The Periodic Table: Chapter 8

Noble gas (core electron)

Valence electrons

F: [He] $2s^2 2p^5$

P: [Ne] $3s^2 3p^3$

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

58 **Ce** $6s^24f^15d^1$	59 **Pr** $6s^24f^3$	60 **Nd** $6s^24f^4$	61 **Pm** $6s^24f^5$	62 **Sm** $6s^24f^6$	63 **Eu** $6s^24f^7$	64 **Gd** $6s^24f^75d^1$	65 **Tb** $6s^24f^9$	66 **Dy** $6s^24f^{10}$	67 **Ho** $6s^24f^{11}$	68 **Er** $6s^24f^{12}$	69 **Tm** $6s^24f^{13}$	70 **Yb** $6s^24f^{14}$	71 **Lu** $6s^24f^{14}5d^1$
90 **Th** $7s^26d^2$	91 **Pa** $7s^25f^26d^1$	92 **U** $7s^25f^36d^1$	93 **Np** $7s^25f^46d^1$	94 **Pu** $7s^25f^6$	95 **Am** $7s^25f^7$	96 **Cm** $7s^25f^76d^1$	97 **Bk** $7s^25f^9$	98 **Cf** $7s^25f^{10}$	99 **Es** $7s^25f^{11}$	100 **Fm** $7s^25f^{12}$	101 **Md** $7s^25f^{13}$	102 **No** $7s^25f^{14}$	103 **Lr** $7s^25f^{14}6d^1$

What Influences Atomic Size?

What factors determine the size of an atom?

Size of Atom Increases down A group

Size decreases

Size roughly constant

Size decreases

Size
ATOM

① location of the outermost electron (e^-) is the size of the atom. The Larger the n for the outermost e^- the Larger the atom.

② How much ⊕ force the outermost e^- experiences will affect the size atom

Effective Nuclear Charge

What factors determine how much positive charge or 'pull' an electron experiences?

① # of protons in nucleus, Z ← Atomic number

② distance from nucleus to outer most e^-

③ electron-electron repulsion

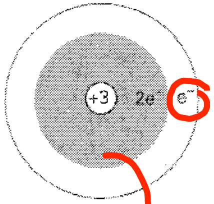
Define a term called *effective nuclear charge*, Z_{eff}, which in any given atom is the amount of nuclear charge or "pull" the outermost electron experiences.

$$Z_{eff} = Z - S$$

TOTAL # number protons

Screening or shielding (electron-electron repulsion)

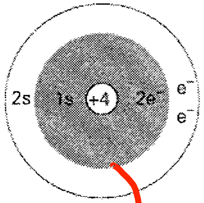
Effective Nuclear Charge: $Z_{eff} = \underline{Z} - \underline{S}$



$Z_{eff} = 3 - 2e \boxed{= +1}$

Li

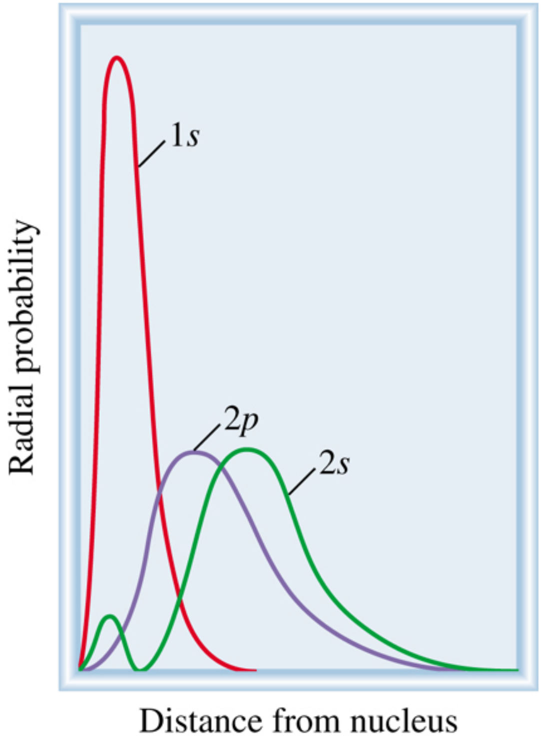
Li [He]2s¹



$Z_{eff} = Z - S$

$= 4 - 2e^-$

Be: [He]2s² $Z_{eff} = +2$

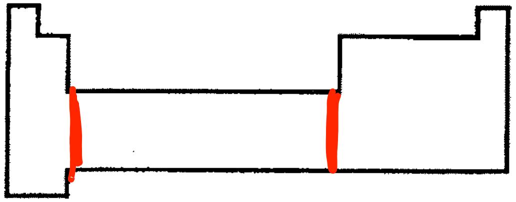


Periodic Trend:

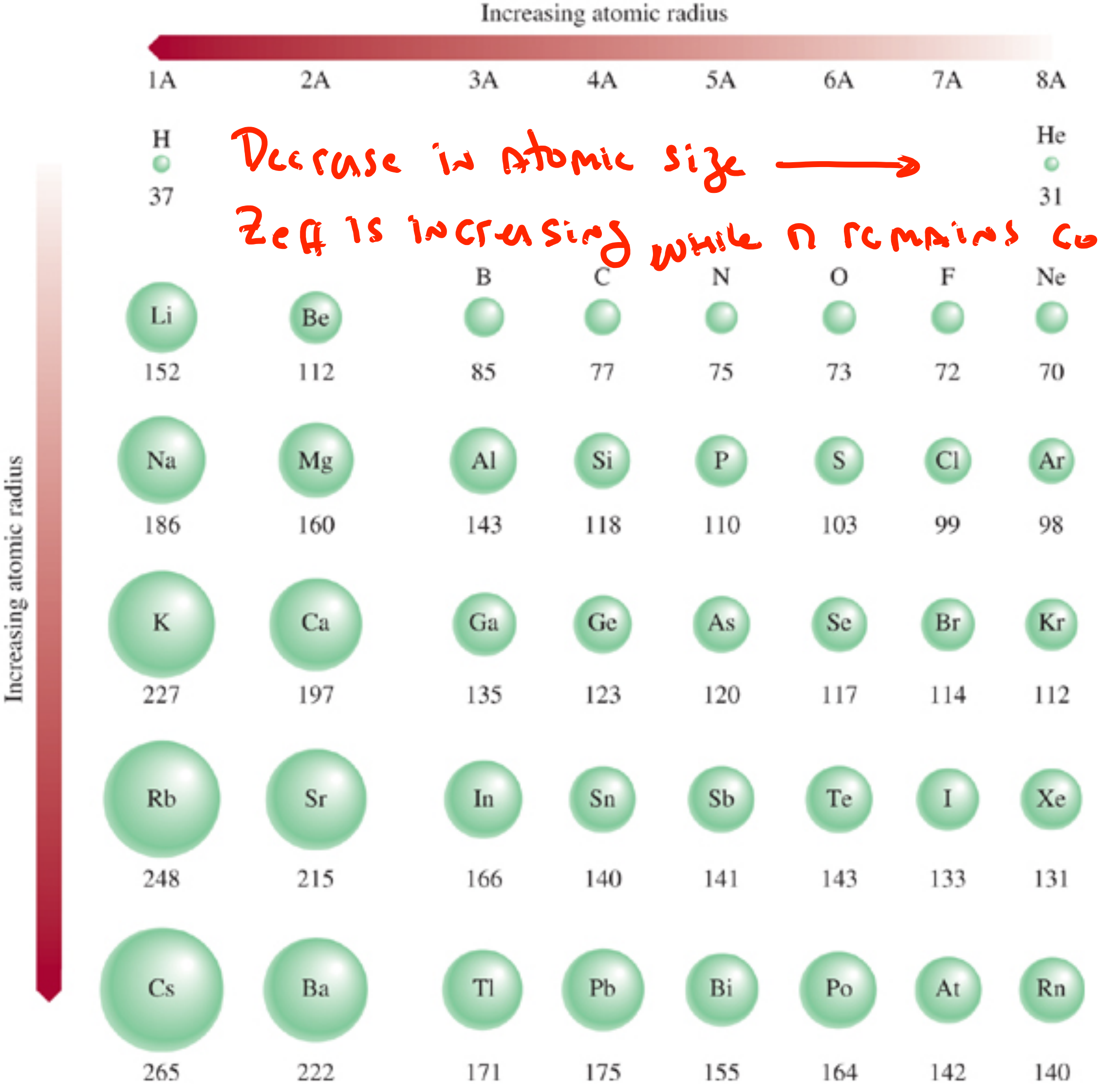
Zeff increases across a period

Zeff →

Zeff Increases →



Explaining the Periodic Trends in Atomic Size



Decrease in atomic size →

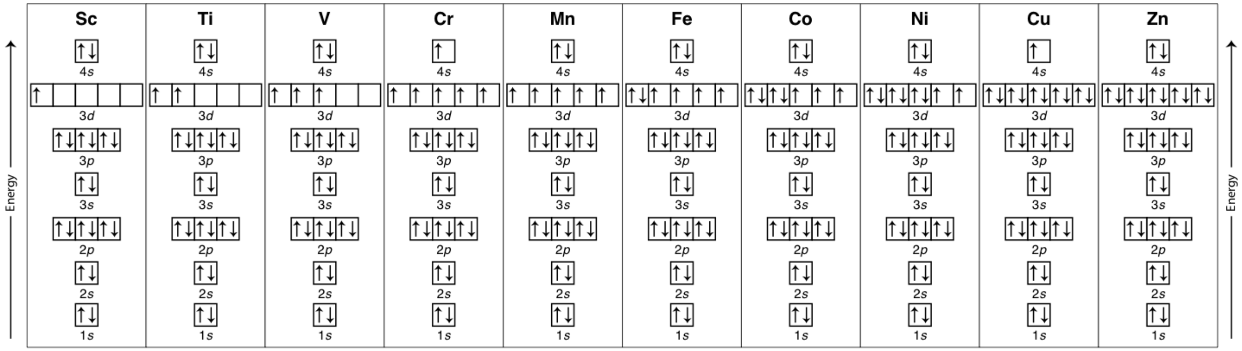
Z_{eff} is increasing while n remains constant

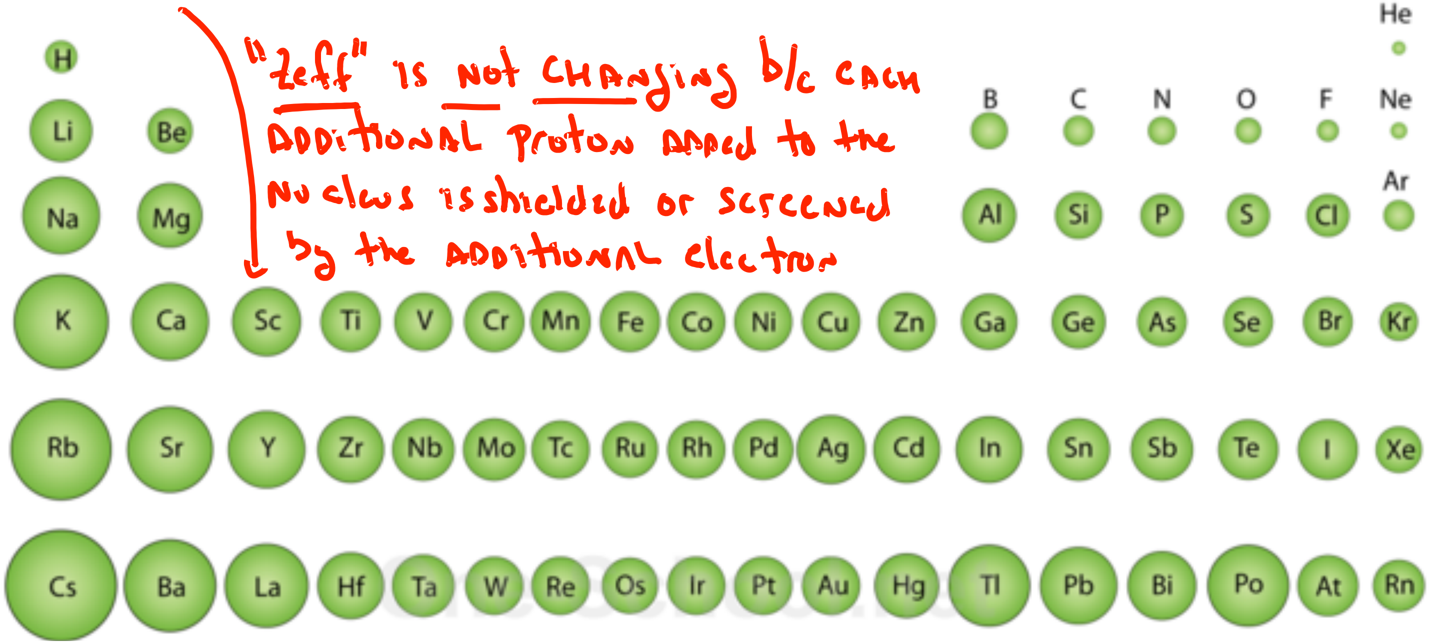
As we move down a group, n increases and so size also increases

What Influences Atomic Size?

What factors determine the size of an atom?

The size of an atom is the distance of the outermost electron to the nucleus. The location of that outermost electrons is determined by the net positive attractive forces of the nucleus, Zeff, and the principal quantum number of the outermost electron, n.

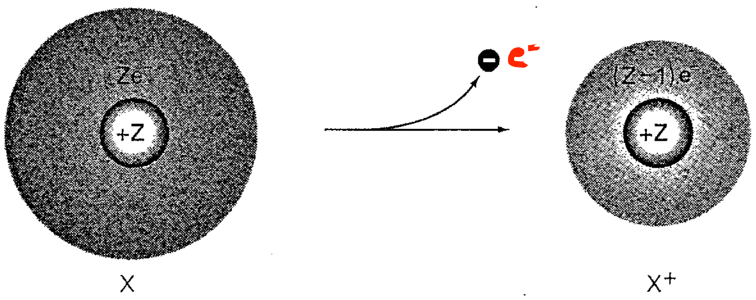




"Zeff" is not changing b/c each additional proton added to the nucleus is shielded or screened by the additional electron

Sizes of Ions

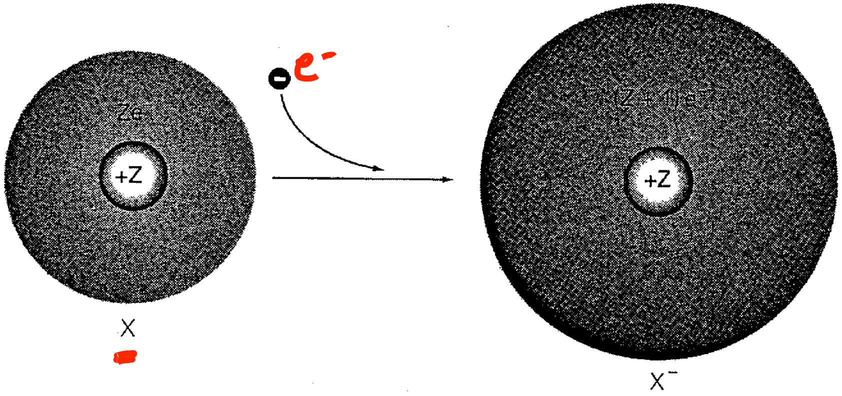
Cations:



Cation (+) is smaller than atom

- Zeff increases
  decreased $e^- - e^-$ repulsion
- removed an outermost e^-

Anions:



Anion (−) is larger than atom

- Zeff decrease, Increasing $e^- - e^-$ repulsion
- Added an outermost e^-

Rank the following according to increasing size Li$^+$, Li$^-$ and Li

$Li^+ < Li < Li^-$

Writing the Electron configuration of Ions

- We will use the electron configuration of the neutral atoms to write the electron configuration of the ions

Rules for writing electron configurations of ions:

Always begin by writing the electron configuration of the neutral atom.

For cations (positively charged ions)

- **When removing an electron** from an element always remove the electron from the orbital that has the highest n (principle quantum number)

- If there are two orbitals with the same highest principle quantum number then remove the electron from the orbital that is highest in energy. (lower energy) s<p<d<f (higher energy)

Fro anions (negatively charged ions)

- **When adding electrons** to an element always add the electrons to the available orbital that has the lowest n (principle quantum number).

- If there are two available vacant orbitals with the same lowest principle quantum number then add the electron to the orbital that is lowest in energy. (lower energy) s<p<d<f (higher energy)

Write the abbreviated electron configurations for:

Rh: $[Kr]\ 5s^2\ 4d^7$

Rh^{2+}: $(Kr)\ 4d^7$

P: $[Ne]\ 3s^2\ 3p^3$

P^{3-}: $[Ne]\ 3s^2\ 3p^6$

Know how to write the electron configuration for any element and how to write the electron configuration for any ion.

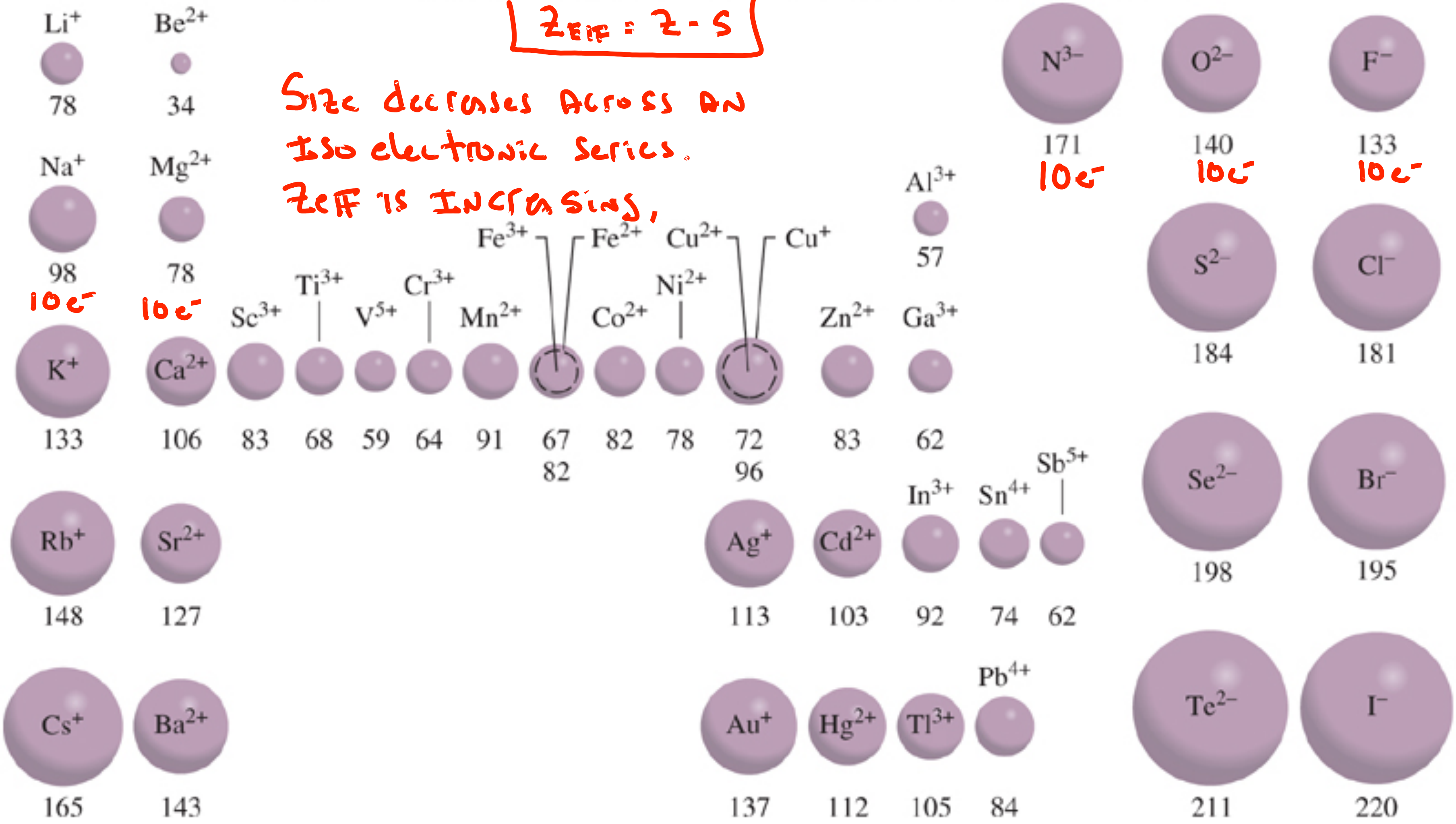
Fig. 8.8

Periodicity of Ionic Size

$\boxed{Z_{eff} = Z - S}$

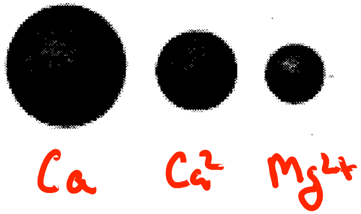
Size decreases across an Iso electronic series.

Zeff is increasing,



Questions

Consider the following spheres: Which represents Ca, Ca^{2+}, Mg^{2+}?



Arrange the following in order of increasing size Ca, Ti^{4+}, Sc^{3+}

18e⁻ 18e⁻

$\boxed{Ti^{4+} < Sc^{3+} < Ca}$

Provide and explain the following

Cl^- is larger than Cl : Adding anotha e⁻ to Cl, ↑ e⁻-e⁻ repulsion, ↓ Z_{eff}

(valence e⁻)

S^{2-} is larger than O^{2-} : outermost e⁻ in S are in a orbital with a larger principal quantum number.

Alkali Metal Reactions Revisited

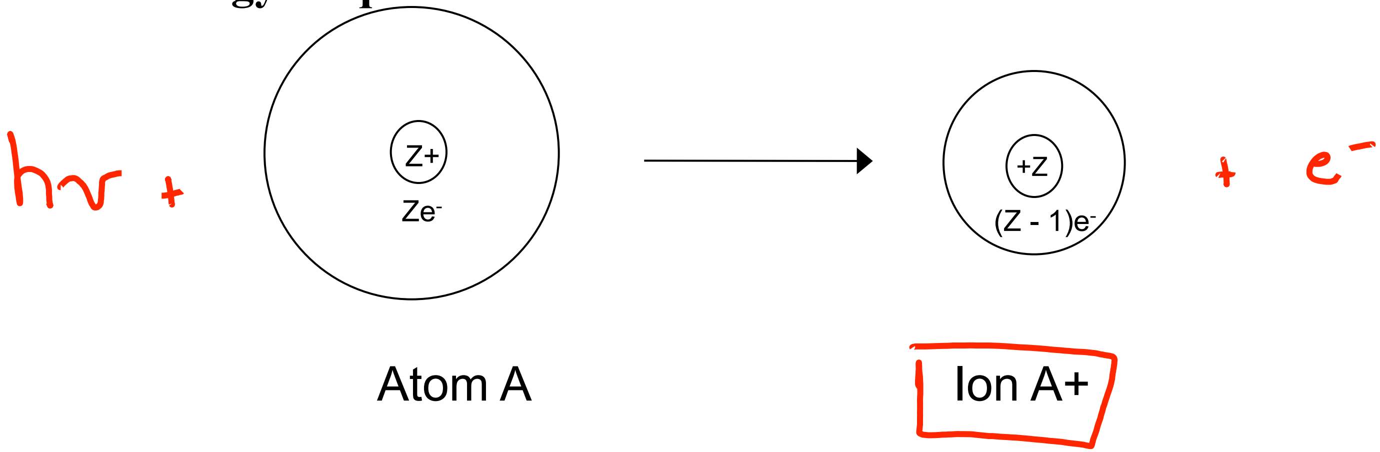
Reaction	How violent?
$\underset{0}{2Li} + 2H_2O$ ---> $\underset{+1}{2LiOH} + H_2$	Less reactive
$2Na + 2H_2O$ ---> $2NaOH + H_2$	↓
$2K + 2H_2O$ ---> $2KOH + H_2$	most reactive
$Ca + 2H_2O$ ---> $Ca(OH)_2 + H_2$	Not very reactive

What is oxidation state of Li, Na, K and Rb in products and reactants?

Taking e- out and putting them in is very important
to understand reactivity.

Ionization Energy:

Energy Required to Remove an Electron from an Atom or Ion



First Ionization Energy: Is the energy required to remove the outermost electron from a neutral atom or molecule that is in the gas phase

$h\nu + Na_{(g)} \rightarrow Na^{+}_{(g)} + e^{-}$

Ionization Energy (IE)

$IE_1 = 496 \text{ kJ/mole}$

Second Ionization Energy: Is the energy required to remove another electron from the singly positive ion that is in the gas phase

$h\nu + Na^{+}_{(g)} \rightarrow Na^{2+}_{(g)} + e^{-}$

$IE_2 = 4{,}650 \text{ kJ/mole}$

$Z_{eff}\ IE_2 > Z_{eff}\ IE_1$

Ionization Energies

$N_{(g)} \rightarrow N^+_{(g)} + e^-$

$[He]2s^2 2p^3 \rightarrow$

$[He]2s^2 2p^2$

1 1 1

2p 2p 2p

½ Filled subshell special stability requires extra energy to disrupt

IE increases across a period

Zeff ↑ across a period, n remains the same for the valence e^-.

So this requires more energy to remove an e^-

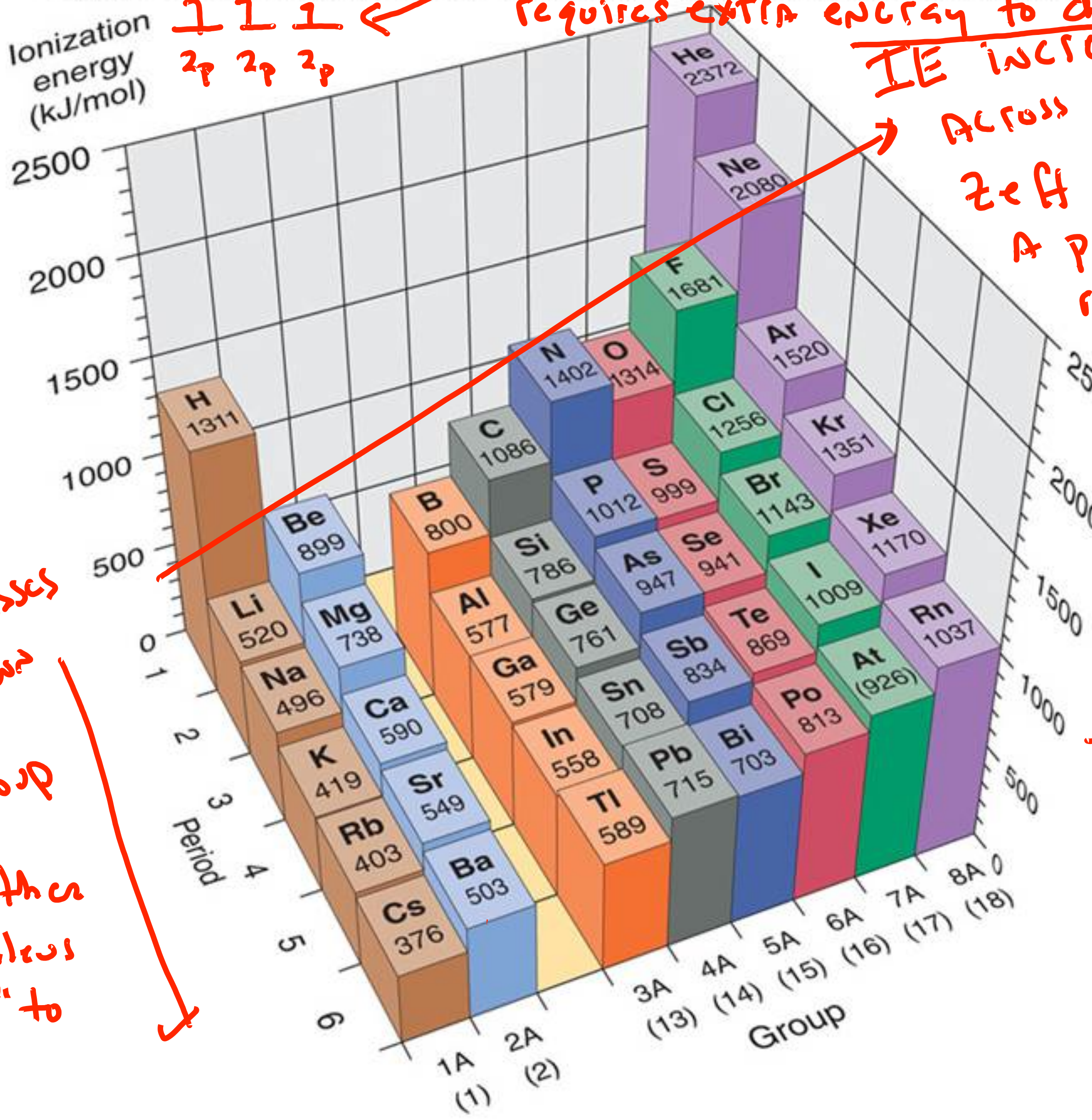
$O_{(g)} \rightarrow O^+_{(g)} + e^-$

$[He]2s^2 2p^4 \rightarrow$

$[He]2s^2 2p^3$

IE decreases down a group

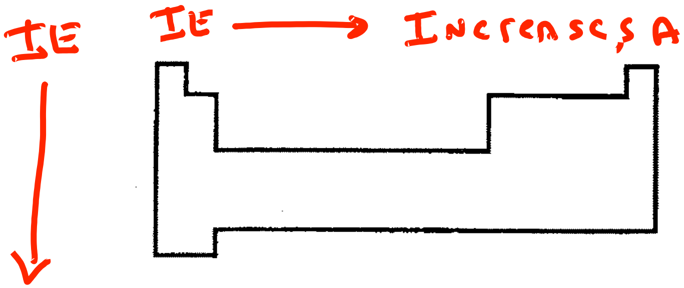
n Increasing down a group, these e^- are located farther away from Nucleus and are "easier" to remove.



http://www.uwec.edu/boulteje/Boulter103Notes/21October.ht

Ionization Energy

What is the trend?



IE → Increases Across A period

IE decreases down A group

Trends in Second Ionization Energies

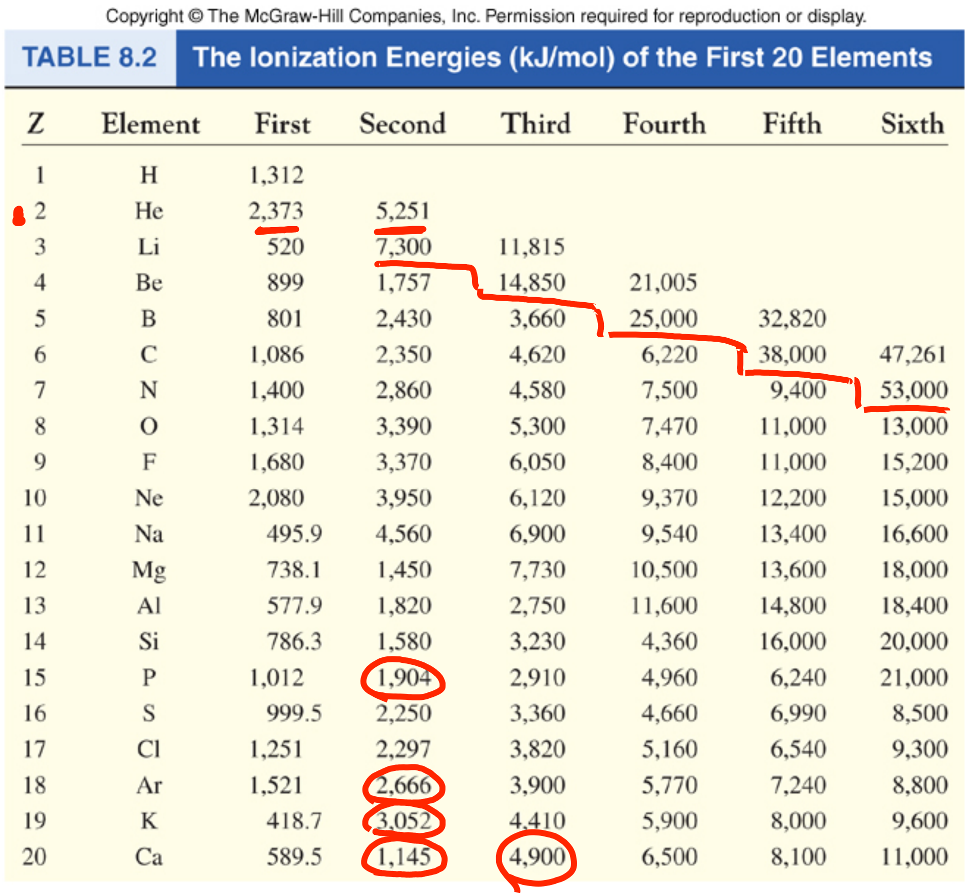


TABLE 8.2 The Ionization Energies (kJ/mol) of the First 20 Elements

Z	Element	First	Second	Third	Fourth	Fifth	Sixth
1	H	1,312					
2	He	2,373	5,251				
3	Li	520	7,300	11,815			
4	Be	899	1,757	14,850	21,005		
5	B	801	2,430	3,660	25,000	32,820	
6	C	1,086	2,350	4,620	6,220	38,000	47,261
7	N	1,400	2,860	4,580	7,500	9,400	53,000
8	O	1,314	3,390	5,300	7,470	11,000	13,000
9	F	1,680	3,370	6,050	8,400	11,000	15,200
10	Ne	2,080	3,950	6,120	9,370	12,200	15,000
11	Na	495.9	4,560	6,900	9,540	13,400	16,600
12	Mg	738.1	1,450	7,730	10,500	13,600	18,000
13	Al	577.9	1,820	2,750	11,600	14,800	18,400
14	Si	786.3	1,580	3,230	4,360	16,000	20,000
15	P	1,012	1,904	2,910	4,960	6,240	21,000
16	S	999.5	2,250	3,360	4,660	6,990	8,500
17	Cl	1,251	2,297	3,820	5,160	6,540	9,300
18	Ar	1,521	2,666	3,900	5,770	7,240	8,800
19	K	418.7	3,052	4,410	5,900	8,000	9,600
20	Ca	589.5	1,145	4,900	6,500	8,100	11,000

$K \rightarrow K^+$ IE_1

$[Ar]4s^1$ $[Ar]$

$K^+ \rightarrow K^{2+}$ IE_2

$[Ar] \rightarrow$ disrupt Noble gas

$Ca \rightarrow Ca^+ + e^-$ $IE_1 = 589.5$

$[Ar]4s^2 \rightarrow [Ar]4s^1$

$Ca^+ \rightarrow Ca^{2+} + e^-$ $IE_2 = 1,145$ KJ/mole

$[Ar]4s^1 \rightarrow [Ar]$

$Ca^{2+} \rightarrow Ca^{3+} + e^-$ $IE_3 = 4,900$

$[Ar] \rightarrow$ disrupting core electrons in Noble gas Config. requires A lot of energy

Ionization Energy: Periodic Trends and Exceptions

1. In general: Increases across row and up a group.

2. But there are exceptions: Consider Be (IE=899 KJ/mol) vs B (IE=801 KJ/mol), why are these the reverse of what we expect?

$$Be_{(g)} \rightarrow Be^{+}_{(g)} + e^{-}$$

$$[He]2s^{2} \rightarrow$$

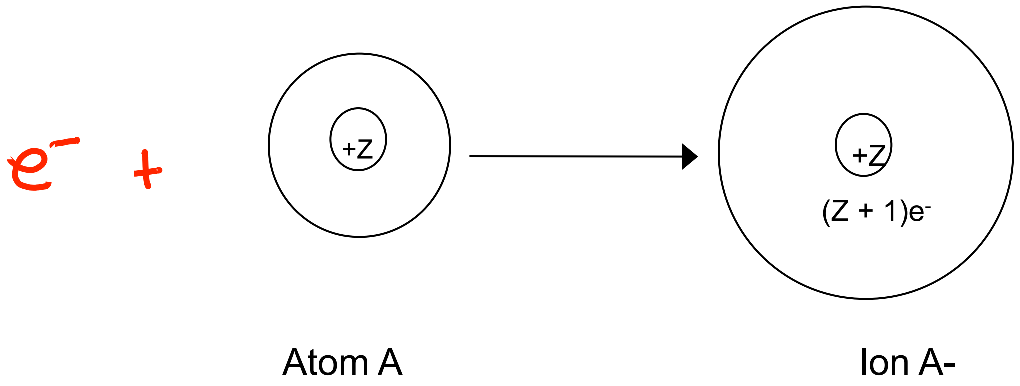
$$B_{(g)} \rightarrow B^{+}_{(g)} + e^{-}$$

$$[He]2s^{2}2p^{1} \rightarrow$$

Higher energy electron in the p orbital requires less energy to remove than the 2s electron in Be

Electron Affinity:

Energy Released or Required to Add an Electron to an Atom, Ion or Molecule



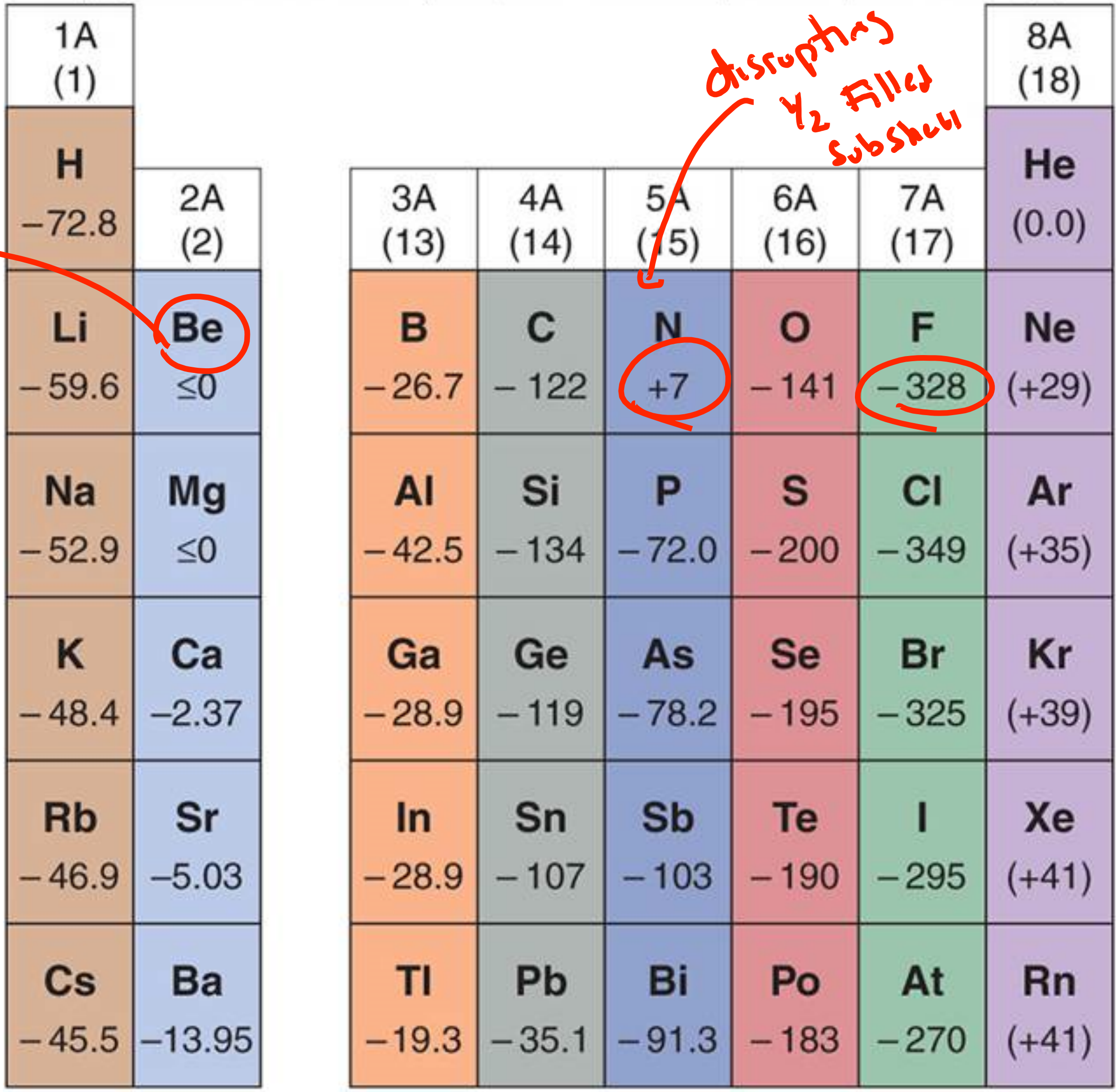
Electron Affinity: is the energy changed when a gaseous atom or molecule gains an electron to form an gaseous ion

$F_{(g)} + e^- \rightarrow F^-_{(g)}$ $\Delta E = -328$ kJ/mole

$[He]2s^2 2p^5 \rightarrow [He]2s^2 2p^6$ or $[Ne]$

$OH_{(g)} + e^- \rightarrow OH^-_{(g)}$

Electron Affinity Used in Chemistry E-1a



1A (1)	2A (2)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
H −72.8							**He** (0.0)
Li −59.6	**Be** ≤0	**B** −26.7	**C** −122	**N** +7	**O** −141	**F** −328	**Ne** (+29)
Na −52.9	**Mg** ≤0	**Al** −42.5	**Si** −134	**P** −72.0	**S** −200	**Cl** −349	**Ar** (+35)
K −48.4	**Ca** −2.37	**Ga** −28.9	**Ge** −119	**As** −78.2	**Se** −195	**Br** −325	**Kr** (+39)
Rb −46.9	**Sr** −5.03	**In** −28.9	**Sn** −107	**Sb** −103	**Te** −190	**I** −295	**Xe** (+41)
Cs −45.5	**Ba** −13.95	**Tl** −19.3	**Pb** −35.1	**Bi** −91.3	**Po** −183	**At** −270	**Rn** (+41)

disrupting ½ filled subshell

ADD An e^- to A New Subshell

http://www.uwec.edu/boulteje/Boulter103Notes/21October.htm

Electron Affinity in Textbook: opposite sign!

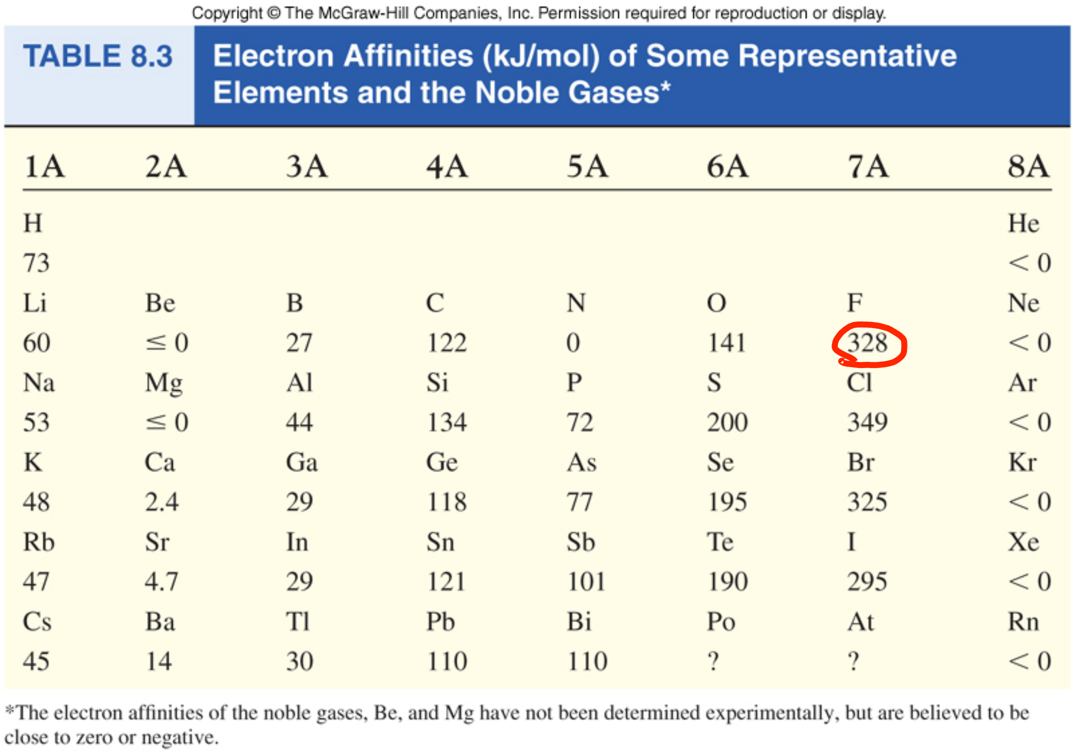


TABLE 8.3 **Electron Affinities (kJ/mol) of Some Representative Elements and the Noble Gases***

1A	2A	3A	4A	5A	6A	7A	8A
H							He
73							< 0
Li	Be	B	C	N	O	F	Ne
60	≤ 0	27	122	0	141	328	< 0
Na	Mg	Al	Si	P	S	Cl	Ar
53	≤ 0	44	134	72	200	349	< 0
K	Ca	Ga	Ge	As	Se	Br	Kr
48	2.4	29	118	77	195	325	< 0
Rb	Sr	In	Sn	Sb	Te	I	Xe
47	4.7	29	121	101	190	295	< 0
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
45	14	30	110	110	?	?	< 0

*The electron affinities of the noble gases, Be, and Mg have not been determined experimentally, but are believed to be close to zero or negative.

$$\boxed{h\nu + F^-_{(g)} \rightarrow e^- + F_{(g)} \quad \Delta E = -EA}$$

Special Stability Situations

Case I: removing an e^- from a higher energy subshell

this requires less energy to remove than the 2s in Be

Be ([He] $2s^2$) ----> Be^+[He] $2s^1$ + e^- $\Delta E = +899$ kJ/mol

B ([He]$2s^22p^1$)----> B^+[He]$2s^2$ + e^- $\Delta E = +801$ kJ/mol

Case II: ½ Filled subshell imparts special stability

N ([He]$2s^22p^3$)----> N^+[He]$2s^22p^2$+ e^- $\Delta E = +1402$ kJ/mol

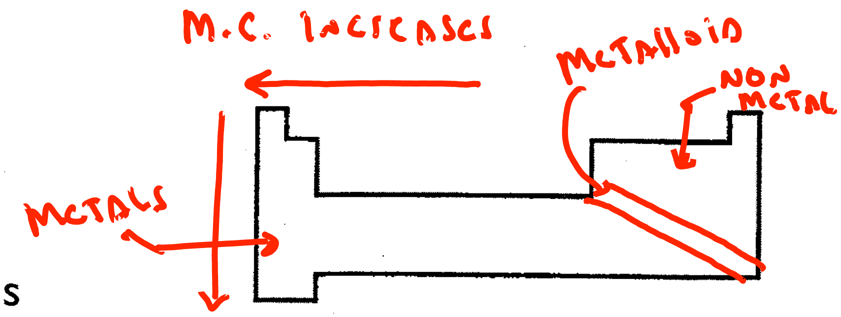
O ([He]$2s^22p^4$)----> O^+[He]$2s^22p^3$ + e^- $\Delta E = +1314$ kJ/mol

Case III: Noble Gas configuration

Cl([Ne]$3s^23p^5$) + e- ----> Cl^- ([Ne]$3s^23p^6$) $\Delta E = \underline{-349}$ kJ/mol

Ar ([Ne]$3s^23p^6$) + e- ----> Ar^- ([Ne]$3s^23p^64s^1$) $\Delta E = + \underline{\text{VBN}}$ kJ/mol

Metals, Nonmetals, and Metalloids



What kinds of elements are metals?

(M.C.)

- Metal character refers to the properties of metals

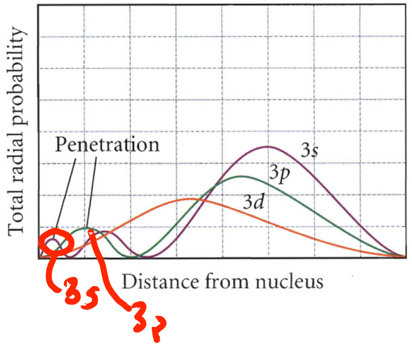
① Shiny
② conduct
heat
electricity
③ malleability
④ Solids
⑤ ductile

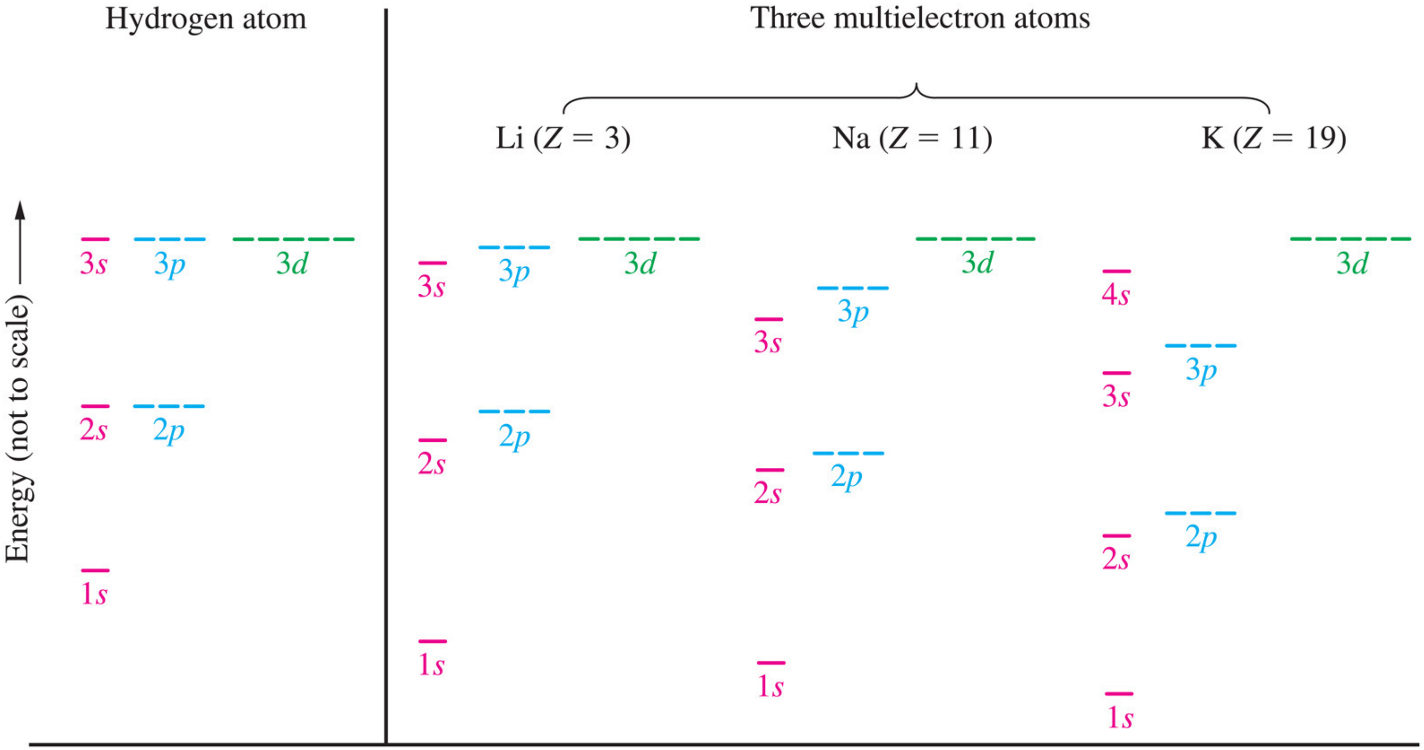
- (Metal character increases down a group, metal character decreases across a period.)

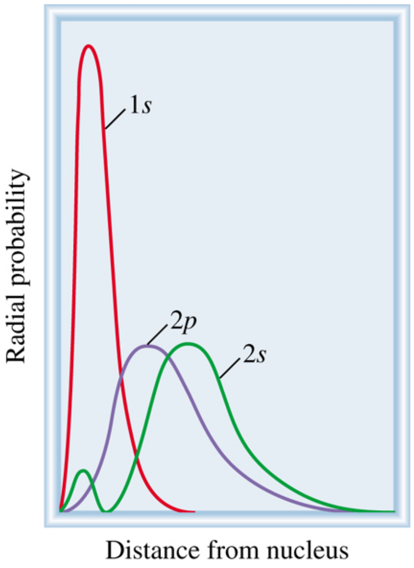
- What is a non-metal and a metalloid?

Multi-electron Atoms

- In multi-electron atoms, orbitals with same ***n*** but different ***l*** have ***different*** energy.







$$\mathcal{E} = -R_h \frac{1}{n^2}$$

$$\boxed{\mathcal{E} = -R_h \frac{Z_{eff}^2}{n^2}}$$

Increase Zeff, more negative energy is lower

Increase n, Less negative energy is higher

Ionization Energy for Many Electron Atoms

We learned that we can use the Rydberg equation to calculate the energies of electrons in hydrogen atoms. We can use a modification of this equation for atoms with more than 1 electron. This equation is:

$$\boxed{\Delta E = \underline{2.18 \text{ X}}\ 10^{-18}\text{J } Z_{eff}^{2}\ (1/n_i^{2} - 1/n_f^{2})}$$

Where ΔE is the first ionization energy of an electron in an atom. Use this equation to calculate the Z_{eff} for Li.

$Li \rightarrow Li$

$IE_{Li} = 520\ kJ/mole$ $[He]2s^1 \rightarrow [He]$

$$\frac{520\ kJ}{mole} \times \frac{1\ mole}{6.02 \times 10^{23}\ atoms} = 8.69 \times 10^{-19}\ J/atom$$

$$\boxed{\Delta E = Rh \cdot Zeff^2 \cdot \left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)}$$

$$\frac{Li \cdot atom}{}$$

$n_i = 2$

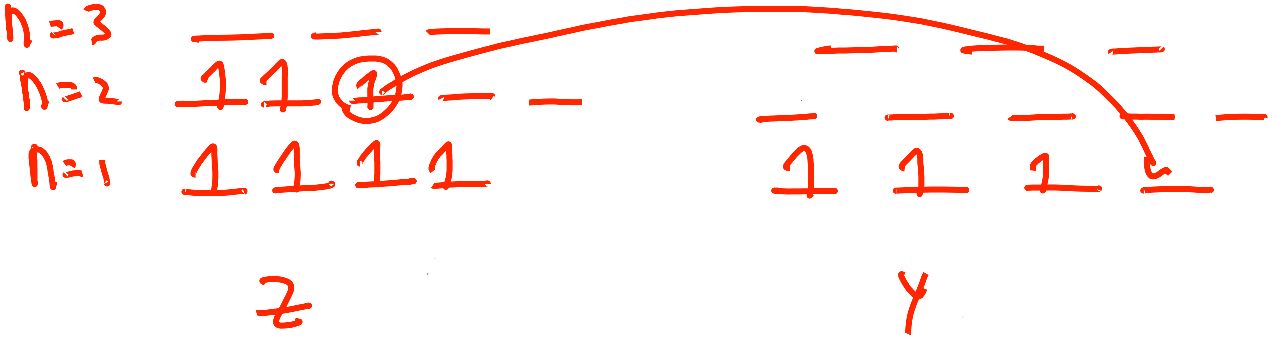
$n_f = \infty$

$$8.69 \times 10^{-19}\ J = 2.18 \times 10^{-18}\ J \cdot Zeff^2 \cdot \left(\frac{1}{2^2} - \cancel{\frac{1}{\infty^2}}^{\,0}\right)$$

$$\boxed{1.26 = Zeff}$$

Different World Periodic Table

You land on a distant planet in another universe and find that the n=1 level can hold a Maximum of 4 electrons, the n=2 level can hold a maximum of 5 electrons, and the n = 3 level can hold a maximum of 3 electrons. Like our universe, protons have a charge of +1, and electrons have a charge of -1, and opposite charges attract. Also, a filled shell results in greater stability of an atom, so the atom tends to gain or lose electrons to give a filled shell. Predict the formula of a compound that results from the reaction of a neutral metal atom Z, which has 7 electrons, and a neutral atom Y, which has three electrons.



Y^{1-}

Z^{3+}

Y^{1-}

Y^{1-}

$\boxed{ZY_3}$