The Periodic Table and Atomic Properties

- The periodic table originally came from the observation that when the elements are arranged by atomic mass, properties recur periodically. (Mendeleev)
- Now we understand the periodic table in terms of atomic number and electronic structure.
- We will look at the properties of elements from this viewpoint.

Metals and Nonmetals

- Metals have the properties:
  - Good conductors of heat and electricity
  - Malleable and ductile
  - High melting points
- Non-metals have the properties:
  - Poor conductors of heat and electricity
  - Brittle
  - Low melting points (some are even gases at room temperature)

Metals and Nonmetals

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 H 1.00794																	2 He 4.00260
3 Li 6.941	4 Be 9.01218											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9381	26 Fe 55.847	27 Co 58.9332	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.60	53 I 126.904	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	57 *La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	89 †Ac 227.028	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (272)		114 (287)		116 (289)		118 (293)

*Lanthanide series	58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
†Actinide series	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Metals and Nonmetals

- Non metals:
  - To the right of the periodic table
  - Includes the noble (inert) gases as a special case
- Metals
  - Most elements are metals
- Metalloids
  - In between metal and non-metals, have some properties of metals and non-metals

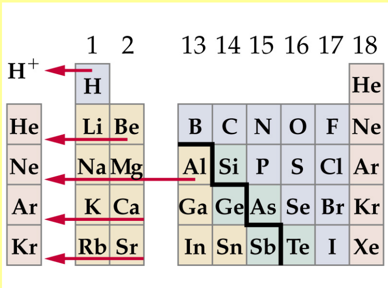
Correlations between electronic configuration and properties

- Noble Gases:
  - All have a full valence shell
  - This gives extreme stability and chemical inertness
- It appears most elements try to achieve this stability by acquiring or losing electrons

Group 1 and 2 metal ions

- These have 1 or 2 electrons more than a Noble gas
  - They can lose these electrons (through reaction for example) to produce very stable ions
  - Aluminum (Group 13) will actually lose 3 electrons to achieve the stable ion

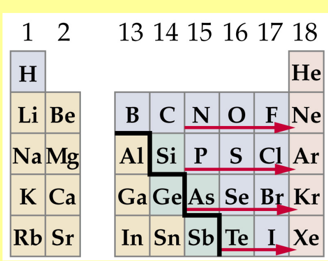
Group 1 and 2 metal ions



Group 16 and 17 non-metal ions

- These have 1 or 2 electrons less than a Noble gas
  - They can gain these electrons (through reaction for example) to produce very stable ions

Group (15),16, and 17 non-metal ions



Transition Metal Ions

- The electrons are lost from Transition metals in a different order than the aufbau principle would suggest
  - **They lose the "s" orbital electrons first**
  - Often they also lose "d" orbital electrons to give a half filled "d" subshell which has special stability.
  - e.g Fe [Ar]$3d^6 4s^2$ gives Fe^{3+} [Ar]$3d^5$

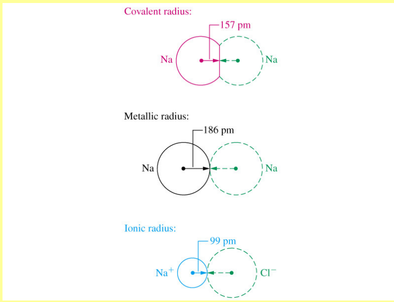
Sizes of Atoms and Ions

- Atomic and ionic radii cannot easily be described as the electron density extends to infinity
- Usually we use the measured distances in compounds to infer sizes, but even these are not all the same

Sizes of Atoms and Ions

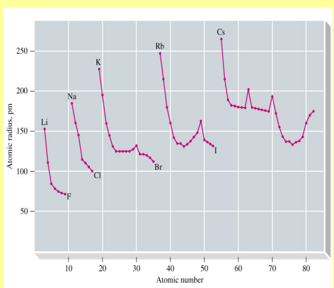
- Definitions
  - Covalent radius
    - Half the distance between identical atoms in a covalent compound
  - Ionic radius
    - Determined from separation between ions joined by ionic bonds
  - Metallic Radius
    - Half the distance between metal atoms in crystalline solid

Sizes of Atoms and Ions

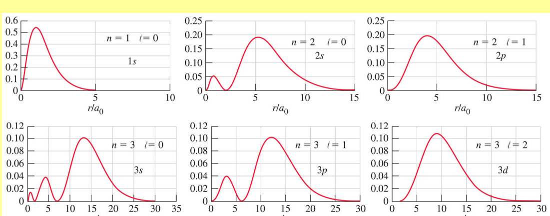


Sizes of Atoms and Ions

Can we explain this variation in radii?
- Down a group radii increase
- Across a period radii decrease
- Transition metal radii don't change much

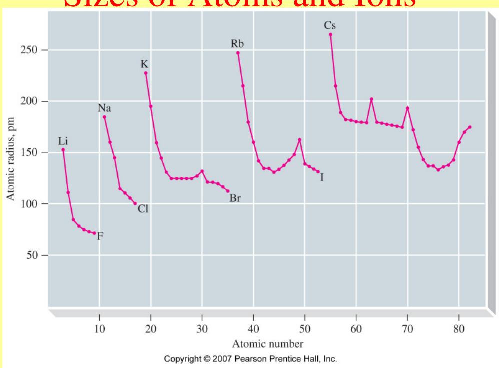


Sizes of Atoms and Ions



- Within (Down) a Group
  - The probability of finding an electron at larger distances is higher for higher n
  - Hence the more electronic shells the larger the atom

Sizes of Atoms and Ions



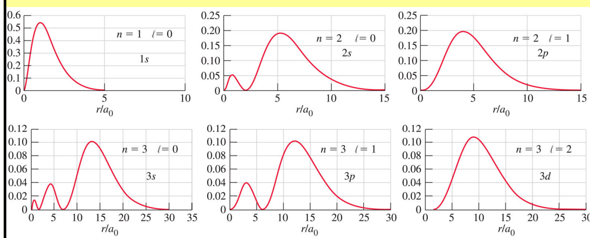
Sizes of Atoms and Ions

- Across a period
  - The nuclear charge and the number of electrons increase while the *n* stays the same.
    - Across a period the electrons go into the outer orbitals. The amount of screening is about the same, so successive electrons see higher effective nuclear charges so the radius decreases across a period.

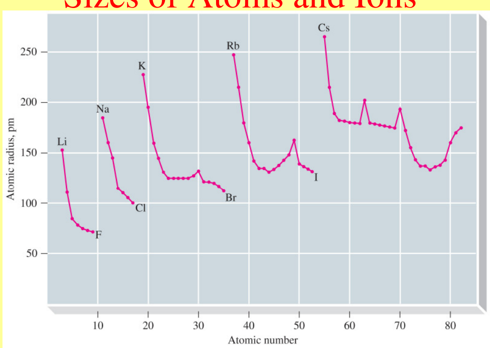
Sizes of Atoms and Ions

- Across a period (ctd)
  - The nuclear charge and the number of electrons increase while the *n* stays the same.
    - For transition metals the electrons are going into an INNER shell so the screening is more pronounced. The number of outer shell electrons stays the same. The increase in the nuclear charge is balanced by the increased screening. The outer electrons see the same effective nuclear charge. Since the size is determined by the outer electrons the radius remains similar across a transition metal series

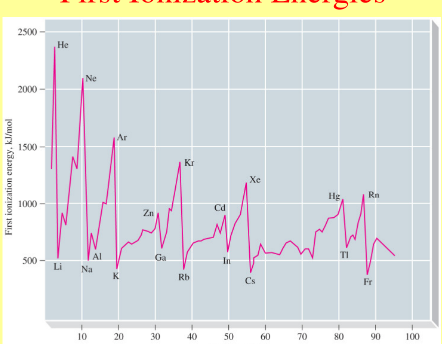
Sizes of Atoms and Ions



Sizes of Atoms and Ions



First Ionization Energies



Ionization Energy

- The ionization energy (IE) is the energy required to remove an electron to make an ion (+).
  - The further an electron is from the nucleus the lower the energy needed to completely remove it. Ionization energies decrease as ionic radii increase

Ionization Energy

- The ionization energy (IE) is the energy required to remove an electron to make an ion (+).
  - There are 2nd and 3rd ionization energies to remove successive electrons. Since the ion is smaller than the atom and there is a net charge, the successive IEs are higher

    $Mg(g) \rightarrow Mg^{+}(g) + e^{-}$ $I_1 = 738$ kJ mol^{-1}

    $Mg^{+}(g) \rightarrow Mg^{2+}(g) + e^{-}$ $I_2 = 1451$ kJ mol^{-1}

Electron Affinity

- The electron affinity (EA) is the energy change when an atom gains an electron to make an ion (-).

  $F(g) + e^{-} \rightarrow F^{-}(g)$ EA = -328 kJ mol^{-1}

  The atom releases energy when it gains the electron
- Atoms that have high EA are those where adding an electron stabilize a shell
  - Group 17 elements gain an electron to fill the shell
  - Group 1 elements gain an electron to fill the “s” orbital

Electron Affinities

1	2	13	14	15	16	17	18
H −72.8							He >0
Li −59.6	Be >0	B −26.7	C −121.8	N +7	O −141.0	F −328.0	Ne >0
Na −52.9	Mg >0	Al −42.5	Si −133.6	P −72	S −200.4	Cl −349.0	Ar >0
K −48.4	Ca −2.37	Ga −28.9	Ge −119.0	As −78	Se −195.0	Br −324.6	Kr >0
Rb −46.9	Sr −5.03	In −28.9	Sn −107.3	Sb −103.2	Te −190.2	I −295.2	Xe >0
Cs −45.5	Ba −13.95	Tl −19.2	Pb −35.1	Bi −91.2	Po −186	At −270	Rn >0

Magnetic Properties

- An atom will only respond significantly to a magnetic field if it has a magnetic field itself.
  - This means it must have an unpaired electron (or more)
- In a diamagnetic atom all electrons are paired and it is weakly repelled by a magnetic field e.g. Mg
- A paramagnetic atom has unpaired electron(s) and it is attracted by a magnetic field e.g. Na