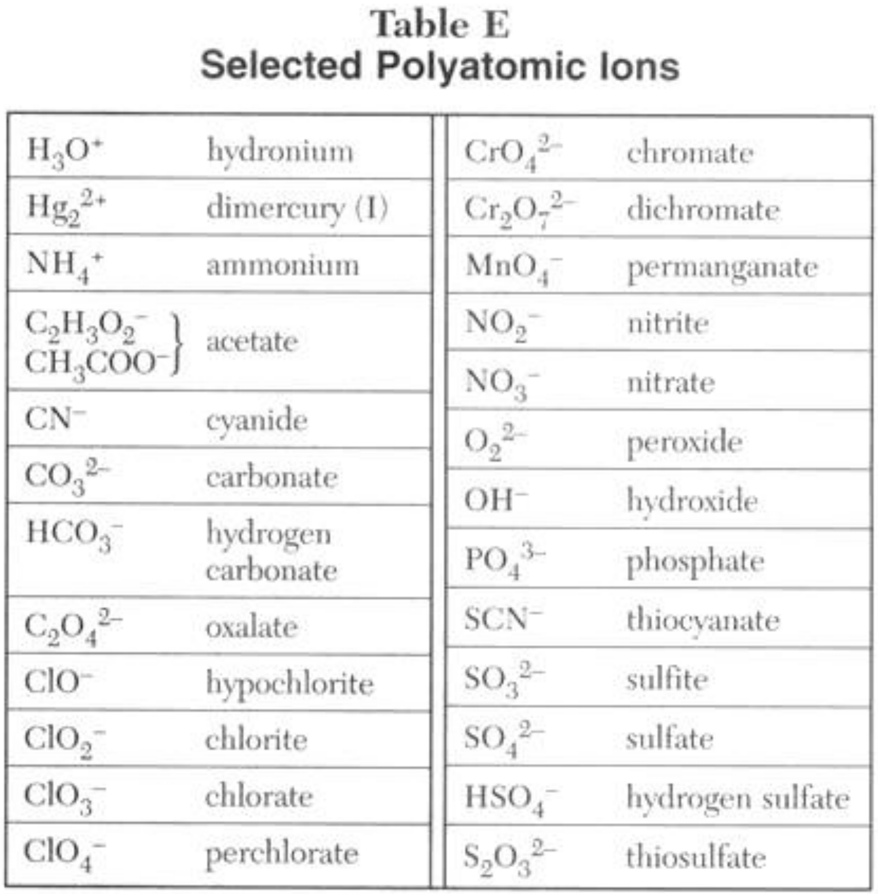


Table E
Selected Polyatomic Ions

H_3O^+	hydronium
Hg_2^{2+}	dimercury (I)
NH_4^+	ammonium
$C_2H_3O_2^-$ CH_3COO^-	acetate
CN^-	cyanide
CO_3^{2-}	carbonate
HCO_3^-	hydrogen carbonate
$C_2O_4^{2-}$	oxalate
ClO^-	hypochlorite
ClO_2^-	chlorite
ClO_3^-	chlorate
ClO_4^-	perchlorate

CrO_4^{2-}	chromate
$Cr_2O_7^{2-}$	dichromate
MnO_4^-	permanganate
NO_2^-	nitrite
NO_3^-	nitrate
O_2^{2-}	peroxide
OH^-	hydroxide
PO_4^{3-}	phosphate
SCN^-	thiocyanate
SO_3^{2-}	sulfite
SO_4^{2-}	sulfate
HSO_4^-	hydrogen sulfate
$S_2O_3^{2-}$	thiosulfate

Oxyanions

- Contain a varying number of oxygen atoms as part of a polyatomic ion

Oxyanion	Name
ClO^-	Hypochlorite
ClO_2^-	Chlorite
ClO_3^-	Chlorate
ClO_4^-	Perchlorate

Formula Unit

- Strictly speaking, this term should be used to describe ionic compounds
- It represents the smallest collection of ions that combine to form something neutral
- Ex. NaCl, Al_2O_3
- In naming formula units, prefixes are NOT used.

Hydrates

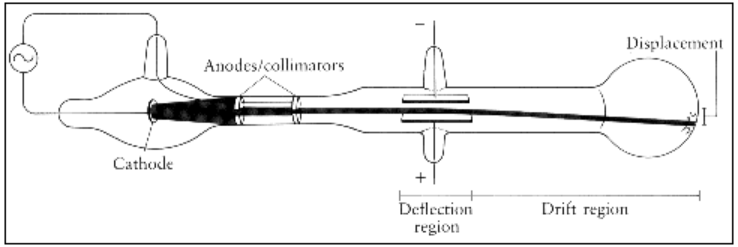
- Chemicals that contain H_2O in their formula
- The water molecules are actually associated with the cations/anions in a well-defined way
- A prefix must be used to indicate the number of H_2O molecules
- Anhydrous (dry) – no H_2O present
- Ex. $CuSO_4$ vs. $CuSO_4 \cdot 5H_2O$

What’s an atom made out of?

- All atoms are comprised of subatomic particles, which are fundamental.
- All subatomic particles are created equal
  - They are exactly the same, even if they are present in different atoms
- Three are important for chemistry
  - Proton
  - Neutron
  - Electron

J. J. Thomson (1897)

- Discovery of the electron
- (-) charged particles were produced, and they behaved exactly the same, regardless of the metal that was used.
- Was able to calculate the m/z ratio, $-5.69X10^{-12}$ kg/C, but wasn't able to get individual values for the mass or charge.

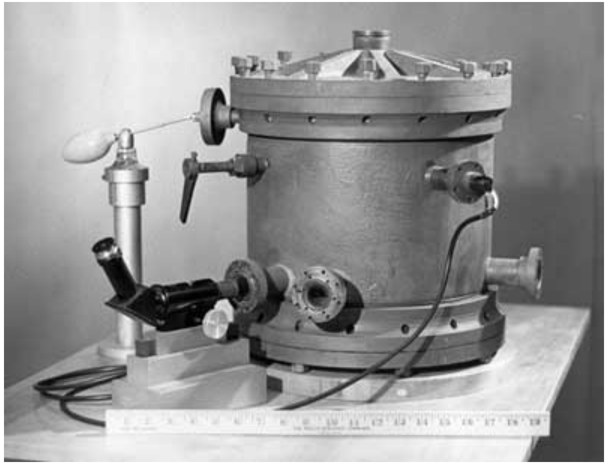


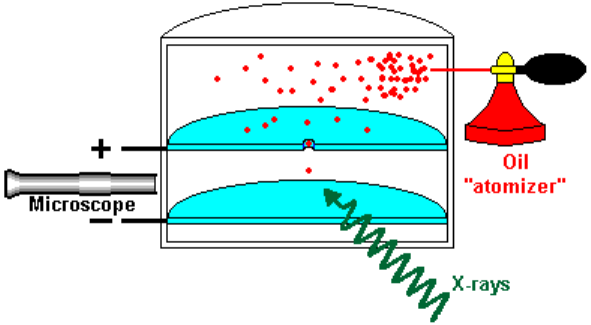
http://www.makingthemodernworld.org.uk/icons_of_invention/science/1880-1939/IC.026/

http://dbhs.wvusd.k12.ca.us/webdocs/AtomicStructure/Disc-of-Electron-Images.html

Robert Millikan (1909)

- Measured the velocity of a falling oil droplet in the presence/absence of a magnetic field
- Determined the charge on an electron (-1.602X10^{-19} C)
  - Mass of electron = 9.11X10^{-31} kg

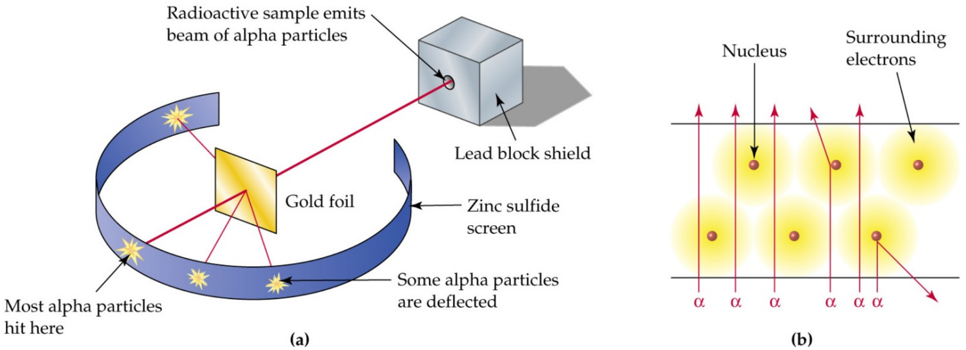




http://www.juliantrubin.com/bigten/millikanoildrop.html

Ernest Rutherford (1911)

- α particle = $^{4}_{2}He^{2+}$
- Most particle went straight through, but some were deflected
- Most of the atom is empty space, but all the (+) charge is concentrated in the center (nucleus)



http://wps.prenhall.com/wps/media/objects/602/616516/Media_Assets/Chapter02/Text_Images/FG02_05.JPG

Some definitions

- Isotope – same # of protons, but different # of neutrons
- Atomic Number (Z) – # of protons
- Mass Number (A, M) - # of nucleons (protons and neutrons)
- Atomic Mass – weighted average of all mass numbers (weighted by fractional abundance)

$$A.M. = \sum_{i} f_i M_i$$

The atomic mass unit (amu)

- One amu = 1/12 the mass of one atom of C-12 (by definition)
- This is the basic unit of mass for chemists, though it isn’t an SI unit

Example

- Calculate the atomic weight of carbon.

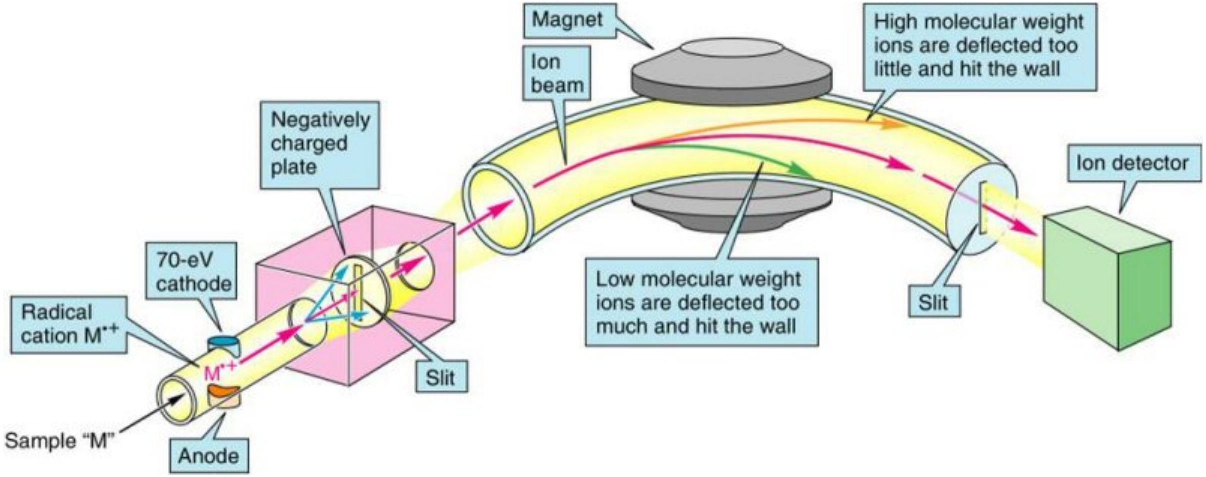
Solution

- Carbon exists in three isotopic forms: ^{12}C, ^{13}C and ^{14}C.
- The relative abundances of these isotopes are approximately 98.8%, 1.1% and 0.1%, respectively (this can be determined by mass spectrometry)
- Therefore the atomic weight would be = 12(0.988) + 13(0.011) + 14(.001) = 12.011 amu

Gas chromatography – Mass spectrometry (GC-MS)

- Usually requires ionization
- Form charged species with an unpaired electron (radical)
- Fragmentation pattern
  - Based on broken chemical bonds
  - Each piece (fragment) has a characteristic m/z ratio
- Molecular jigsaw puzzle

Diagram of a mass spectrometer



http://chemistry.umeche.maine.edu/CHY251/Ch13-Overhead4.html

GC-MS instruments

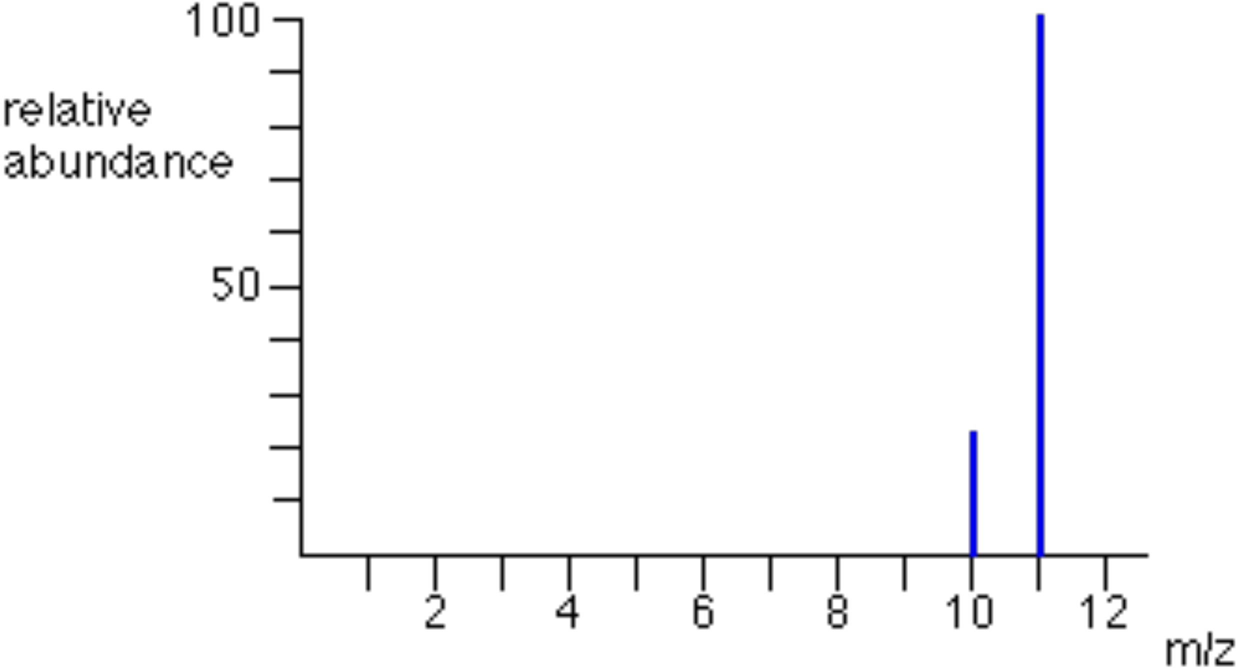
http://www.cooper.edu/~newmark/CH251/gcms.html

Common isotopic ratios

Element	Isotopes	Abundance (%)
Hydrogen	^{1}H, ^{2}H, ^{3}H	99.985, 0.015, (0)
Carbon	^{12}C, ^{13}C, ^{14}C	98.90, 1.10, (0)
Nitrogen	^{14}N, ^{15}N	99.63, 0.37
Oxygen	^{16}O, ^{17}O, ^{18}O	99.762, 0.038, 0.200
Chlorine	^{35}Cl, ^{37}Cl	75.77, 24.23
Bromine	^{79}Br, ^{81}Br	50.69, 49.31

- Ratios can tell you which atoms you have present (by comparing relative intensities)

Example: Boron

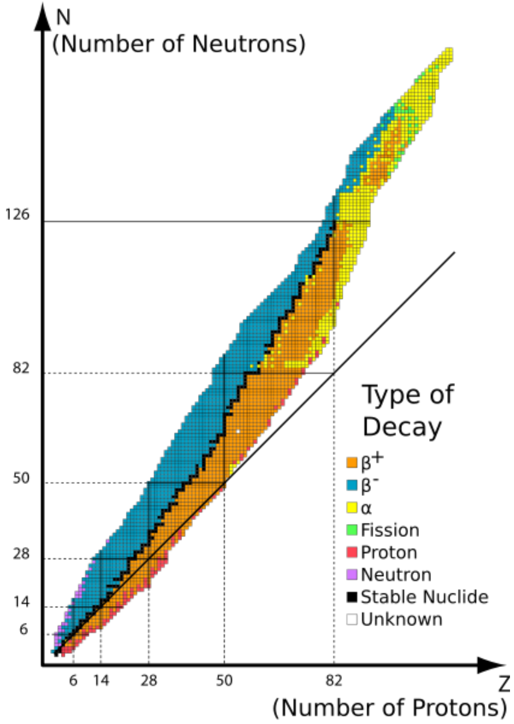


http://www.chemguide.co.uk/analysis/masspec/elements.html

Average atomic masses listed by IUPAC are based on a study of experimental results. Bromine has two isotopes ^{79}Br and ^{81}Br, whose masses (78.9183 and 80.9163 amu) and abundances (50.69% and 49.31%) were determined in earlier experiments. Calculate the average atomic mass of bromine based on these experiments.

Nuclear Stability

- Nuclei can be predicted to be stable or unstable “radioactive” based on the number of nucleons (protons and neutrons).
- Generally if Z>84 (Po) the nuclide will undergo radioactive decay. All elements where Z>92 are “artificial” in the sense that they are not naturally occurring.
- For “small” nuclei, stable configurations are achieved when (A-Z)/Z is 1.
- For “large” nuclei, (A-Z)/Z is >1 (1.2-1.4)
- “Magic numbers” exist where nuclei are exceptionally stable: 2, 8, 20, 28, 50, 82, 126.



http://www.kentchemistry.com/links/Nuclear/BandStability.htm

Radioactive Decay

- In order to achieve stability, radioactive nuclei will typically try to change their (A-Z)/Z ratio so they can fall in the band of stability. (α and β decays)
- It is also possible to become more stable yet keep the mass of the nucleus the same (γ decay)
- Other possibilities are *fission* (splitting of a heavy nuclide into smaller nuclides) and *fusion* (joining lighter nuclides into a heavier nuclide)

α decay

- Loss of a helium nucleus $^{4}_{2}He$
  - Results in ejection of positive particles
- Typically occurs with heavier nuclei
- Example $^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th$

β decay

- Common for medium-sized nuclides
- <u>β⁻ decay</u> – loss of an electron $_{-1}^{0}e$
  - Example $_{6}^{14}C \rightarrow {}_{-1}^{0}e + {}_{7}^{14}N$
  - Net conversion of a neutron into a proton [(A-Z)/Z too high] $_{0}^{1}n \rightarrow {}_{-1}^{0}e + {}_{1}^{1}H$
- <u>β⁺ decay (positron emission)</u> – loss of an positron $_{1}^{0}e$
  - Example $_{11}^{22}Na \rightarrow {}_{1}^{0}e + {}_{10}^{22}Ne$
  - A positron is the *antiparticle* of an electron $_{1}^{0}e + {}_{-1}^{0}e \rightarrow 2\,{}_{0}^{0}\gamma$
- <u>Electron capture</u> – gain of an electron
  - Example $_{33}^{73}As + {}_{-1}^{0}e \rightarrow {}_{32}^{73}Ge$
  - Net conversion of a proton into a neutron [(A-Z)/Z too low]

γ decay

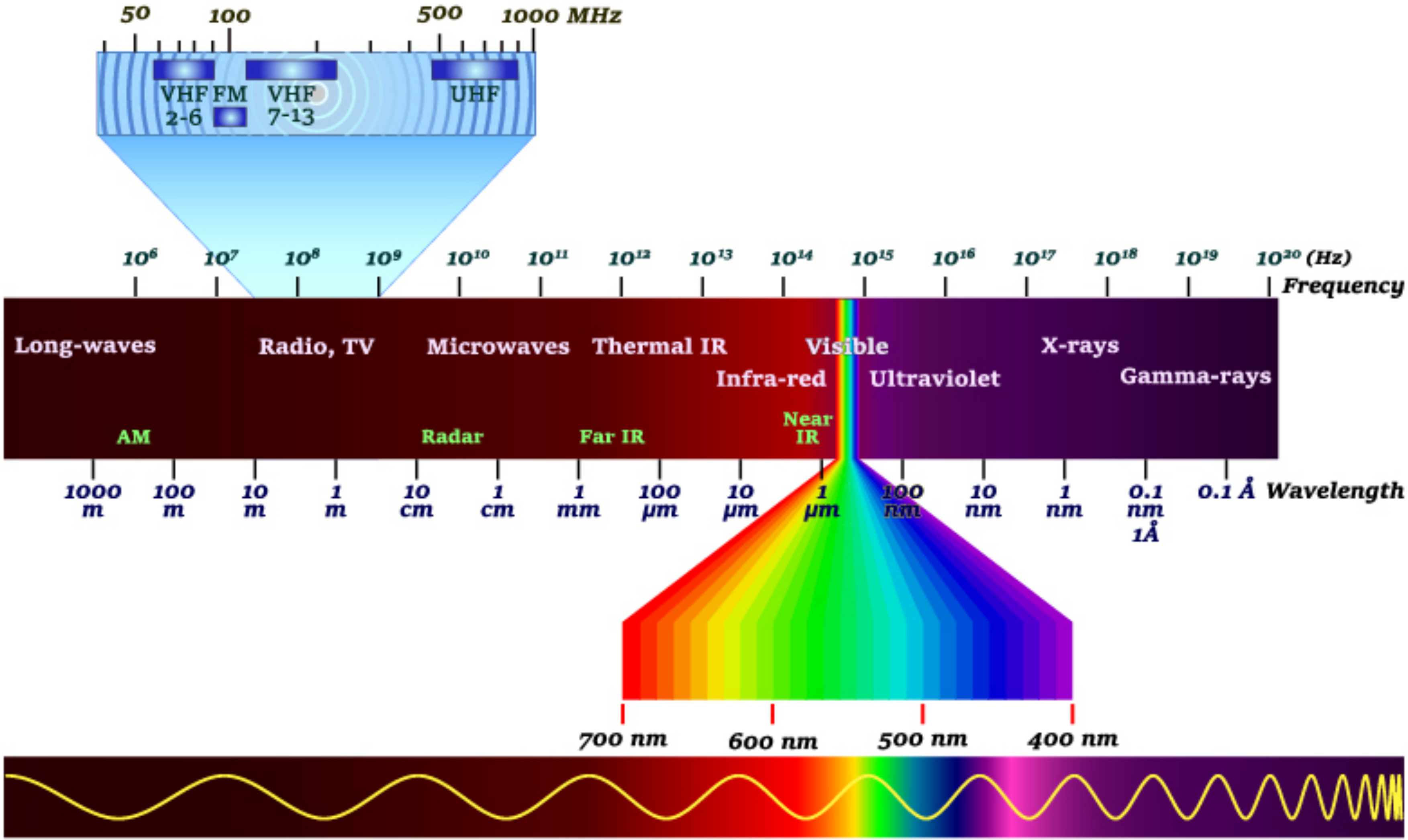
- Loss of a high energy photon $^{0}_{0}\gamma$
- No change in atomic or mass number
  - Example $^{99,m}_{43}Tc \rightarrow {}^{0}_{0}\gamma + {}^{99}_{43}Tc$
- We can think of the nucleons as being found in various energy levels, just like electrons

Nuclear fission

- Artificial transmutation process that releases a tremendous amount of energy $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$
- Typically initiated by a “magic bullet”, commonly a neutron:
- Notice that for every one neutron that is used, three neutrons are produced. Each of these neutrons can then be used for another fission reaction, and so the reaction leads to an unstable (supercritical) situation since the number of particles grows exponentially. This is known as a *chain reaction*.

Light and spectroscopy

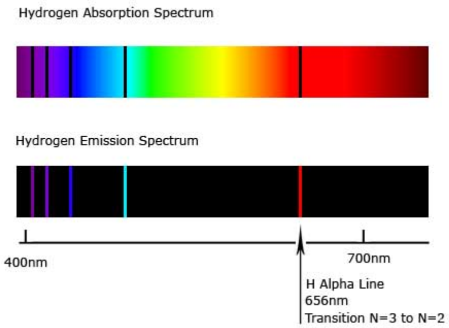
- EM Spectrum has waves of varying frequencies and wavelengths
- $E = h\nu = hc/\lambda$
- Spectroscopy deals with the interaction of matter with light

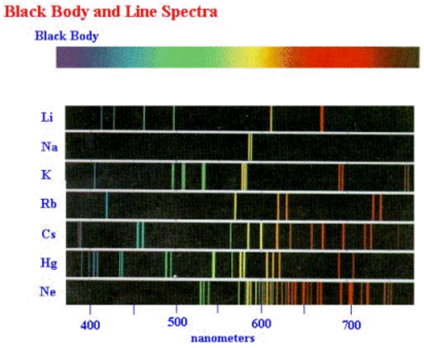

50
100
500
1000 MHz
VHF 2-6
FM
VHF 7-13
UHF
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20} (Hz)
Frequency
Long-waves
Radio, TV
Microwaves
Thermal IR
Visible
X-rays
Infra-red
Ultraviolet
Gamma-rays
AM
Radar
Far IR
Near IR
1000 m
100 m
10 m
1 m
10 cm
1 cm
1 mm
100 μm
10 μm
1 μm
100 nm
10 nm
1 nm
0.1 nm 1Å
0.1 Å
Wavelength
700 nm
600 nm
500 nm
400 nm

Atomic line spectra

- A cuvette filled with a sample is then exposed to a beam of light. Since light of all possible wavelengths are incident, it was believed that all possible wavelengths should be emitted, so the spectrum should be a rainbow (continuous emission)
- However, something else was observed…
- Balmer (1885) n = 3, 4, 5…

$$\frac{1}{\lambda} = 1.097 * 10^7 m^{-1}\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$





http://www.faculty.virginia.edu/consciousness/new_page_6.htm
http://www.astronomyknowhow.com/hydrogen-alpha.htm

A simple, yet revolutionary idea

- Planck proposed that energy is quantized:

$$E=h\nu$$

h= Planck's constant = $6.626*10^{-34}$ J*s

“Old” Quantum Mechanics

- Niels Bohr (1913)
  - Assumed that the angular momentum (not the energy!) of the electron in a hydrogen atom is quantized
  - Used a combination of classical physics and this new interpretation for energy to derive “orbits”, or energy levels (very similar to a planetary model)

$$E_n = -\frac{me^4}{8\varepsilon_o h^2}\frac{1}{n^2} = -\frac{B}{n^2}$$

  - This was based on well-understood fundamental constants in physics (and Planck’s constant)

A theoretical explanation of atomic line spectra

- Photons of light are emitted when electrons go from a higher to lower energy level (opposite is true for absorption)
- Because the energy levels are fixed, only certain wavelengths of light will be observed

The good, the bad and the ugly

- The good
  - Bohr was able to come up with a theoretical model for the energy levels in the hydrogen atom which accounted for the experimentally observed line spectra (Balmer series)
- The bad
  - It only worked for hydrogen!!! (and other one-electron systems)
- The ugly
  - The necessary mathematics get very difficult very quickly
  - Multi-electron systems often don’t have closed form solutions

Quantum numbers

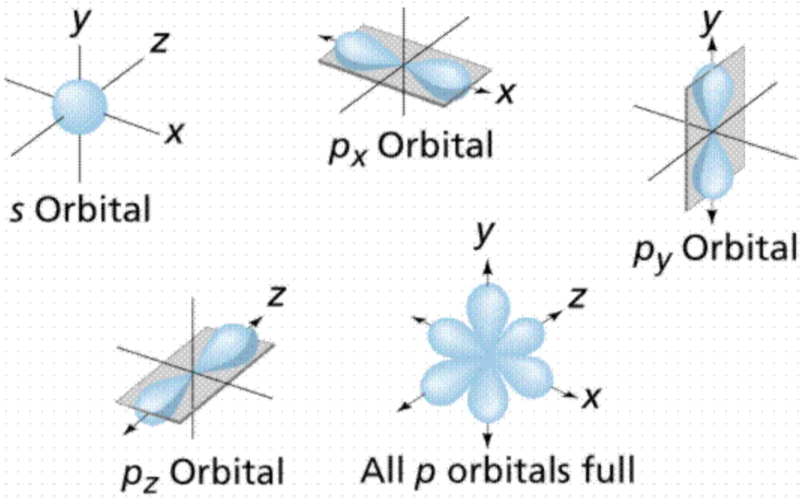
- Principal quantum number (n)
  - n = 1, 2, 3…
  - Same as Bohr’s energy levels
  - Indicates what “shell” the electron is in
- Angular momentum quantum number (l)
  - $l \leq n-1$
  - Ex. l=0 → s orbital, l=1 → p orbital, l=2 → d orbital, l=3 → f orbital
  - Determines the *shape* of the orbital, or “subshell”

Quantum numbers

- Magnetic quantum number (m_l)
  - $|m_l| \leq l$
  - Determines the spatial *orientation* and degeneracy of the orbital
  - Ex. if l=1 (p orbital) then m_l = -1, 0, 1. These are usually called p_x, p_y, and p_z (directions do not directly correspond to these numbers). We can also see why there are three p orbitals, since there are three allowed values for m_l.

Subshell (orbital) shapes

- Orbitals



- Nodes are possible – regions of zero probability of finding the electron

http://www.emc.maricopa.edu/faculty/farabee/biobk/biobookchem

Quantum numbers

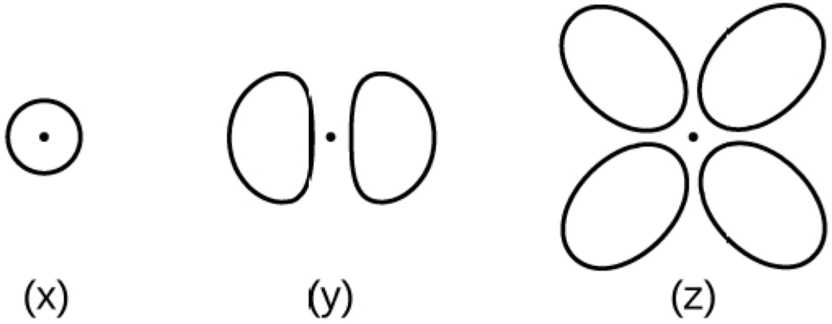
- Spin quantum number (m_s)
  - Unrelated to the other three quantum numbers
  - Unrelated to spatial coordinates
  - Each electron has an “intrinsic” spin coordinate
    - There is no classical analog, but it behaves similar to angular momentum
  - m_s = +/- ½ (half-integer)

- “All electronic wave functions must be antisymmetric under the interchange of any two electrons”

- It is impossible for two electrons in the same orbital to have the same spin

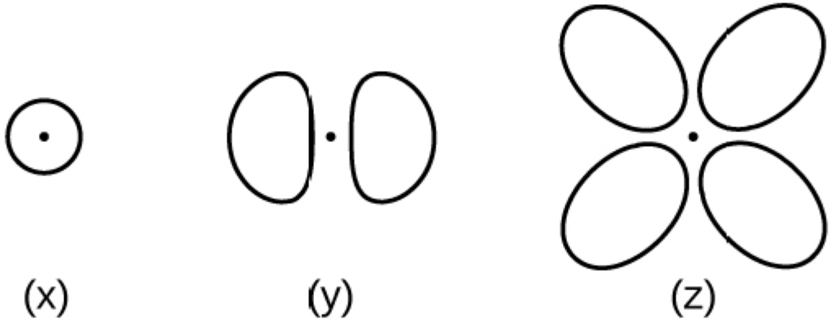
- No two electrons can have identical quantum numbers (in the same atom)

Consider the orbitals shown here in outline.



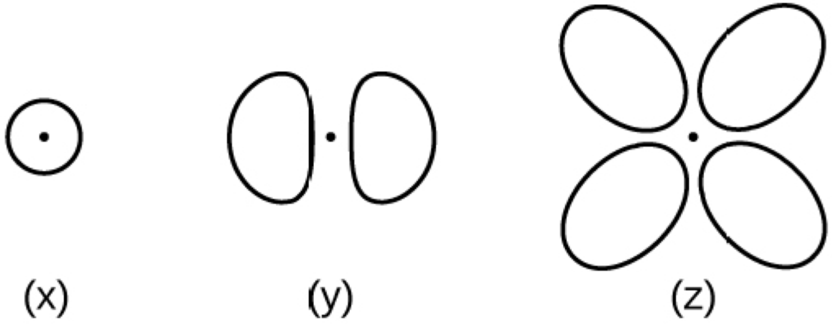
(a) What is the maximum number of electrons contained in an orbital of type (x)? Of type (y)? Of type (z)?

Consider the orbitals shown here in outline.



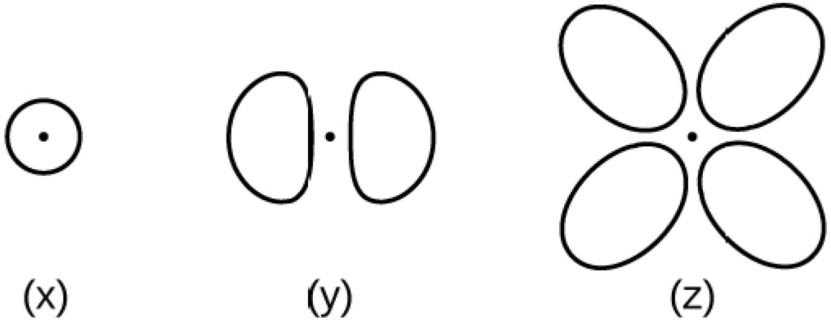
(b) How many orbitals of type (x) are found in a shell with *n* = 2? How many of type (y)? How many of type (z)?

Consider the orbitals shown here in outline.



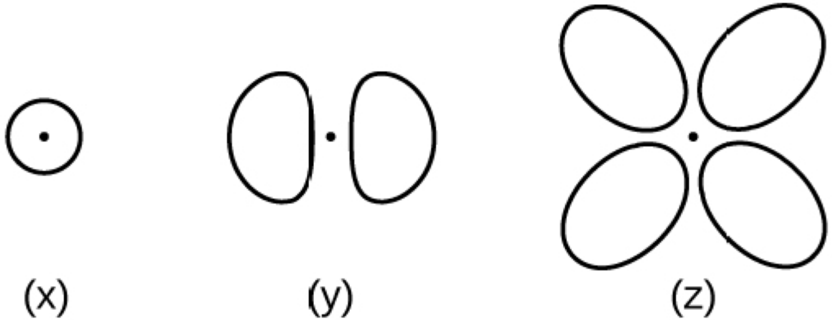
(c) Write a set of quantum numbers for an electron in an orbital of type (x) in a shell with *n* = 4. Of an orbital of type (y) in a shell with *n* = 2. Of an orbital of type (z) in a shell with *n* = 3.

Consider the orbitals shown here in outline.



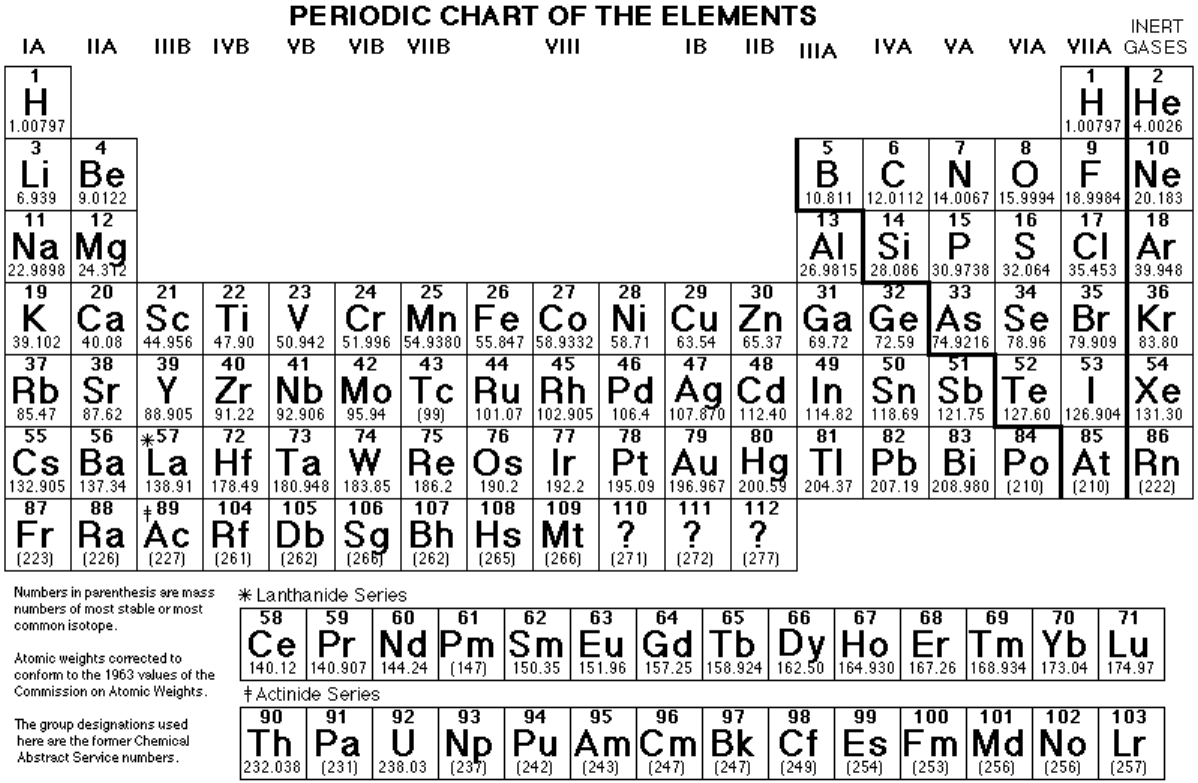
(d) What is the smallest possible *n* value for an orbital of typ

Consider the orbitals shown here in outline.



(e) What are the possible *l* and *ml* values for an orbital of type (x)? Of type (y)? Of type (z)?

The periodic table



PERIODIC CHART OF THE ELEMENTS

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	INERT GASES
1 H 1.00797																1 H 1.00797	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.0112	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.183
11 Na 22.9898	12 Mg 24.312											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.905	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	✳57 La 138.91	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	‡89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 ? (271)	111 ? (272)	112 ? (277)						

✳ Lanthanide Series

58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm (147)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97

‡ Actinide Series

90 Th 232.038	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (256)	103 Lr (257)

Numbers in parenthesis are mass numbers of most stable or most common isotope.

Atomic weights corrected to conform to the 1963 values of the Commission on Atomic Weights.

The group designations used here are the former Chemical Abstract Service numbers.

Main-group elements (“the A-list”)

- The valence (outer shell) consists only of s and p orbital electrons
- Group number = # of electrons in the valence shell (using the older Roman numeral system)
- Period number = principal quantum number (n)
- s block – alkali metals and alkali earth metals
- p block – metals, metalloids and nonmetals (including halogens and noble gases)

Transition metals (“the B-team”)

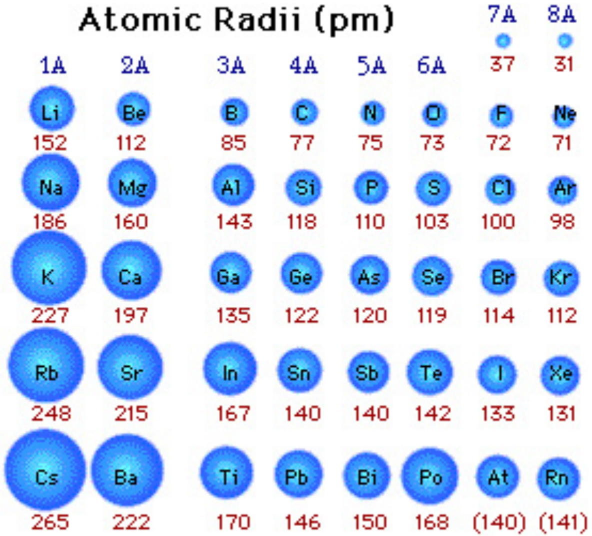
- Contain d and f orbitals
- d block - transition metals
- f block – rare earth (lanthanide/actinide)
- These are considered “inner shell” electrons
- The highest energy electrons are actually in a shell with a smaller value of n that that of the outermost shell (valence shell)
  - d block – (n-1)
  - f block – (n-2)

Periodic Trends

- Patterns that emerge in chemical and physical properties when elements are arranged in the periodic table
- Can usually be explained by the number of valence electrons, the number of core electrons, and the number of protons (nuclear charge)

Atomic Radius

- Generally atomic radius decreases across a period and increases down a group
  - – The trend only works for main group elements



Atomic Radii (pm)

1A	2A	3A	4A	5A	6A	7A	8A
						37	31
Li 152	Be 112	B 85	C 77	N 75	O 73	F 72	Ne 71
Na 186	Mg 160	Al 143	Si 118	P 110	S 103	Cl 100	Ar 98
K 227	Ca 197	Ga 135	Ge 122	As 120	Se 119	Br 114	Kr 112
Rb 248	Sr 215	In 167	Sn 140	Sb 140	Te 142	I 133	Xe 131
Cs 265	Ba 222	Tl 170	Pb 146	Bi 150	Po 168	At (140)	Rn (141)

http://edtech2.boisestate.edu/kilnerr/502/jigsaw.html

Atomic Radius

- Group – increase in the number of principal energy levels (greater average distance that the electron is from the nucleus)
- Period – increase in effective nuclear charge (the net charge the valence electrons “feel”)

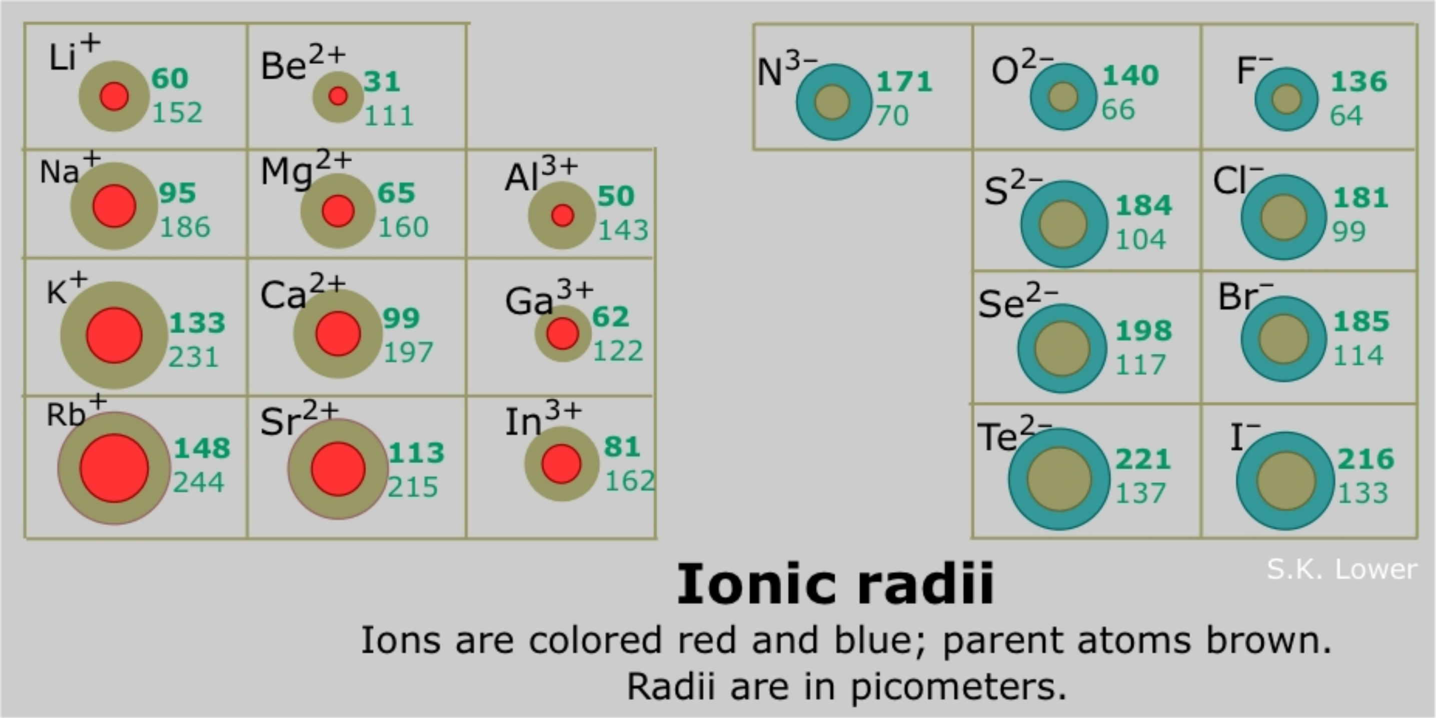
Effective Nuclear Charge (Z_{eff})

- Z_{eff} is meant to incorporate the shielding effect of core (inner) electrons
  - Valence electrons can penetrate inner shells (ex 3d and 4s)
  - Core electrons are not all equally effective in shielding valence electrons
  - Valence electrons can shield each other, though the effect is weak
- Transition metals in the same period have almost the same radius since Z_{eff} is the same

Ionic Radius

- Defined in a similar fashion to atomic radius (distance between two ions in a formula unit)
- Metals tend to lose valence electrons, so their highest occupied principal energy level decrease by one
  - Ionic radii for metals are smaller than those of the corresponding atomic radii
- Nonmetals tend to gain valence electrons, so their highest occupied principal energy level remains the same, but there is increased repulsion among the electrons in that level
  - Ionic radii for nonmetals are larger than those of the corresponding atomic radii

In pictures



Ionic radii

Ions are colored red and blue; parent atoms brown.
Radii are in picometers.

http://chemwiki.ucdavis.edu/Wikitexts/UC_Davis/UCD_Chem_124A%3A_Kauzlarich/ChemWiki_Module_Topics/Periodic_Trends_in_Ionic_Radii

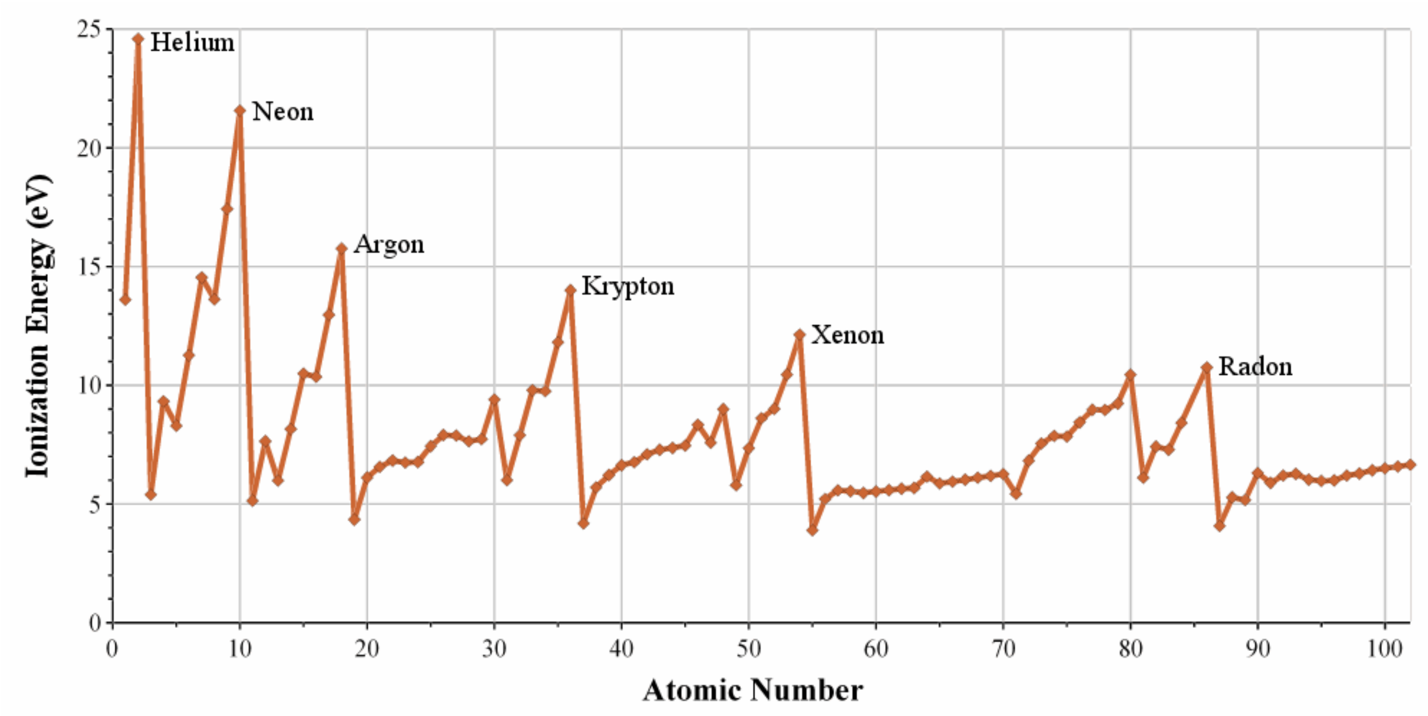
Ionization Energy

- Defined as the energy required to *remove* an electron from the ground state, in the gas phase
  - $A(g) \rightarrow A^+(g) + e^-$
- This can be repeated successively (1st, 2nd, 3rd, etc.)
  - It gets progressively harder to remove electrons since the species is already charged
  - Large jumps occur for a given element as you break up an octet (going from valence electrons to core electrons)

Ionization Energy

- Generally decreases as you go down a group
  - Outermost electrons are (on average) further away from the nucleus, so there is a greater shielding effect
- Generally increases as you go across a period
  - Elements have a greater tendency to gain electrons (rather than lose)
- Minor effects can be due to
  - what subshell the electron is in (s>p>d>f because of energy)
  - Paired vs. unpaired electrons (unpaired>paired because of repulsions)

In pictures

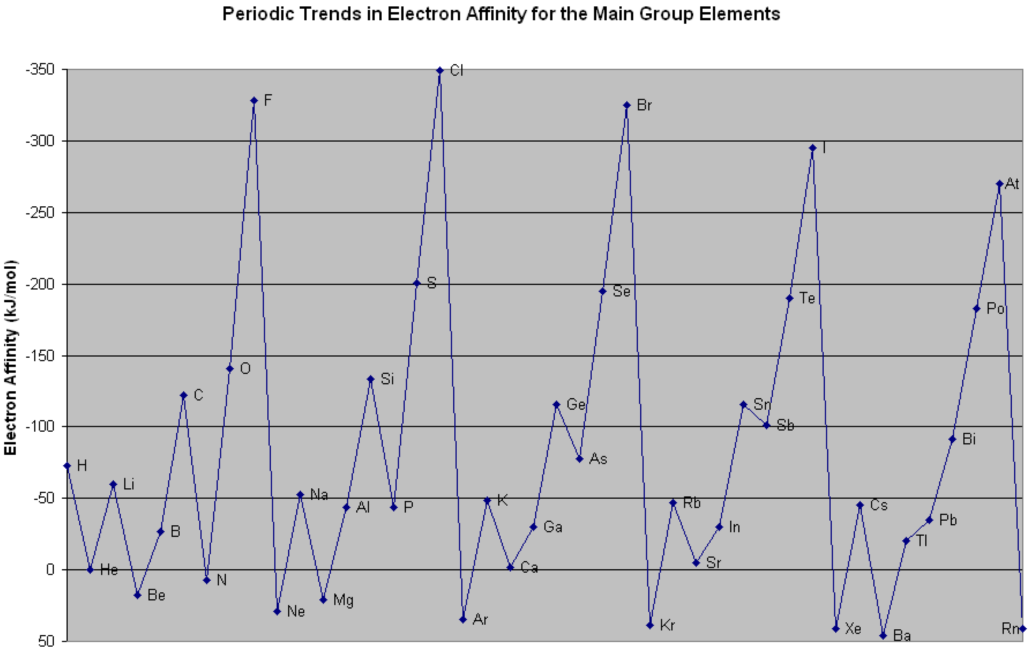


http://websites.pdesas.org/jvogus/2010/5/18/44324/page.aspx

Electron Affinity

- Defined as the energy required to *add* an electron to the ground state, in the gas phase
  - $A(g) + e^- \rightarrow A^-(g)$
- This has the same general trend as ionization energy, although it is less clear-cut
  - Complications due to repulsions between the incoming electron and the atomic electrons

In pictures



http://www.angelo.edu/faculty/kboudrea/periodic/trends_electron_affinity.htm

Electronegativity

- “Tendency” of an element to gain electrons

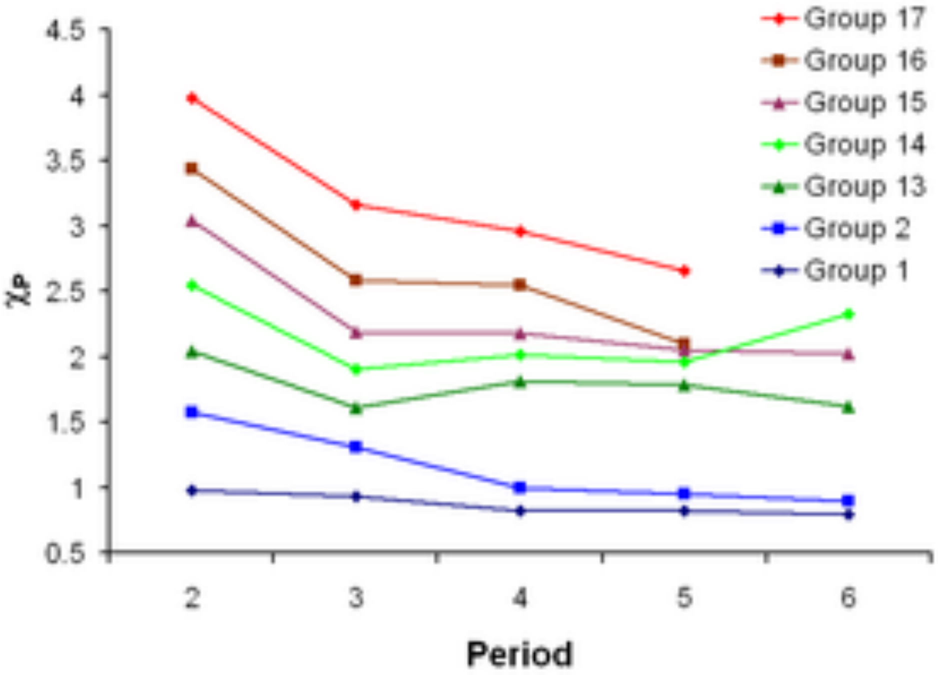
$$\chi = \frac{I.E. - E.A.}{2}$$

- Pauling scale:

$$\chi_B = \chi_A + 0.102\{(A-B) - [(A-A)(B-B)]^{1/2}\}^{1/2}$$

  - (i-j) = bond-dissociation energy between i and j
  - F is arbitrarily given the maximum value of 4.0
- Also follows the same general trend as ionization energy and electron affinity

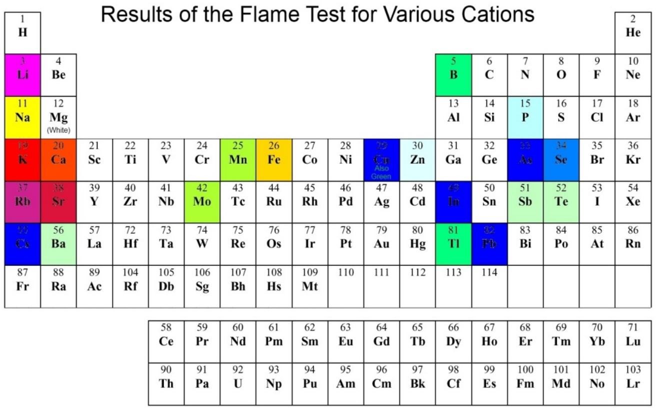
In pictures



http://en.wikipedia.org/wiki/Electronegativity

Chemical Properties of Elements

- Flame test
  - Based on characteristic absorbance of light energy
  - Wavelength emitted will be related to the energy gap between electronic levels
  - Used to identify various metals



Results of the Flame Test for Various Cations

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg (White)											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 Also Green	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	111	112	113	114				
				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

http://wesleydowler.com/?p=242

http://alchemist.edublogs.org/2008/11/17/which-ion-causes-the-color/

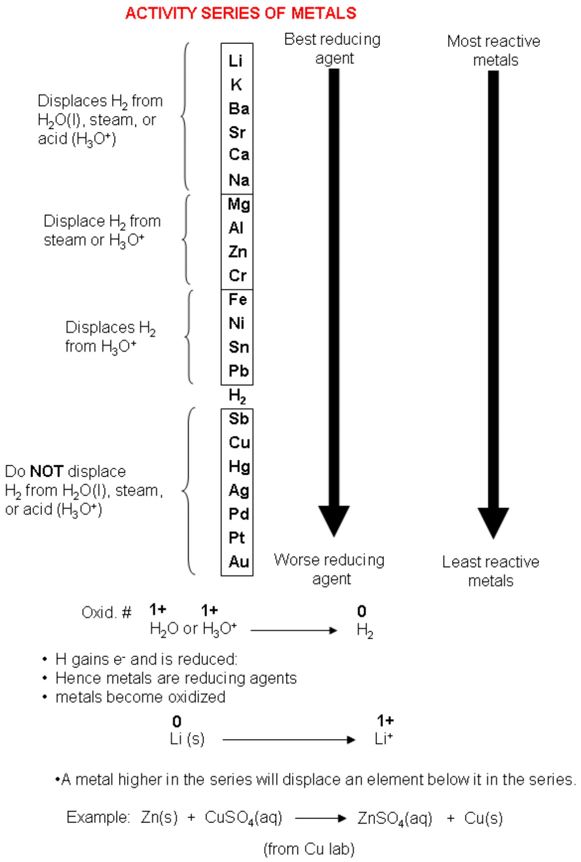
Redox reactions (an introduction)

- Redox reactions involve a simultaneous *red*uction and *ox*idation.
- Reduction – gain of electrons
  - oxidation number is decreased
- Oxidation – loss of electrons
  - Oxidation number is increased
- Disproportionation – redox reaction where the same species is both oxidized and reduced.
  - Ex. $2H_2O_2 \rightarrow 2H_2O + O_2$

Agents

- Reducing agent – causes a reduction
  - Gets oxidized
  - Usually metal
- Oxidizing agent – causes an oxidation
  - Gets reduced
  - Usually nonmetal

Activity series



ACTIVITY SERIES OF METALS

Displaces H_2 from $H_2O(l)$, steam, or acid (H_3O^+): Li, K, Ba, Sr, Ca, Na

Displace H_2 from steam or H_3O^+: Mg, Al, Zn, Cr

Displaces H_2 from H_3O^+: Fe, Ni, Sn, Pb

H_2

Do **NOT** displace H_2 from $H_2O(l)$, steam, or acid (H_3O^+): Sb, Cu, Hg, Ag, Pd, Pt, Au

Oxid. #

$$\overset{1+}{H_2O} \text{ or } \overset{1+}{H_3O^+} \longrightarrow \overset{0}{H_2}$$

- H gains e^- and is reduced:
- Hence metals are reducing agents
- metals become oxidized

$$\overset{0}{\text{Li (s)}} \longrightarrow \overset{1+}{Li^+}$$

•A metal higher in the series will displace an element below it in the series.

Example: $Zn(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$

(from Cu lab)

- “Noble” metals (Cu, Ag, Hg, Au) – can’t produce H_2

http://employees.csbsju.edu/hjakubowski/classes/ch123/summer_chem/ch123OLSGMM0405.htm

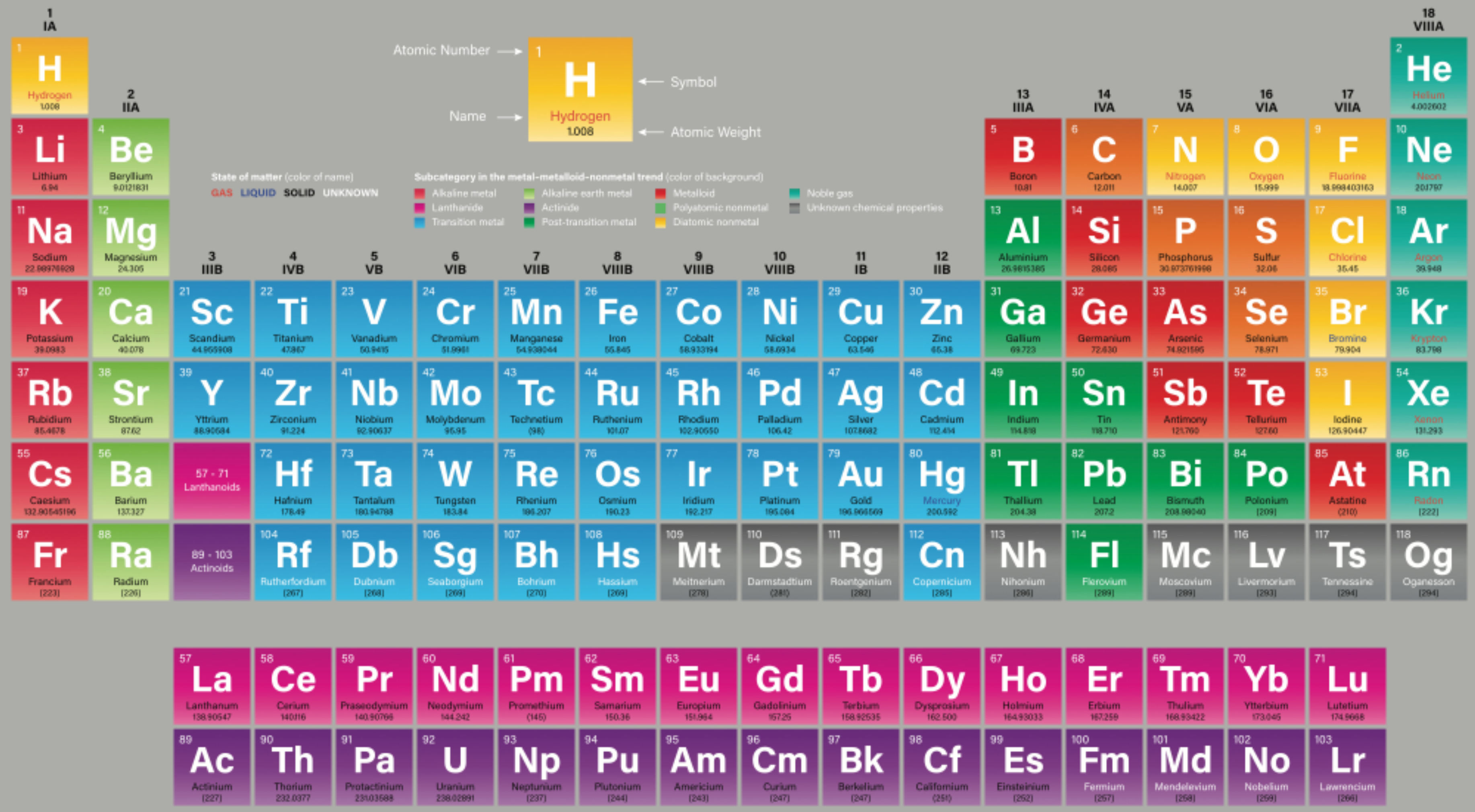
Chemical Properties of Elements

- Reduction
  - Reducing agents have a tendency to lose electrons
  - This property can be correlated with ionization energy, electronegativity and electron affinity
- Metals can react with sources of H^+ (acids, or even water if they are active enough) to generate ions and hydrogen gas
- $Mg + 2H^+ \rightarrow Mg^{2+} + H_2$
- $Ca + 2H_2O \rightarrow Ca^{2+} + 2OH^- + H_2$

Chemical Properties of Elements

- Oxidation
  - Oxidizing agents have a tendency to gain electrons
  - This property can be correlated with ionization energy, electronegativity, and electron affinity
- $Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$ will occur since Cl atoms have a higher (more negative) electron affinity than I atoms (-349 kJ/mol vs. -295 kJ/mol)
- $I_2 + Cl^- \rightarrow 2I^- + Cl_2$ will NOT occur

List the following ions in order of increasing radius: Li^+, Mg^{2+}, Br^-, Te^{2-}.



Atomic Number → 1

H ← Symbol

Name → Hydrogen

1.008 ← Atomic Weight

State of matter (color of name)

GAS LIQUID **SOLID** UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)

🟥 Alkaline metal	🟩 Alkaline earth metal	🟥 Metalloid	🟩 Noble gas
🟪 Lanthanide	🟪 Actinide	🟩 Polyatomic nonmetal	⬛ Unknown chemical properties
🟦 Transition metal	🟩 Post-transition metal	🟨 Diatomic nonmetal	

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.008																	2 He Helium 4.002602
3 Li Lithium 6.94	4 Be Beryllium 9.0121831											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998403163	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305											13 Al Aluminium 26.9815385	14 Si Silicon 28.085	15 P Phosphorus 30.973761998	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955908	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.921595	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90637	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.90545196	56 Ba Barium 137.327	57 - 71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium [209]	85 At Astatine (210)	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89 - 103 Actinoids	104 Rf Rutherfordium [267]	105 Db Dubnium [268]	106 Sg Seaborgium [269]	107 Bh Bohrium [270]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium (281)	111 Rg Roentgenium [282]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668
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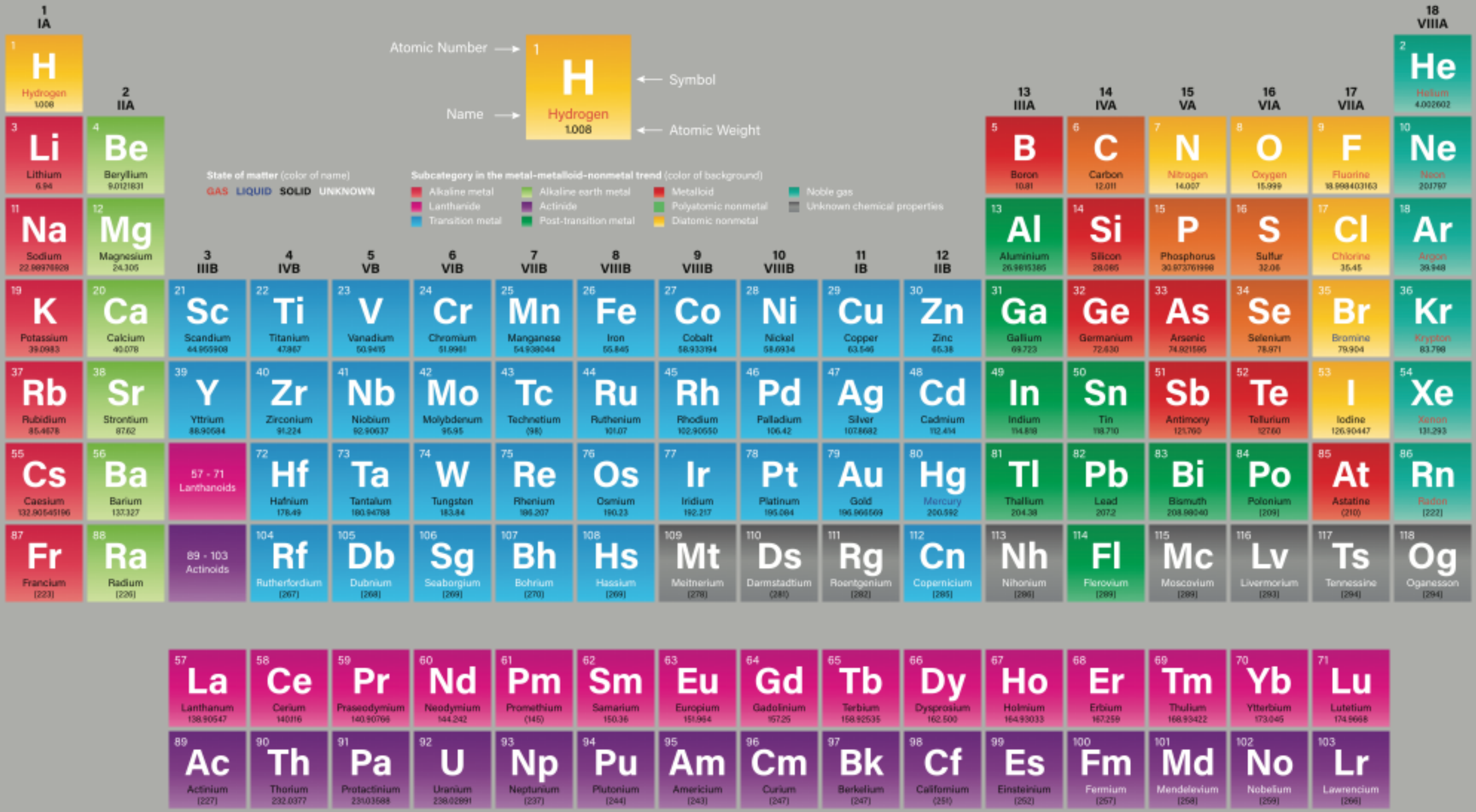
Write the Lewis structure for $SeCl_3^+$.



Atomic Number → 1
Symbol ← H
Name → Hydrogen
Atomic Weight ← 1.008

State of matter (color of name)
GAS LIQUID **SOLID** UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)
- 🟥 Alkaline metal
- 🟪 Lanthanide
- 🟦 Transition metal
- 🟩 Alkaline earth metal
- 🟪 Actinide
- 🟩 Post-transition metal
- 🟥 Metalloid
- 🟩 Polyatomic nonmetal
- 🟨 Diatomic nonmetal
- 🟩 Noble gas
- ⬜ Unknown chemical properties

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
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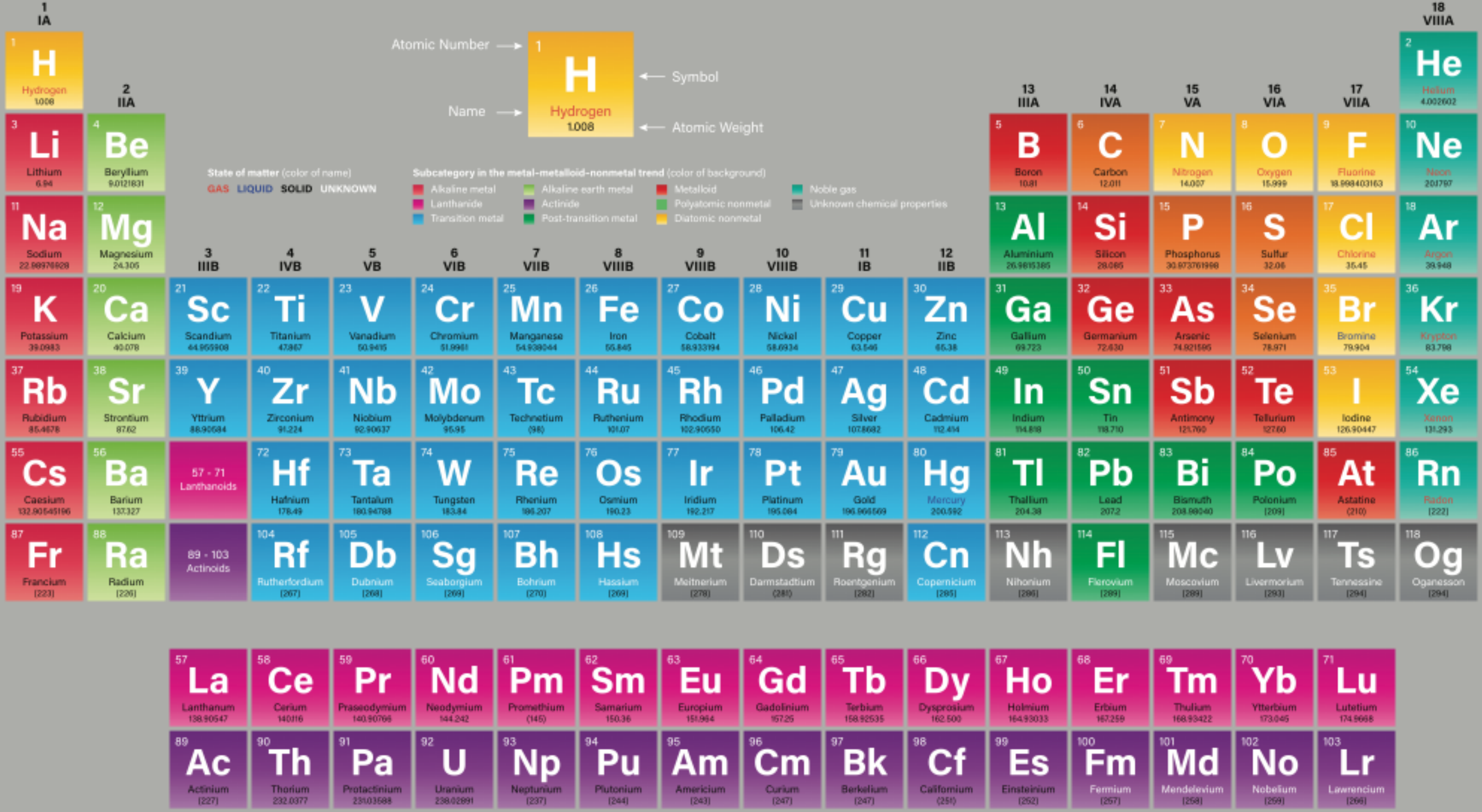
		89 Ac Actinium [227]	90 Th Thorium 232.0377	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium (251)	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]	103 Lr Lawrencium [266]	

Explain why the H_2O molecule is bent, whereas the BeH_2 molecule is linear.



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- 🟥 Metalloid
- 🟩 Polyatomic nonmetal
- 🟨 Diatomic nonmetal
- 🟩 Noble gas
- ⬛ Unknown chemical properties

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.008																	2 He Helium 4.002602
3 Li Lithium 6.94	4 Be Beryllium 9.0121831											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998403163	10 Ne Neon 20.1797
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305											13 Al Aluminium 26.9815385	14 Si Silicon 28.085	15 P Phosphorus 30.973761998	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955908	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.921595	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90637	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.90545196	56 Ba Barium 137.327	57 - 71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium [209]	85 At Astatine (210)	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89 - 103 Actinoids	104 Rf Rutherfordium [267]	105 Db Dubnium [268]	106 Sg Seaborgium [269]	107 Bh Bohrium [270]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium (281)	111 Rg Roentgenium [282]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668
89 Ac Actinium [227]	90 Th Thorium 232.0377	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	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 [266]

Reactions of alkali metals

- With halogens (F_2, Cl_2, Br_2, I_2):
  - $M + X_2 \rightarrow MX$
- With hydrogen:
  - $M + H_2 \rightarrow MH$
- With (excess) oxygen:
  - $Li + O_2 \rightarrow Li_2O$ (plus some Li_2O_2)
  - $Na + O_2 \rightarrow Na_2O_2$ (plus some Na_2O)
  - $M + O_2 \rightarrow MO_2$ (M = K, Rb, Cs)
- With water:
  - $M + H_2O \rightarrow MOH + H_2$

Reactions of alkaline earth metals

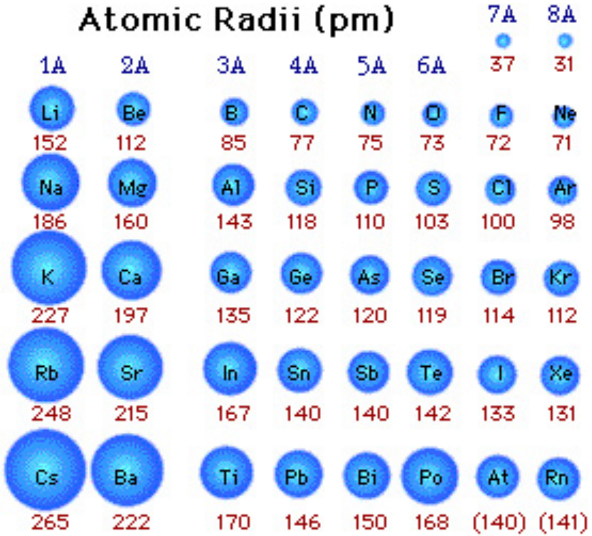
- With halogens (F_2, Cl_2, Br_2, I_2):
  - $M + X_2 \rightarrow MX_2$
- With nitrogen:
  - $M + N_2 \rightarrow M_3N_2$
- With oxygen:
  - $M + O_2 \rightarrow MO$
- With water:
  - $Mg + H_2O(g) \rightarrow MgO + H_2$
  - $M + H_2O \rightarrow M(OH)_2 + H_2$ ($M \neq Mg$)

Periodic Trends

- Patterns that emerge in chemical and physical properties when elements are arranged in the periodic table
- Can usually be explained by the number of valence electrons, the number of core electrons, and the number of protons (nuclear charge)

Atomic Radius

- Generally atomic radius decreases across a period and increases down a group
  - The trend only works for main group elements



Atomic Radii (pm)

1A	2A	3A	4A	5A	6A	7A	8A
						37	31
Li 152	Be 112	B 85	C 77	N 75	O 73	F 72	Ne 71
Na 186	Mg 160	Al 143	Si 118	P 110	S 103	Cl 100	Ar 98
K 227	Ca 197	Ga 135	Ge 122	As 120	Se 119	Br 114	Kr 112
Rb 248	Sr 215	In 167	Sn 140	Sb 140	Te 142	I 133	Xe 131
Cs 265	Ba 222	Tl 170	Pb 146	Bi 150	Po 168	At (140)	Rn (141)

http://edtech2.boisestate.edu/kilnerr/502/jigsaw.html

Ionization Energy

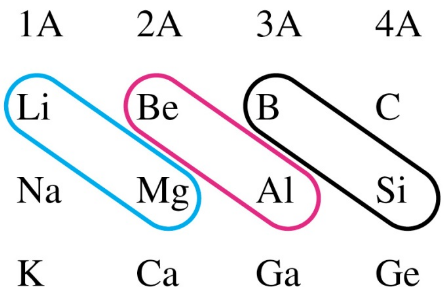
- Generally decreases as you go down a group
  - Outermost electrons are (on average) further away from the nucleus, so there is a greater shielding effect
- Generally increases as you go across a period
  - Elements have a greater tendency to gain electrons (rather than lose)
- Minor effects can be due to
  - what subshell the electron is in (s>p>d>f because of energy)
  - Paired vs. unpaired electrons (unpaired>paired because of repulsions)

Overview - Periodic Trends in Group 13

- B is a nonmetal/metalloid – forms covalent bonds but displays electrical properties of semiconductors (diagonal relationship with Si)
- Al is a metal/metalloid –forms covalent bonds but can also lose valence electrons to form ions (Al^{3+})
- Ga – forms Ga^{3+} ions to achieve stable configuration ($[Ar]3d^{10}$)
- In and Tl tend to form +1 ions because they lose the valence p electron but NOT the valence s electrons (inert pair)

Diagonal relationships

- Often the 1st member of a group has properties that are different from the other members of the group, but are similar to those of the 2nd member of the adjacent group
  - Relatively high charge density



- Example: Li
- Li_2CO_3, LiF, LiOH and Li_3PO_4 are much less soluble than the corresponding salts of the other alkali metals
  - Li_2CO_3 and LiOH form Li_2O
- $Li + N_2 \rightarrow Li_3N$ (other alkali metals don't react)
- $Li + O_2 \rightarrow Li_2O$ (other alkali metals form peroxides or superoxides)