Periodic Trends in Atomic Properties

Section 1.3

Periodic Law

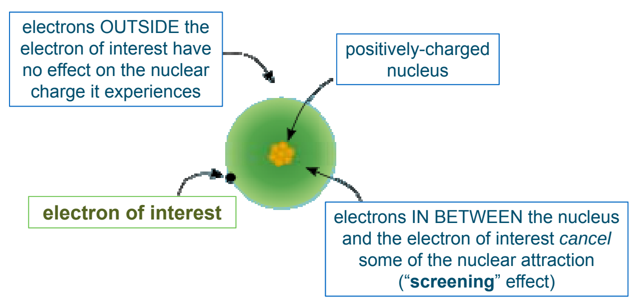
Elements, when arranged **in order of atomic number**, display **periodic trends** in their physical and chemical properties.

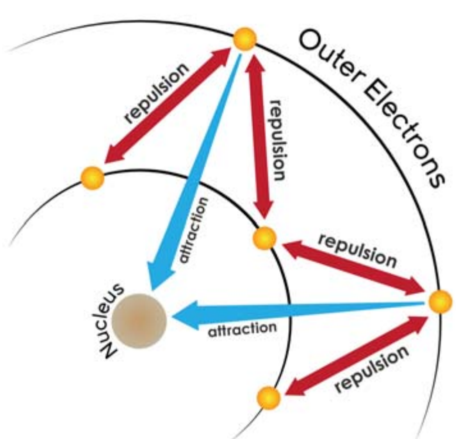
Numerous trends:

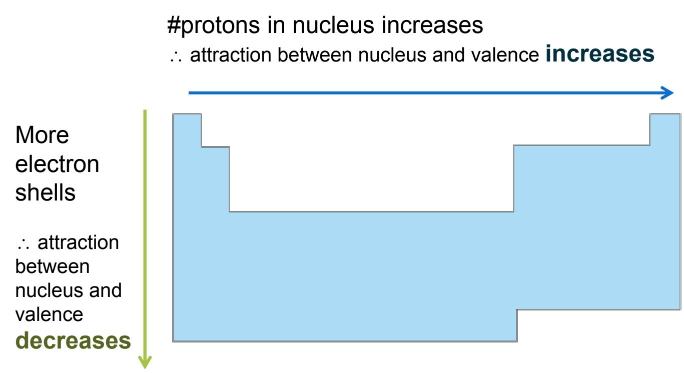
- atomic radius & ionic radius
- ionization energy
- electron affinity
- chemical reactivity

Periodic properties can be explained in terms of ***attraction*** between the positive nucleus and its electrons

- the **effective nuclear charge** – the net positive charge experienced by each of an atom's valence electrons

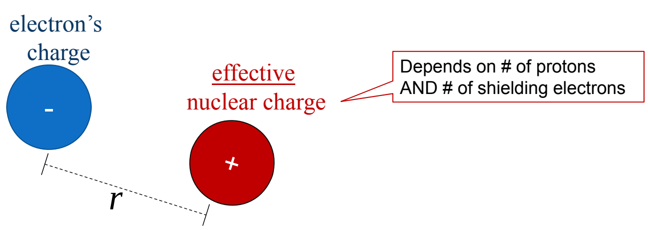






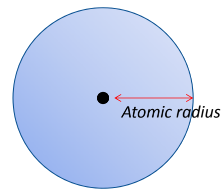
The magnitude of the **attraction** between an electron and the nucleus can be quantified using Coulomb's Law:

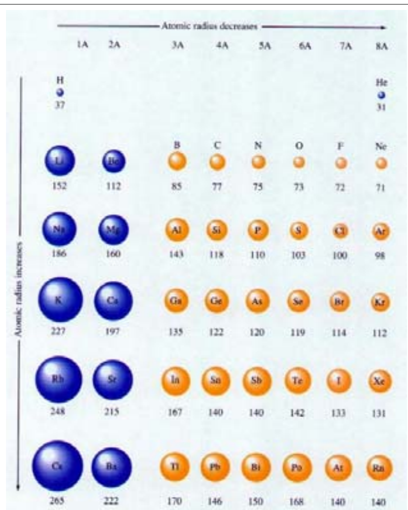
$$F = k \frac{q_1 \times q_2}{r^2}$$



Atomic Radius

- size of the atom
- average distance from the nucleus of an atom to the valence electrons
- expressed in picometres (1 pm = 1 x 10^{-12} m)





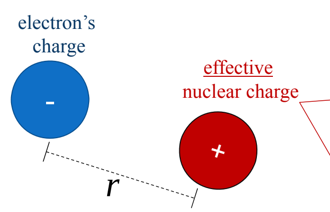
Atomic radii of the representative elements

What happens to atomic radius:

a) moving **L to R** across a period?

b) moving **down** a group?

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

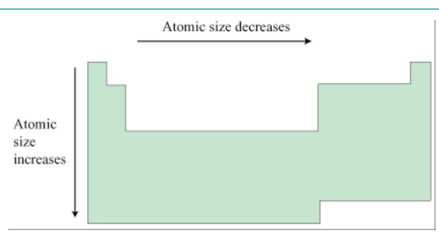


Explain why effective nuclear charge…
- **INCREASES** across a row?
- **DECREASES** down a group?

Across a period (L to R): Atomic radius decreases

With each successive element:
- one more proton is added
- greater concentration of positive charge in the nucleus
  → pulls valence electrons inwards

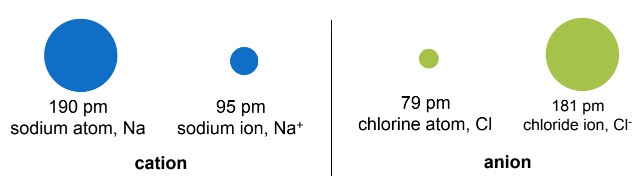
Down a group: Atomic radius increases
- increasing number of energy levels ("shells")
  ∴ greater distance from nucleus → bigger size



Ionic Radius

…the distance from the nucleus of an **ion** to its valence electrons

Ion	Loses/gains electrons?	Effective nuclear charge	Ionic radius (vs. Atomic radius)
Cation	loses	___________ (positive attraction spread over fewer e-)	___________ (valence electrons are pulled in)
Anion	gains	___________ (attraction spread over more e-, *PLUS* repulsion between e-)	___________



Ionization Energy & Electron Affinity

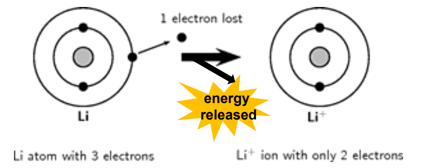
- valence electrons are bound to an atom by their attractive forces to the nucleus
- removing electrons <u>always</u> requires energy: Ionization energy
- gaining electrons <u>often</u> releases energy: Electron affinity

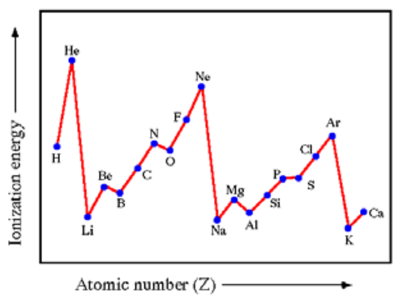
Ionization Energy

- the amount of energy required to **remove** a single valence electron from an atom/ion

general X (g) + **energy** → X^+ (g) + e^-

example Li (g) + **52 kJ/mol** → Li^+ (g) + e^-





What happens to ionization energy:

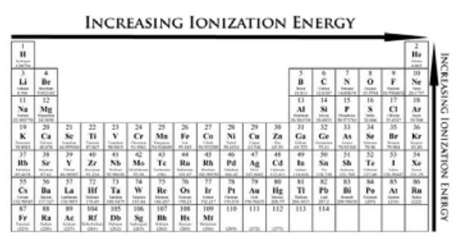
a) moving L to R across a period?
b) moving down a group?

Across a period: Ionization energy tends to increase

- increased attraction between nucleus and valence
  → harder to remove electrons

Down a group: Ionization energy tends to decrease

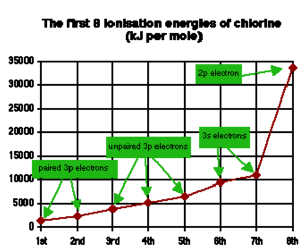
- screening effect: addition of more energy levels
- nuclear charge is **shielded** from valence electrons
  → easier to remove an electron



There are multiple ionization energies:

- <u>First ionization energy</u> –
  Energy required to remove the most loosely held e^-
- <u>Second ionization energy</u> –
  Required to remove next most loosely held e^-

etc...



Which do you think requires more energy? <u>Why</u>?

Removal of each successive electron requires more and more energy.

General increase →

General decrease ↓

Successive Ionization Energies for Period 3 Elements

Element	IE_1	IE_2	IE_3	IE_4	IE_5	IE_6	IE_7
Na	498	4560	6910	9540	13 400	16 600	20 100
Mg	736	1445	7730	10 600	13 600	18 000	21 700
Al	577	1815	2740	11 600	15 000	18 310	23 290
Si	787	1575	3220	4350	16 100	19 800	23 800
P	1063	1890	2905	4950	6270	21 200	25 400
S	1000	2260	3375	4565	6950	8490	27 000
Cl	1255	2295	3850	5160	6560	9360	11 000
Ar	1519	2665	3945	5770	7230	8780	12 000

Electron Affinity

- the energy change that occurs when an electron is **gained** by an atom
- first electron affinity, second electron affinity, etc.

general $X (g) + e^- \rightarrow X^- (g) +$ **energy**

specific $Cl (g) + e^- \rightarrow Cl^- (g) +$ **349 kJ/mol**

In the equation above, is the chlorine atom absorbing or releasing energy?

"**Tug-of-war**" of forces:

electrons' attraction to nucleus	VERSUS	repulsion towards other electrons
favours addition of e⁻'s		**discourages addition of e⁻'s**
Positive value of EA: Energy is *released*		Negative value: Energy is *required*

energetically-favourable

Note: This convention of assigning positive values to exothermic reactions is the opposite of typical thermodynamic notation

+

Positive value of EA:

- Addition of e- is favoured
- Energy is released

0

Negative value of EA:

- Addition of e- is NOT favoured
- Energy is required

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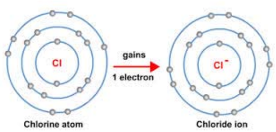


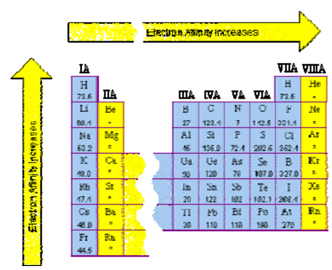
$Cl (g) + e^- \rightarrow Cl^- (g) +$ **349 kJ/mol**

Another way of expressing the EA of chlorine is as a single value: + 349 kJ/mol

Can you give an example of an element that would have a NEGATIVE electron affinity?

More energy is released when:

- it is easy to add electrons to form anions
  - non-metals have higher EA
- the added electron is close to the nucleus
  - smaller atoms - higher EA



Trends for Electron Affinity:

- *Across a period:* increases (more E is released)
- *Down a group:* decreases (less E released, or E required)

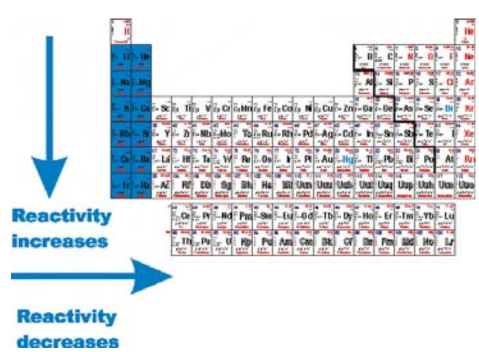
Chemical Reactivity

The most reactive elements are easily able to obtain **stable octets**.

- metals and non-metals achieve stability in different ways
  - reactivity trends are opposite each other

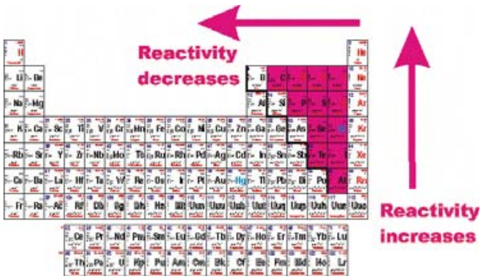
Metals:

- The easier it is to lose an electron, the more reactive the element.

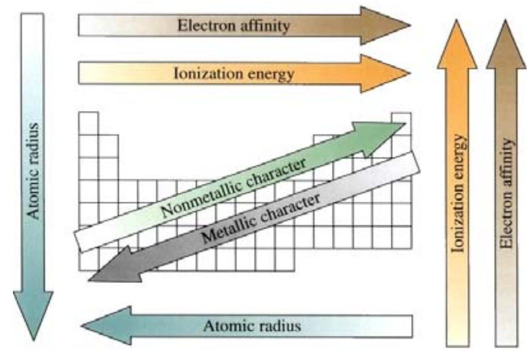


Non-Metals:

- The easier it is to gain an electron, the more reactive the element.



Summary of Periodic Trends



Arrows indicate direction of increase.

Homework

- Pg. 41 #1-7, 9-10