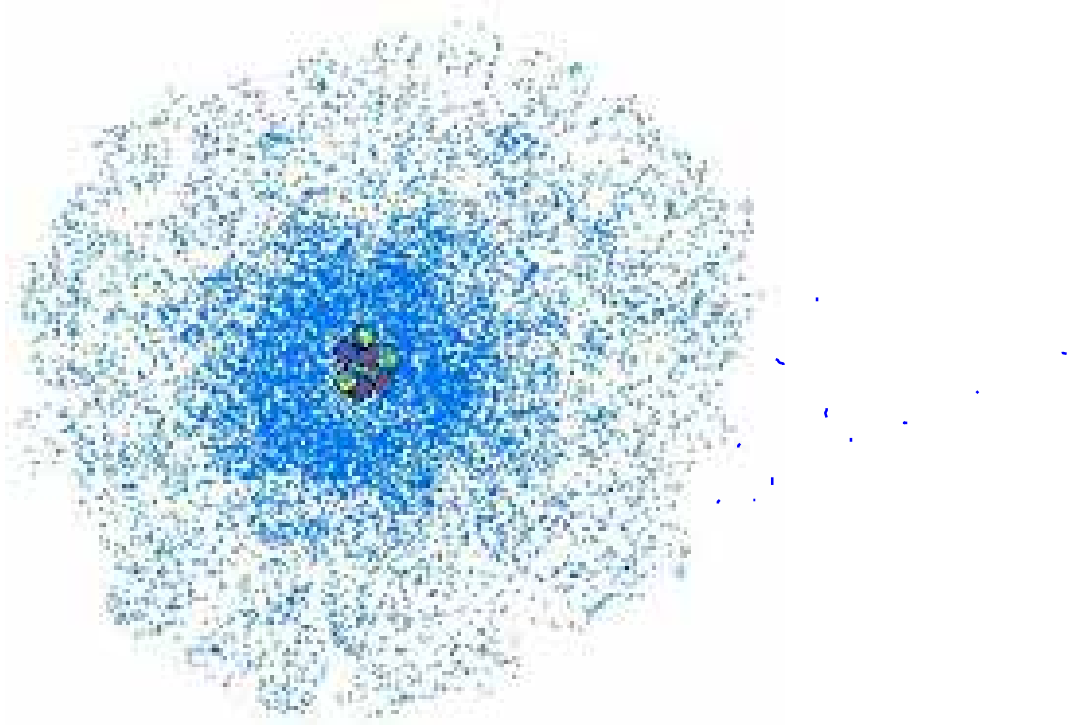
Periodic Trends in Atomic Radii & Ionization Energy

Outcome:

Identify and account for periodic trends among the properties of elements, and relate to electron configuration. *Include: atomic radii, ionic radii, ionization energy, electronegativity*

Atomic Radius

We have seen before that the electron orbitals are more like a **FUZZY CLOUD** (region of **PROBABILITY**) where an electron may be found:

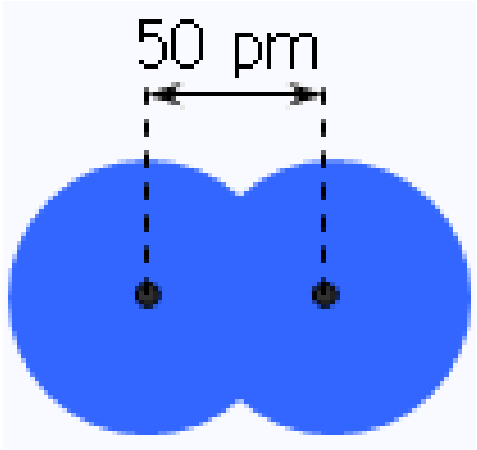


http://physics.stackexchange.com/questions/15097/what-is-the-shape-of-atomic-subatomic-particles

Since the border of the atom is **FUZZY**, Chemists had to devise a way of measuring the size of an atom…

Atomic Radius

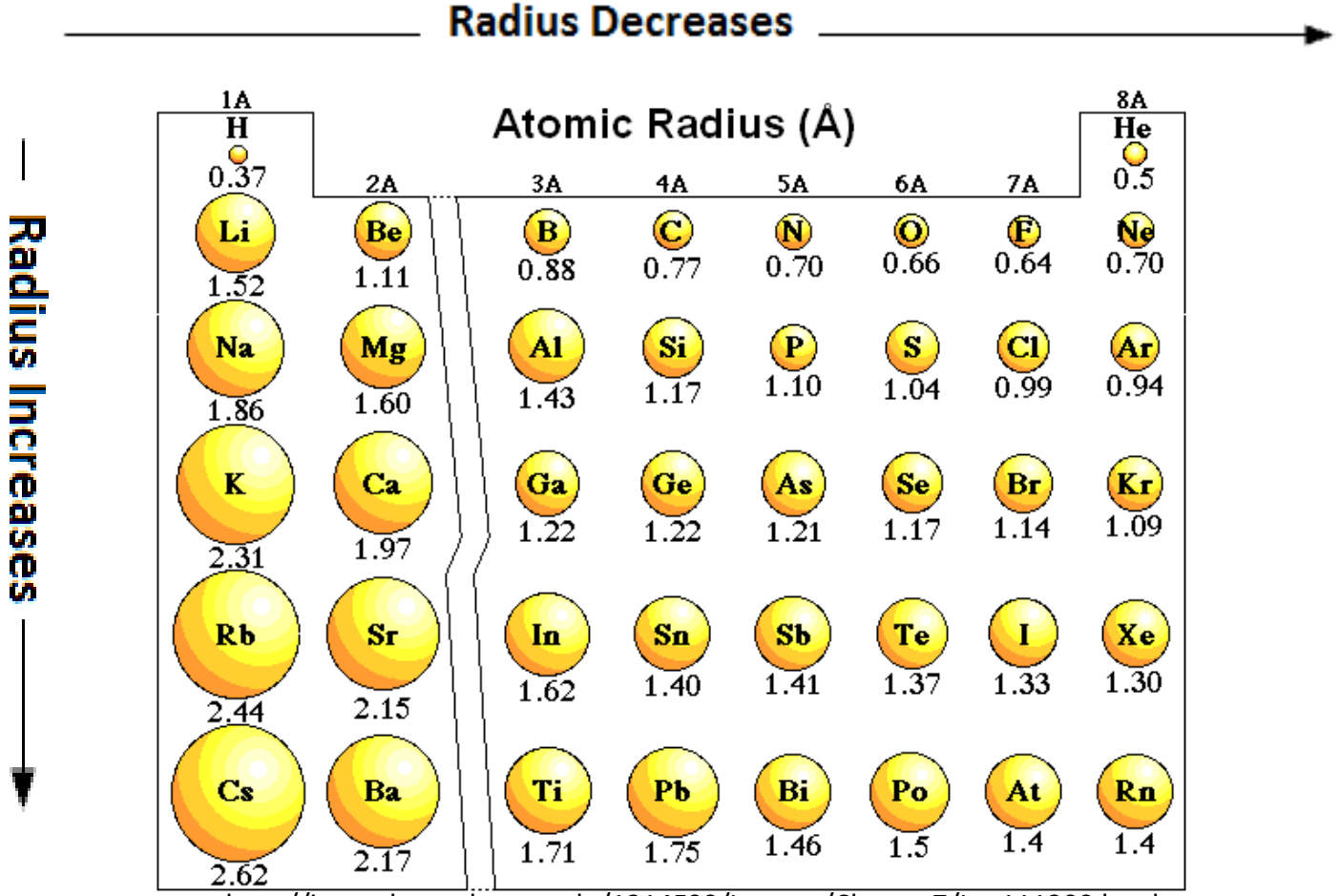
When two **LIKE** atoms are bonded together, the distance between their **NUCLEI** is used to determine the atomic **RADIUS**:



- In the example above, the distance between the nuclei is **50pm** (***1pm = 10^{-12}m***), so the **RADIUS OF 1 ATOM** is **25pm**.
- Atomic radius is measured in **pm, nm (10^{-9}m)** or **ANGSTROMS** (**Å**) (***1Å = 10^{-10}m***)
- There are many different ways to measure the distance between nuclei, and depending on the method, you may achieve different results.

Atomic Radius

The accepted values are as follows:



http://intro.chem.okstate.edu/1314F00/Lecture/Chapter7/Lec111300.html

What trends do you notice? Label them on the table.

Forces on an Electron

You would think that logically, as the number of protons and electrons increases, so would the size of the atom.

We can see this is not true from the values above. Why?

→ Because of the **FORCES** acting on electrons in their **CLOUDS**

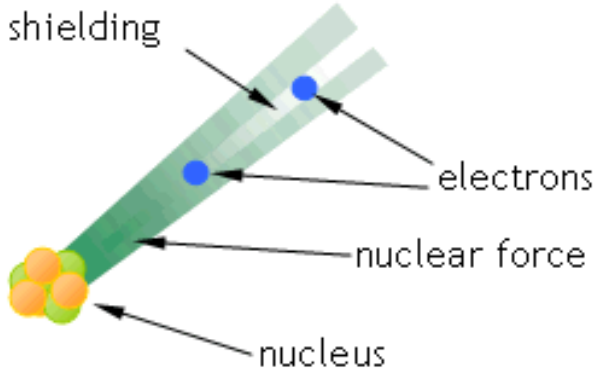
The force on an electron depends on its **POSITION** in the atom as well as the following three factors:

1. **The Nuclear Charge**
   - The more **PROTONS** in the nucleus, the greater the **NUCLEAR CHARGE**.
   - This means a **STRONGER PULL** on electrons **INWARD**.

Forces on an Electron

2. **Distance from the Nucleus**
   - The **FARTHER** from the nucleus an electron is, the **LESS FORCE** there will be acting upon it.
   - Think of two **MAGNETS** close together and far apart.

3. **The Shielding Effect**
   - **INNER ELECTRONS** tend to **SCREEN** or **SHIELD** the **FORCE** of the nucleus on the outer electrons.



http://slideplayer.com/slide/5663158/

   - The inner electrons almost cast a **SHADOW** on the outer electrons.
   - The **EFFECTIVE** nuclear charge on outer electrons is **LOWER** as more **ORBITALS** are **ADDED** to an atom.

Trends in Atomic Radii

1. **Group/Family Trends** (Down a column)

"Atomic radii generally increase as you move down a group."

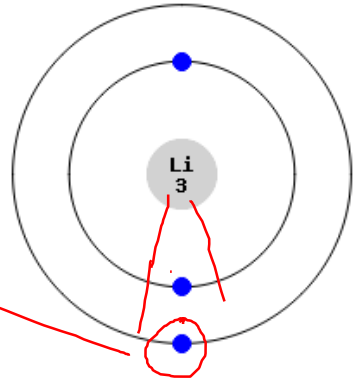
- As you move down a group, a **NEW ENERGY LEVEL** is added for every atom in that group.
- With each new energy level, **ELECTRONS** get **FARTHER** from the nucleus **REDUCING** the **FORCE** of the nucleus on the outermost electrons.
- Every new energy level **INCREASES SHIELDING** on the outermost electrons, resulting in a **LOWER EFFECTIVE** nuclear **FORCE**.
- The **LOWER FORCE** on the outermost electrons allows them to move **FURTHER** from the nucleus, producing a **LARGER** atomic **RADIUS**.

Trends in Atomic Radii

1. **Group/Family Trends** (Down a column)

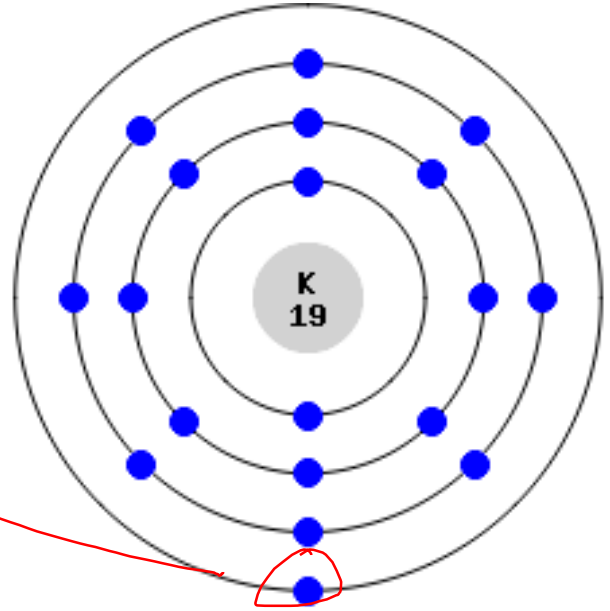
Lithium:

force of 3p+,
shielded by 2e-
only 2 energy levels away



Potassium:

force of 19 p+
shielded by 18 e-
is 4 energy levels away
(Jonathan)



Trends in Atomic Radii

2. **Periodic Trends** (across the row)

*"**Atomic radii generally decrease as you go across a period.**"*

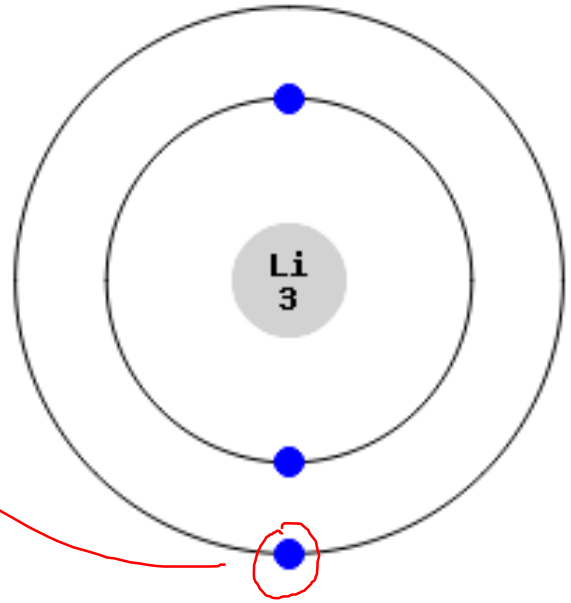
- As you go across the row, **ELECTRONS** are **ADDED** to the same **ENERGY LEVEL**.
- These added electrons all get the **SAME** amount of **SHIELDING** from the **INCREASINGLY POSITIVE** nucleus.
- There is **MORE NUCLEAR CHARGE** pulling on each electron, causing the **RADIUS** to **DECREASE**.

Trends in Atomic Radii

2. **Periodic Trends** (across a row)

Lithium:

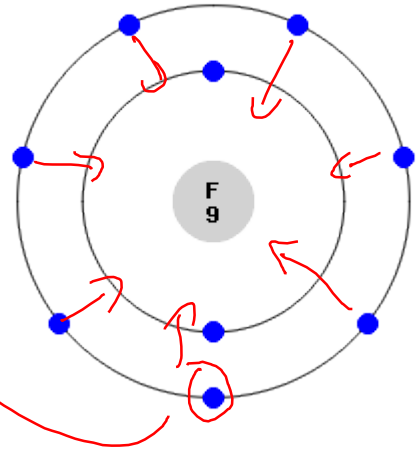
- force of $3p^+$
- shielded by $2e^-$
- in 2nd energy level (low nuclear force)



Fluorine:

- force of $9p^+$
- shielded $2e^-$
- still in 2nd energy level

strong net force ∴ smaller



Ionic Radii

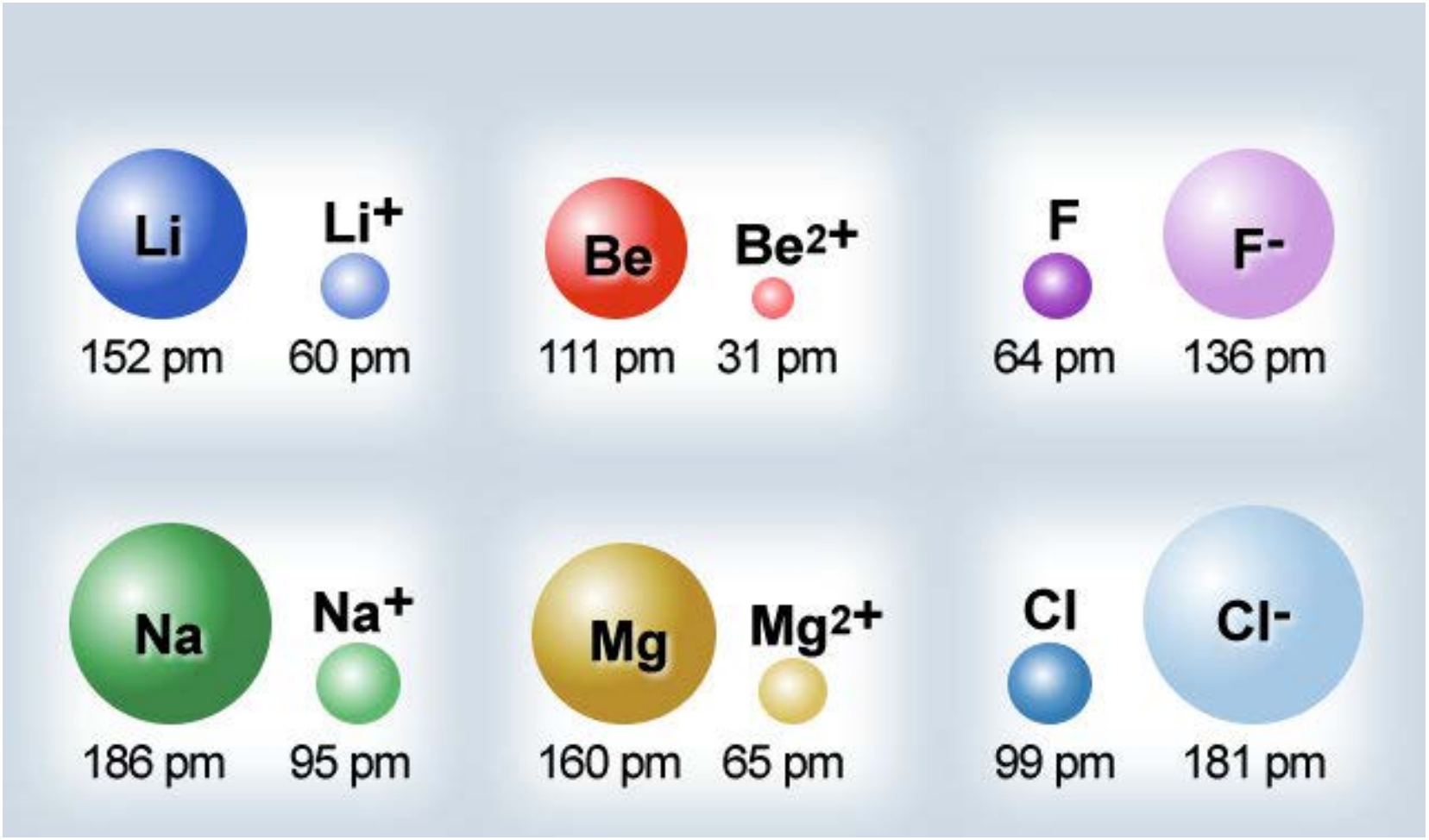
Negative Ions:

- Electrons have been **ADDED** to the atom, and it gets **LARGER**.
- The more electrons that are added to an atom, the **LOWER** the **FORCE** (more **SHIELDING**) of the nucleus on each electron.
- There is also a **GREATER FORCE OF REPULSION** of electrons.

Positive Ions:

- Electrons have been **REMOVED** and it gets **SMALLER**.
- A lost valence electron may result in an **EMPTY ORBITAL**
- There is now **MORE THAN ONE PROTON FOR EVERY ELECTRON** in the ion, so the **FORCE** pulling on each electron is **INCREASED**.

Ionic Radii


Li
Li+
152 pm
60 pm
Be
Be2+
111 pm
31 pm
F
F-
64 pm
136 pm
Na
Na+
186 pm
95 pm
Mg
Mg2+
160 pm
65 pm
Cl
Cl-
99 pm
181 pm

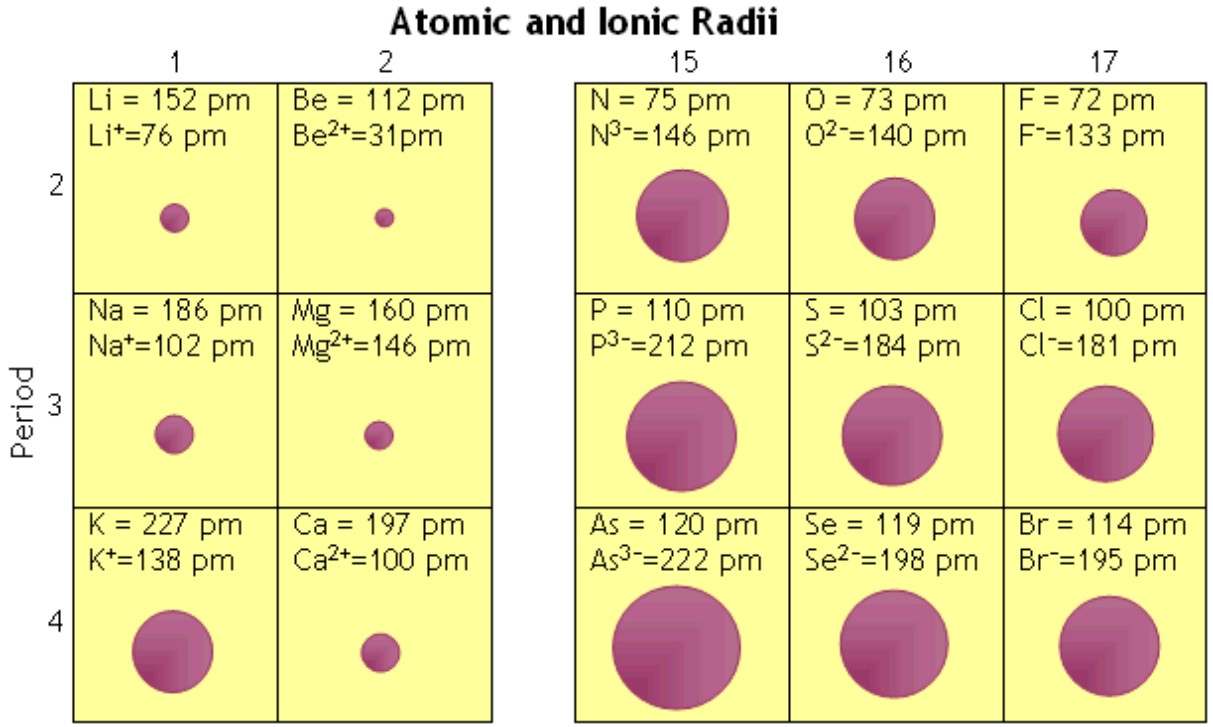
Trends in Ionic Radii

1. **Group/Family Trends** (Down a column)

"Ionic radii generally increase as you move down a group."

2. **Periodic Trends** (across the row)

"***Ionic radii generally decrease as you go across a period, except during the transition from metals to non-metals"***



Ionization Energy

Ionization energy is the amount of energy required to **REMOVE** an **ELECTRON** from an atom in the **GAS** state.

$$A_{(g)} + IE \rightarrow A^{+}_{(g)} + 1e^{-}$$

Shows the **STRENGTH** of **HOLD** on electrons by the **NUCLEUS**

→ **LOW IE** = **WEAK HOLD** on electrons

→ **HIGH IE** = **STRONG HOLD** on electrons

Atoms with **HIGH IE'S** will **NOT** likely **LOSE** electrons to form a **POSITIVE** ion.

Trends in Ionization Energy

1. **Group/Family Trends** (Down a column)

"Ionization energies decrease as you move down a group"

- The increase in **ATOMIC SIZE** means the **VALENCE** electrons are **FARTHER** out, and have **LESS FORCE** acting on them.
- This is due to the **INCREASED DISTANCE** from the nucleus and the **INCREASED SHIELDING** by the inner electrons.

2. **Periodic Trends** (across the row)

"As you move across a period, the ionization energy generally increases"

- Going across the period, the **SHIELDING REMAINS CONSTANT**, but the **NUCLEAR FORCE INCREASES** (more **PROTONS**)
- This **INCREASES THE ENERGY REQUIRED** to remove an electron.

Successive Ionization Energies

The **FIRST** ionization energy is removing **ONE** electron, the **SECOND** ionization energy is removing a **SECOND** electron from the 1+ ion,

$$A^{+}_{(g)} \rightarrow A^{2+} + 1e^{-}$$

The **THIRD** ionization energy removes a **THIRD** electron from the 2+ ion, and so on.

The tables refer to first (IE1), second (IE2), third (IE3), etc. ionization energies.

Look at the tables to see if you can find any patterns…

Successive Ionization Energies

Ionization Energies of the First 20 Elements			
Element	Ionization Energy (kJ/mol)		
	First	Second	Third
H	1312		
He	2372	5247	
Li	520	7297	11 810
Be	899	1757	14 840
B	801	2430	3659
C	1086	2352	4619
N	1402	2857	4577
O	1314	3391	5301
F	1681	3375	6045
Ne	2080	3963	6276
Na	496	4565	6912
Mg	738	1450	7732
Al	578	1816	2744
Si	786	1577	3229
P	1012	1896	2910
S	999	2260	3380
Cl	1256	2297	3850
Ar	1520	2665	3947
K	419	3069	4600
Ca	590	1146	4941

Successive Ionization Energies

Ionization Energies of Period 3 Elements							
Element	Ionization Energy (kJ/mol)						
	IE1	IE2	IE3	IE4	IE5	IE6	IE7
Na	495	4560	6912	9543	13 354	16 613	20 177
Mg	735	1445	7730	10 540	13 630	18 020	21 711
Al	580	1815	2740	11 600	14 842	18 379	23 326
Si	780	1575	3220	4350	16 100	19 805	23 780
P	1060	1890	2905	4950	6270	21 200	25 430
S	1005	2260	3375	4565	6950	8490	27 000
Cl	1255	2295	3850	5160	6560	9360	11 000
Ar	1527	2665	3945	5770	7230	8780	12 000

Successive Ionization Energies

"Ionization energy tends to increase with each successive electron removed."

- Each time you remove an electron, the resulting **POSITIVE CHARGE** will **BIND** the other electrons **MORE STRONGLY**.

Ionization Energies of a Noble Gas Configuration

"Removing an electron from a noble gas electron configuration causes the ionization energy to increase considerably."

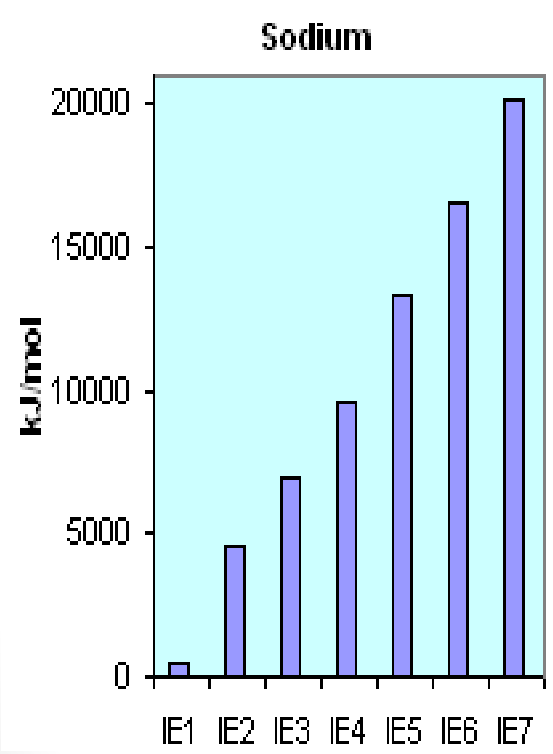
- The **BOLD LINES** in the tables represent **NOBLE GAS** structures.
- Atoms try to **LOSE**/**GAIN** to get a full **ENERGY LEVEL**

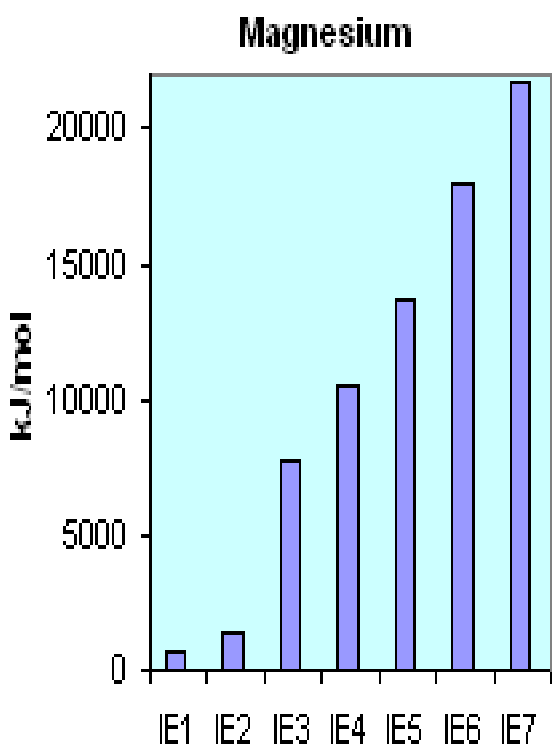
  → most **STABLE** state.
- It takes significantly **MORE ENERGY** to remove an electron from this **STABLE STATE**!

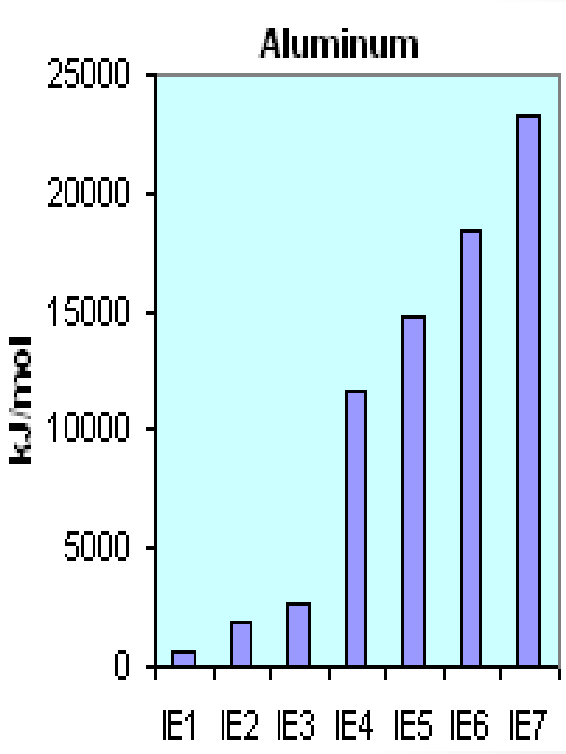
Successive Ionization Energies

Example:

Notice the jump in IE to make sodium lose a second electron, magnesium lose a third electron and aluminum lose a fourth electron:







Finally...Everything all Together!