Trends in the Periodic Table…
…revisited!

SCH4U1
SP04

Factors Affecting the Properties

- Many of the properties of the elements are related to the **force of attraction** between the nucleus and the electrons.

- The force of attraction is dependent on 2 factors… distance and charge.

Coulomb's Law

Coulomb's law quantifies the electrostatic attraction between charged particles:

$$F = k\frac{q_1 q_2}{r^2}$$

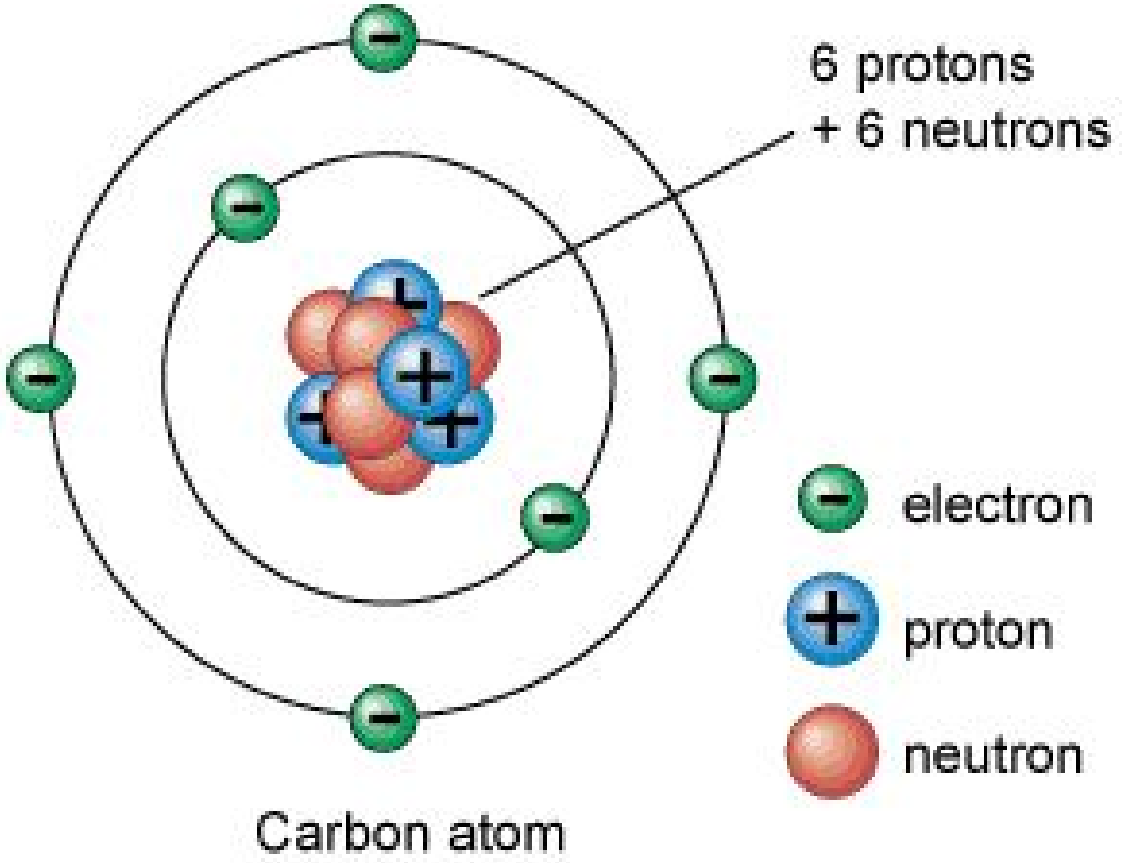
F is the force of attraction between opposite charges.

q_1 is the charge of the nucleus (# protons).

q_2 is the charge on the electron

r is the distance from the nucleus to the electron.

Consider the Bohr Model:



Factor 1: The distance between the nucleus and the outer electrons

- As the distance between the nucleus and the valence electrons increases, the attraction decreases. This means that electrons in higher energy levels have a weaker attraction to the nucleus.

Factor 2: The number of protons in the nucleus (the nuclear charge)

- As the nuclear charge increases, the force of attraction for the nucleus increases.

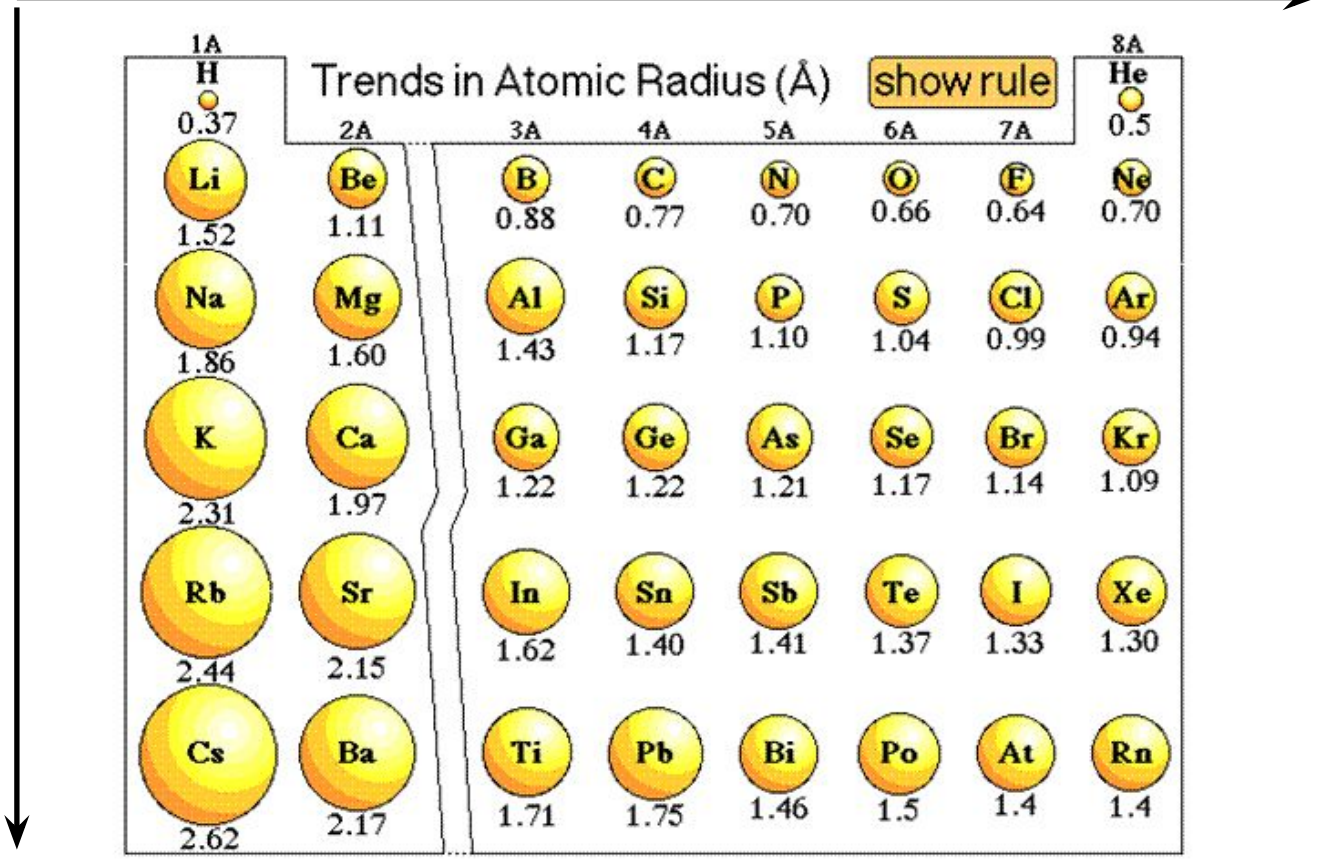
Trends in Atomic Radius

Across a Period:
Greater nuclear charge pulls electrons closer to the nucleus.

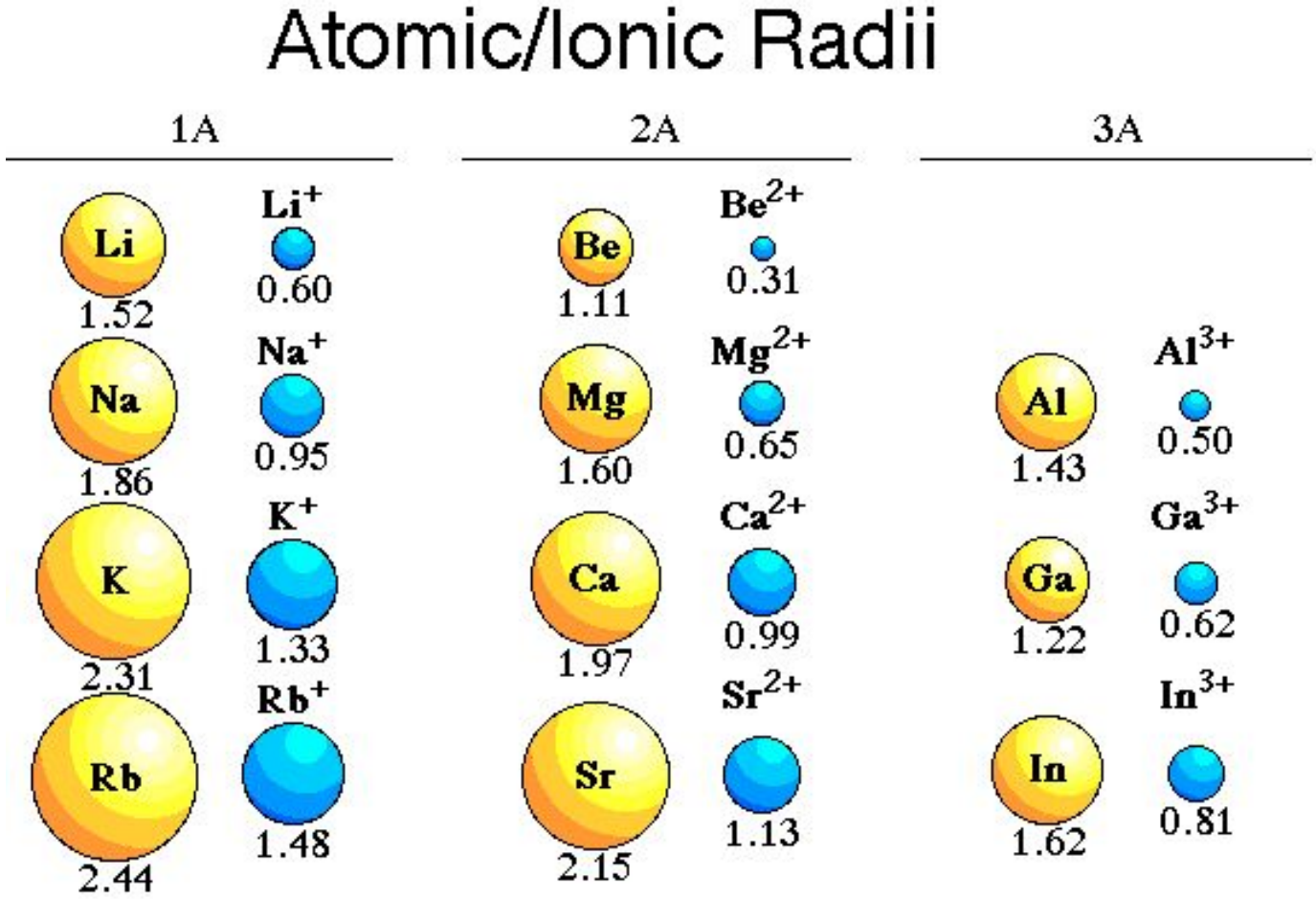
∴ Radius *decreases*

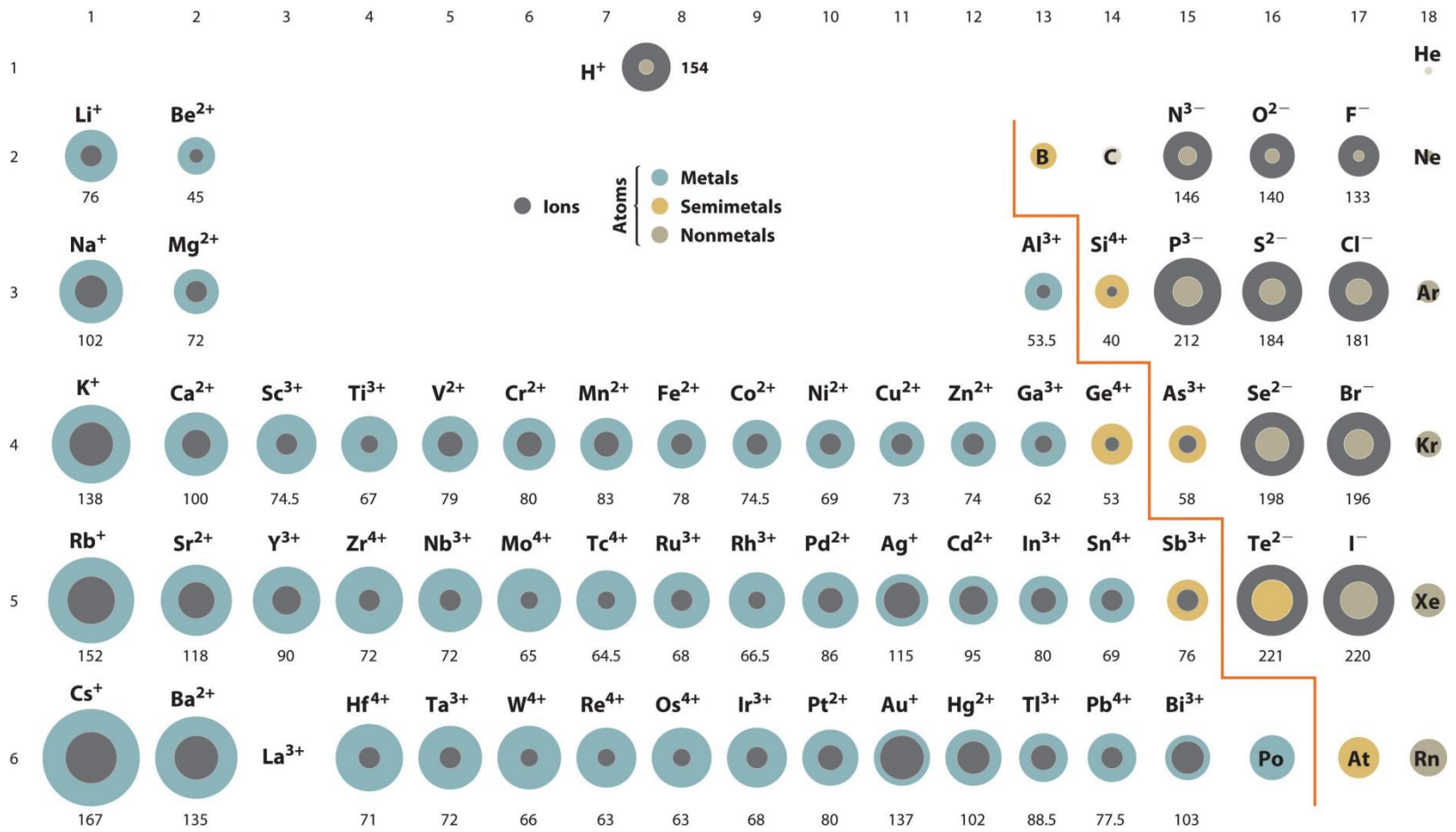
Down a Group:
Electrons in higher energy orbitals are further from the nucleus.

∴ Radius *increases*



Atomic Radii of Stable Metals




1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
H+ 154
He
Li+ 76
Be2+ 45
N3− 146
O2− 140
F− 133
B
C
Ne
Ions
Atoms
Metals
Semimetals
Nonmetals
Na+ 102
Mg2+ 72
Al3+ 53.5
Si4+ 40
P3− 212
S2− 184
Cl− 181
Ar
K+ 138
Ca2+ 100
Sc3+ 74.5
Ti3+ 67
V2+ 79
Cr2+ 80
Mn2+ 83
Fe2+ 78
Co2+ 74.5
Ni2+ 69
Cu2+ 73
Zn2+ 74
Ga3+ 62
Ge4+ 53
As3+ 58
Se2− 198
Br− 196
Kr
Rb+ 152
Sr2+ 118
Y3+ 90
Zr4+ 72
Nb3+ 72
Mo4+ 65
Tc4+ 64.5
Ru3+ 68
Rh3+ 66.5
Pd2+ 86
Ag+ 115
Cd2+ 95
In3+ 80
Sn4+ 69
Sb3+ 76
Te2− 221
I− 220
Xe
Cs+ 167
Ba2+ 135
La3+
Hf4+ 71
Ta3+ 72
W4+ 66
Re4+ 63
Os4+ 63
Ir3+ 68
Pt2+ 80
Au+ 137
Hg2+ 102
Tl3+ 88.5
Pb4+ 77.5
Bi3+ 103
Po
At
Rn

Ionization Energy

- Ionization energy is the energy required to remove one electron from an atom in the gas state.

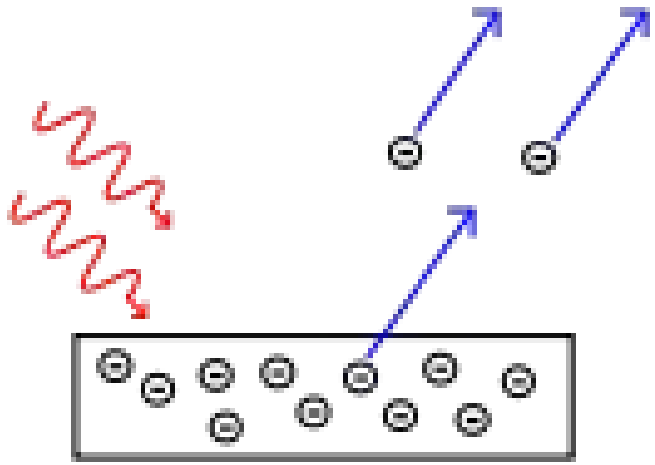
- **First Ionization Energy** is the energy to remove the electron furthest from the nucleus.

FIRST IONIZATION (IE_1)

$$A + \text{energy} \rightarrow A^+ + e^-$$

Photoelectric Effect

- Electrons will be ejected from a metal surface only when their energy (E = hv) exceeds a certain threshold (IE_1)



Further Ionization Energies

SECOND IONIZATION (IE_2)

$$A^+ + \text{energy} \rightarrow A^{2+} + e^-$$

THIRD IONIZATION ENERGY (IE_3)

$$A^{2+} + \text{energy} \rightarrow A^{3+} + e^-$$

Etc.!

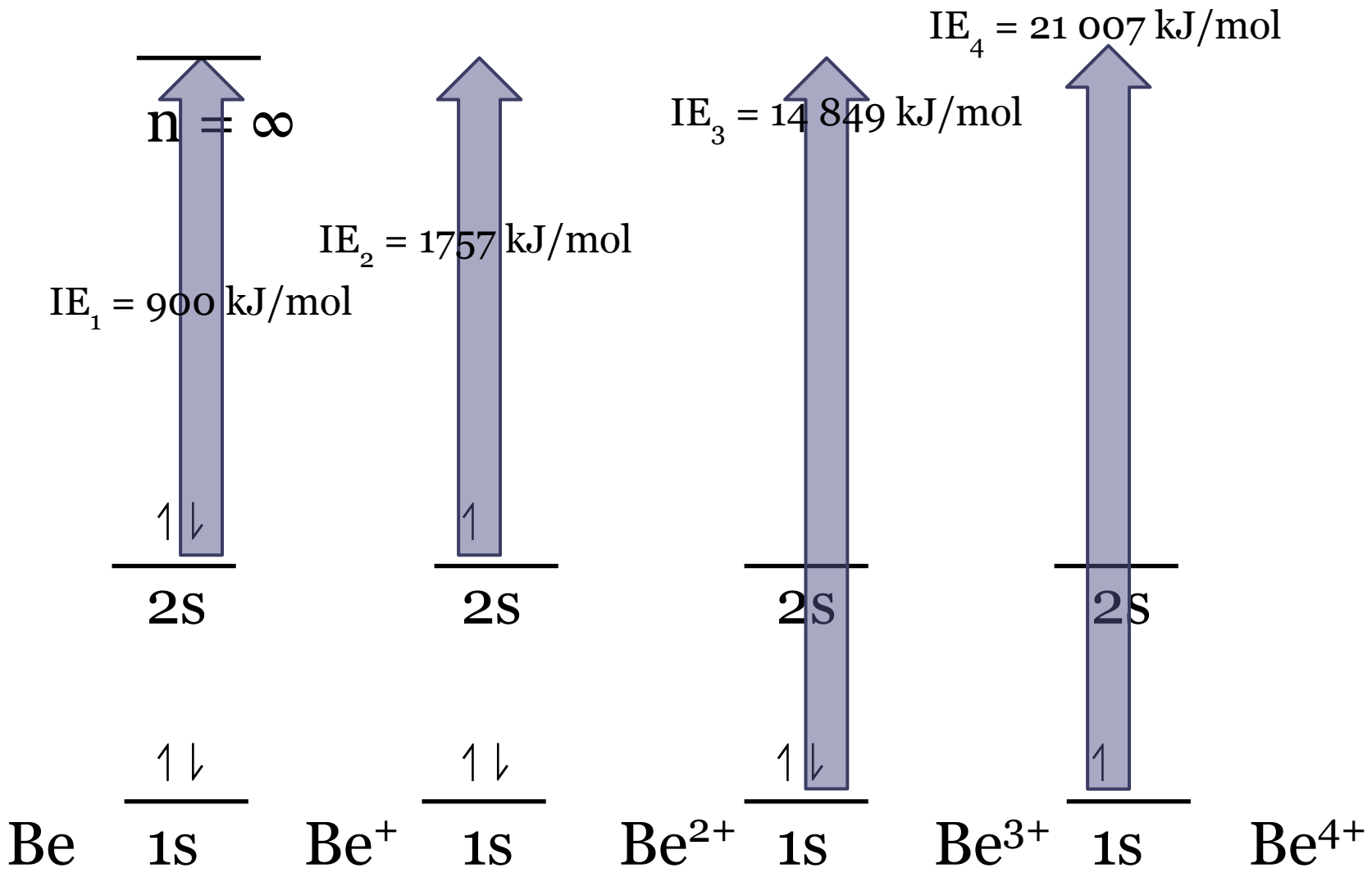
Ionization Energies of Beryllium

Be ($1s^2 2s^2$) has four ionization energies.

- $1s^2\ 2s^2 \xrightarrow{IE_1} 1s^2\ 2s^1 \xrightarrow{IE_2} 1s^2 \xrightarrow{IE_3} 1s^1 \xrightarrow{IE_4} \text{no } e^-$

  $Be \qquad Be^+ \qquad Be^{2+} \qquad Be^{3+} \qquad Be^{4+}$

How do the IE_x values relate to the properties of this element?


IE4 = 21 007 kJ/mol
n = ∞
IE3 = 14 849 kJ/mol
IE2 = 1757 kJ/mol
IE1 = 900 kJ/mol
2s
2s
2s
2s
1s
1s
1s
1s
Be
Be+
Be2+
Be3+
Be4+

IE and Ionic Charge

- As each electron is removed, the net positive charge increases and it becomes more difficult to remove electrons. Ionization energy increases:

$$IE_1 < IE_2 < IE_3 < IE_4$$

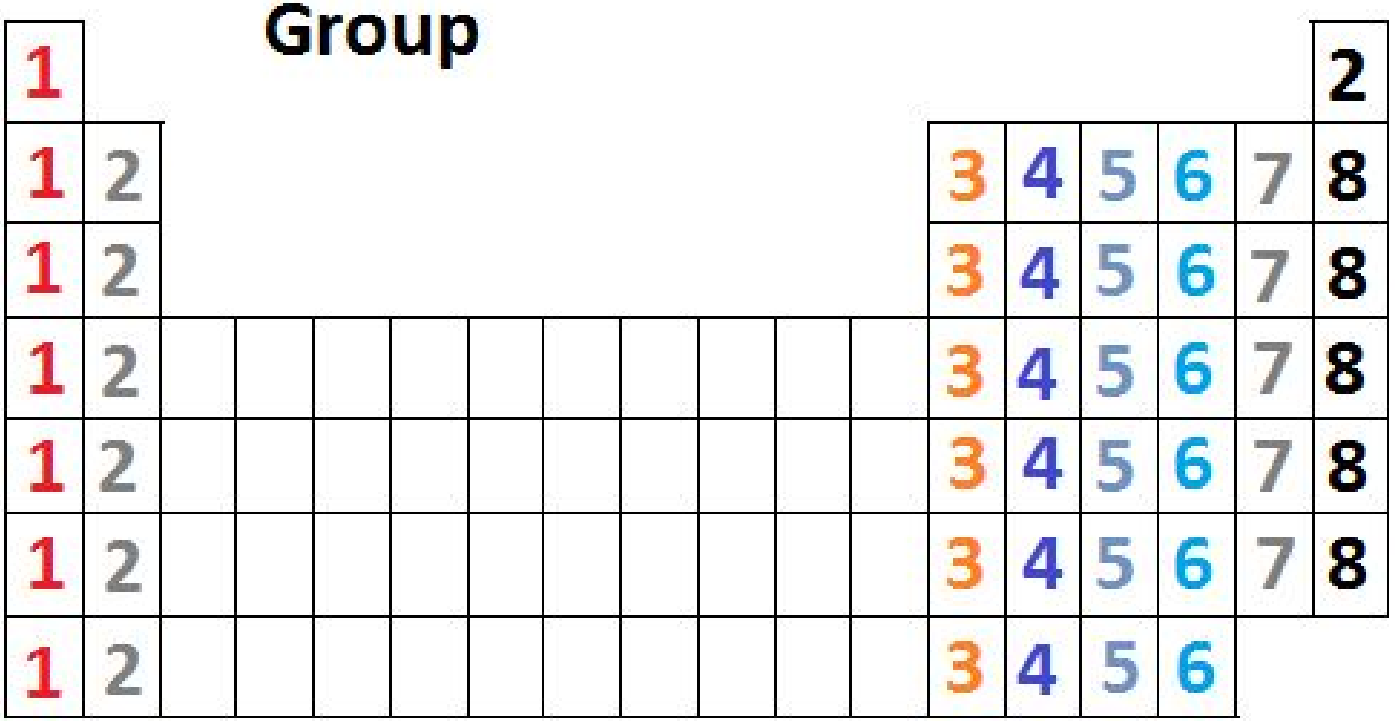
IE and Ionic Charge

- Ionization energies of valence electrons from the same energy level have the same order of magnitude, but IE increases 10-fold when electrons are removed from the 1s orbital:

$$IE_1 < IE_2 <<<<< IE_3 < IE_4$$

- Therefore the stable ionic charge of beryllium is due to fact that two electrons can easily be removed.

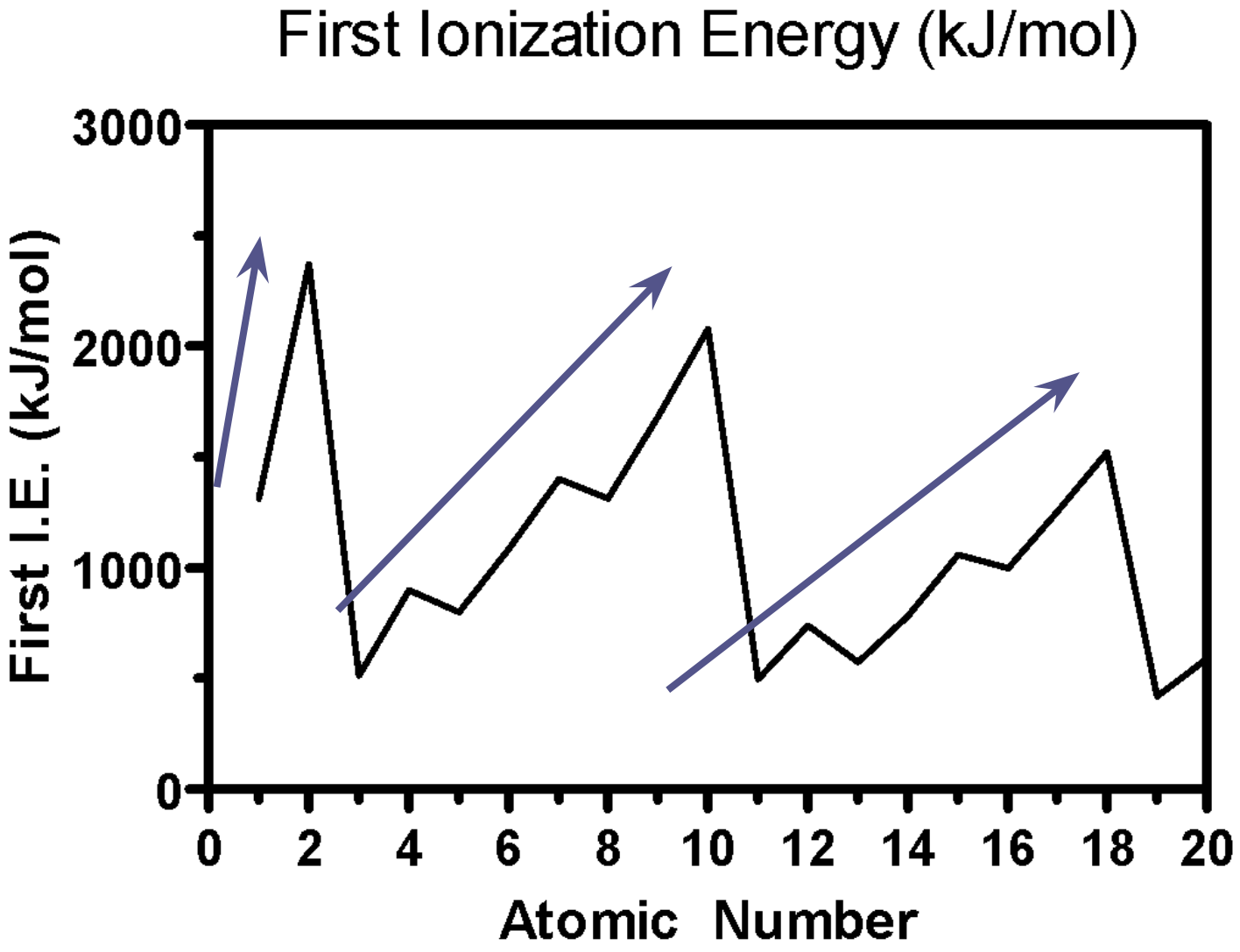
Valence Electrons in Each Group



Trends in the First Ionization Energy

1) Across the Period (Row): Ionization energy increases as the number of protons increases. Electrons are bound more tightly and more energy is required to remove them.

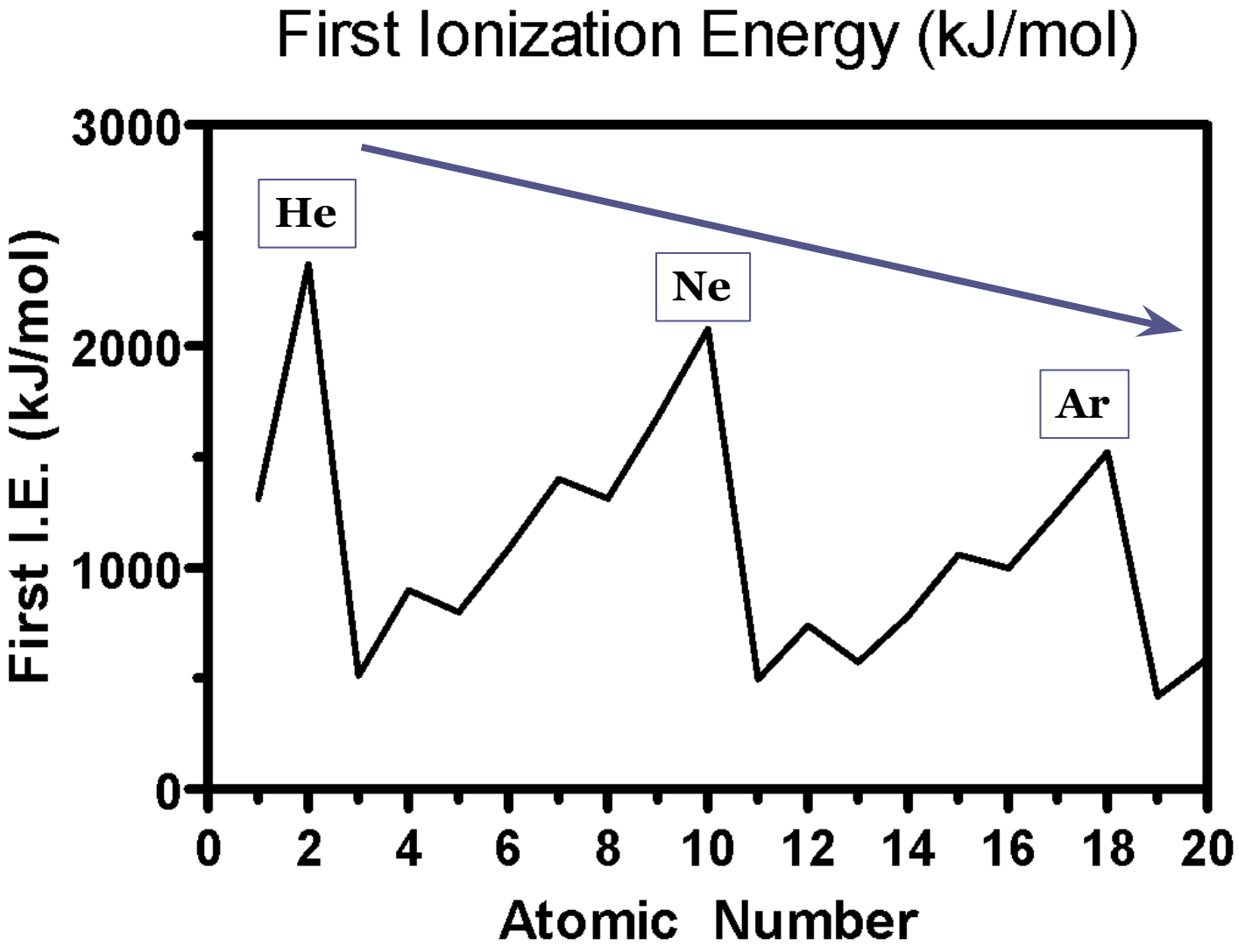
Trends in the First Ionization Energy



Trends in the First Ionization Energy

2) Down a Group (Column): Ionization energy decreases because the highest occupied orbital is further from the nucleus.

Trends in the First Ionization Energy

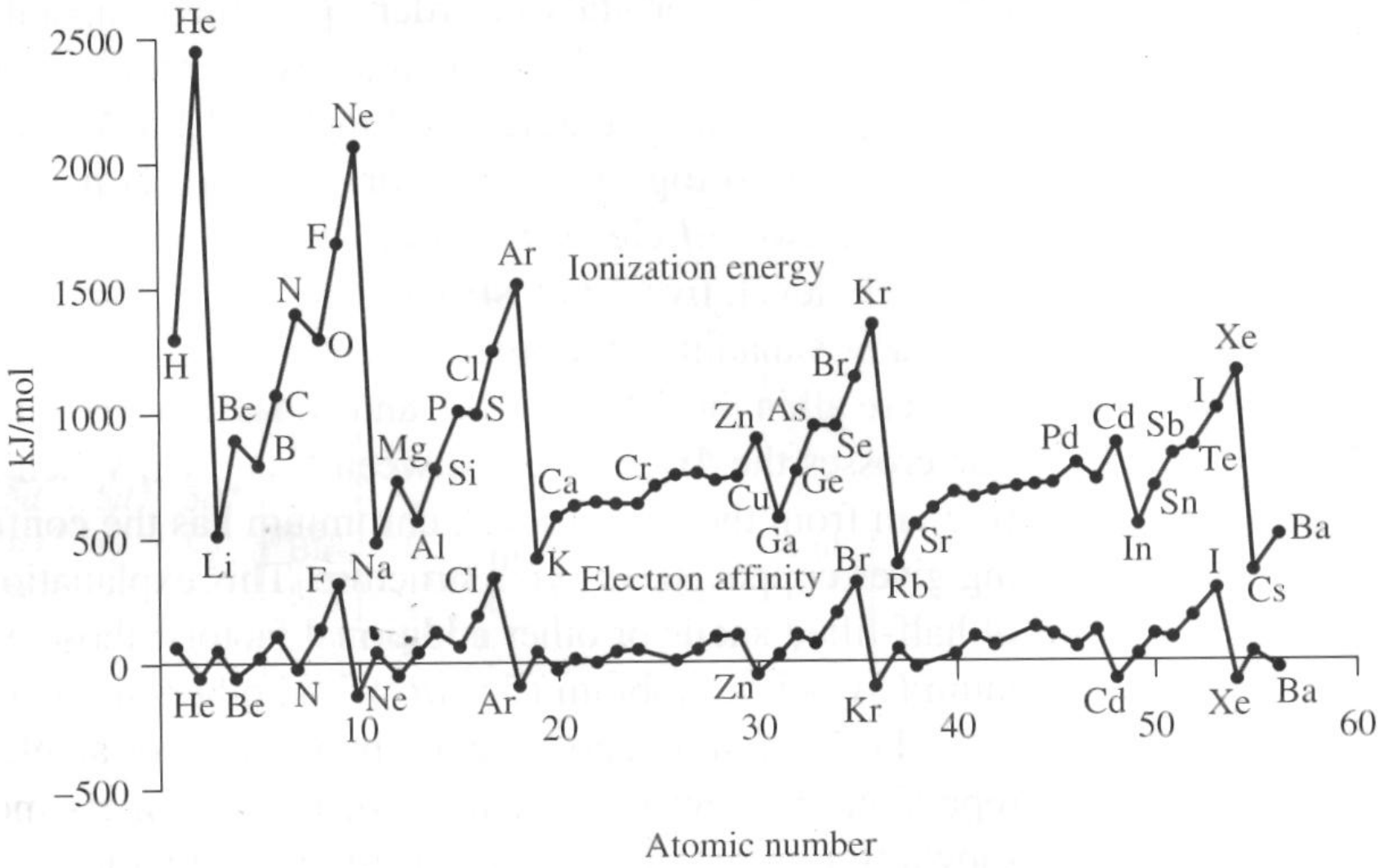


Electron Affinity

- Electron affinity is the amount of energy released when an electron is added to a neutral atom:

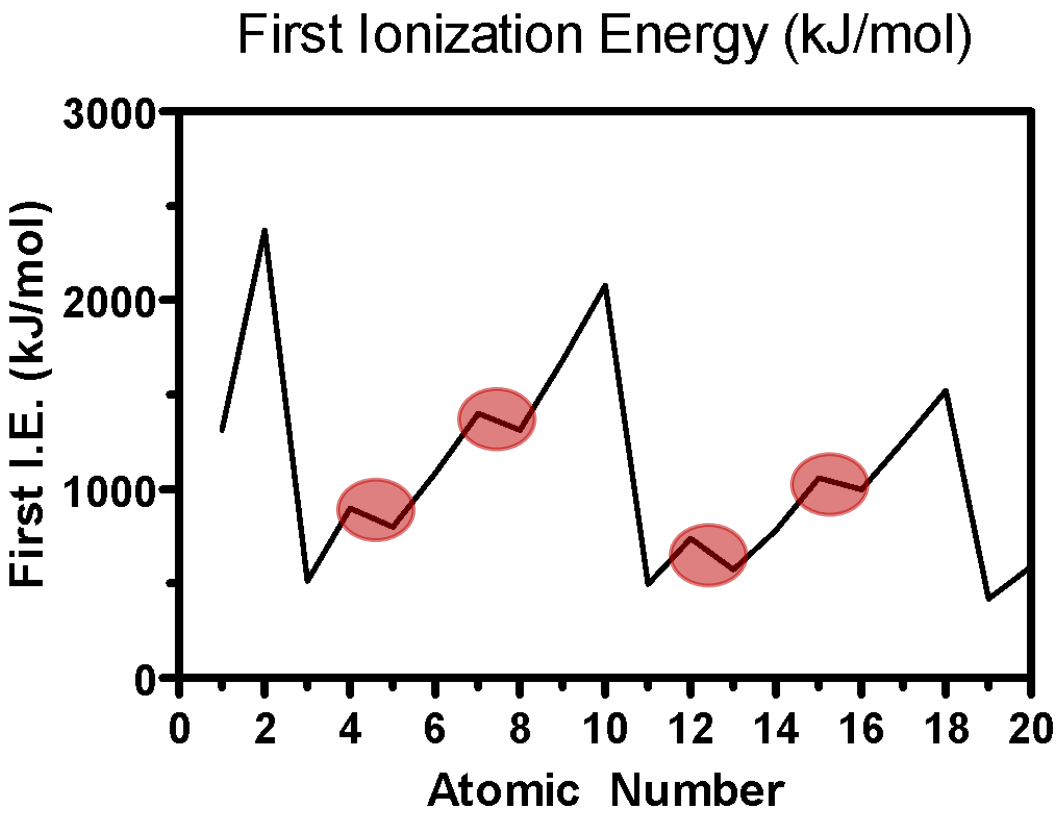
$$A + e^- \rightarrow A^- + \text{energy}$$

- Trend follows the same general trend as IE_1 except noble gases have the lowest EA


2500
2000
1500
1000
500
0
−500
kJ/mol
Ionization energy
Electron affinity
Atomic number
10
20
30
40
50
60
He
Ne
Ar
Kr
Xe
H
Li
Na
K
Rb
Cs
Be
B
C
N
O
F
Mg
Al
Si
P
S
Cl
Ca
Cr
Zn
Cu
Ga
Ge
As
Se
Br
Sr
Pd
Cd
In
Sn
Sb
Te
I
Ba

Exceptions to the Trends in IE_1

- Be > B
- N > O
- Mg > Al
- P > S



Task:

- 1. Draw the energy level diagrams of four elements that are exceptions to the general trend in either Period 2 or Period 3.

- 2. Write an explanation for each exception based on their electron configurations.

You may want to check this reference:

- Chemguide → Ionization Energy

Explanation for Be > B

- Boron's outer electron is in a higher energy orbital (slightly further from the nucleus). Therefore it takes less energy to ionize despite the higher nuclear charge.

- (Similar explanation for Mg vs. Al in period 3.)

Explanation for N > O

- There is electron repulsion in one of the 2*p* orbitals of oxygen. Therefore it takes less energy to ionize oxygen than nitrogen.

- (Similar explanation for P vs. S in period 3.)