

Periodic Table of the Elements

| | | | | | | | | | | | | | | | | | |
|---------------------------------|---------------------------------|----------------------------------|-------------------------------------|-------------------------------------|----------------------------------|-----------------------------------|---------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------------------------------|------------------------------------|---------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|-------------------------------------|
| 1 H Hydrogen 1.008 | | | | | | | | | | | | | | | | | 18 He Helium 4.000 |
| 3 Li Lithium 6.941 | 4 Be Beryllium 9.012 | | | | | | | | | | | 5 B Boron 10.811 | 6 C Carbon 12.011 | 7 N Nitrogen 14.007 | 8 O Oxygen 15.999 | 9 F Fluorine 18.998 | 10 Ne Neon 20.180 |
| 11 Na Sodium 22.990 | 12 Mg Magnesium 24.305 | | | | | | | | | | | 13 Al Aluminum 26.982 | 14 Si Silicon 28.086 | 15 P Phosphorus 30.974 | 16 S Sulfur 32.065 | 17 Cl Chlorine 35.453 | 18 Ar Argon 39.948 |
| 19 K Potassium 39.098 | 20 Ca Calcium 40.078 | 21 Sc Scandium 44.956 | 22 Ti Titanium 47.867 | 23 V Vanadium 50.942 | 24 Cr Chromium 51.996 | 25 Mn Manganese 54.938 | 26 Fe Iron 55.845 | 27 Co Cobalt 58.933 | 28 Ni Nickel 58.693 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.38 | 31 Ga Gallium 69.723 | 32 Ge Germanium 72.631 | 33 As Arsenic 74.922 | 34 Se Selenium 78.971 | 35 Br Bromine 79.904 | 36 Kr Krypton 84.796 |
| 37 Rb Rubidium 84.464 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.906 | 40 Zr Zirconium 91.224 | 41 Nb Niobium 92.906 | 42 Mo Molybdenum 95.94 | 43 Tc Technetium 98.907 | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.905 | 46 Pd Palladium 106.42 | 47 Ag Silver 107.868 | 48 Cd Cadmium 112.411 | 49 In Indium 114.818 | 50 Sn Tin 118.710 | 51 Sb Antimony 121.757 | 52 Te Tellurium 127.6 | 53 I Iodine 126.905 | 54 Xe Xenon 131.29 |
| 55 Cs Cesium 132.905 | 56 Ba Barium 137.327 | 57 La Lanthanum 138.905 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.242 | 61 Pm Promethium 144.913 | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.925 | 66 Dy Dysprosium 162.502 | 67 Ho Holmium 164.930 | 68 Er Erbium 167.259 | 69 Tm Thulium 168.934 | 70 Yb Ytterbium 173.055 | 71 Lu Lutetium 174.967 | |
| 87 Fr Francium 223.021 | 88 Ra Radium 226.025 | 89-103 Ac Actinides | 104 Rf Rutherfordium [261] | 105 Db Dubnium [262] | 106 Sg Seaborgium [266] | 107 Bh Bohrium [264] | 108 Hs Hassium [269] | 109 Mt Meitnerium [268] | 110 Ds Darmstadtium [271] | 111 Rg Roentgenium [272] | 112 Cn Copernicium [285] | 113 Uut Ununtrium unknown | 114 Fl Flerovium [289] | 115 Uup Ununpentium unknown | 116 Lv Livermorium [293] | 117 Uus Ununseptium unknown | 118 Uuo Ununoctium unknown |

Chapter Eight

The Periodic Table

| | | | | | | | | | | | | | | |
|----------------------------------|--------------------------------|-------------------------------------|----------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------------------|----------------------------------|---------------------------------|-----------------------------------|----------------------------------|----------------------------------|
| 57 La Lanthanum 138.905 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.242 | 61 Pm Promethium 144.913 | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.925 | 66 Dy Dysprosium 162.502 | 67 Ho Holmium 164.930 | 68 Er Erbium 167.259 | 69 Tm Thulium 168.934 | 70 Yb Ytterbium 173.055 | 71 Lu Lutetium 174.967 |
| 89 Ac Actinium 227.028 | 90 Th Thorium 232.038 | 91 Pa Protactinium 231.036 | 92 U Uranium 238.029 | 93 Np Neptunium 237.048 | 94 Pu Plutonium 244.064 | 95 Am Americium 243.061 | 96 Cm Curium 247.070 | 97 Bk Berkelium 247.070 | 98 Cf Californium 251.080 | 99 Es Einsteinium [254] | 100 Fm Fermium 257.085 | 101 Md Mendelevium 258.1 | 102 No Nobelium 259.101 | 103 Lr Lawrencium [262] |

| | | | | | | | | | |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|
| Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|

The Modern Periodic Table

- Representative Elements: (main group elements)
 - Incomplete s or p shell determine elemental properties
- Transition metals – d orbitals also play a role in bonding

| 1 1A | | 2 2A | | Representative elements | | | | | | | | | | Noble gases | | | | | 18 8A | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|----------|---|-----------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|---------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|
| 3 3A | | 4 4A | 5 5A | 6 6A | 7 7A | 8 8A | 9 9A | 10 10A | 11 11A | 12 12A | 13 3A | 14 4A | 15 5A | 16 6A | 17 7A | 18 8A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 H | 2 He | 3 Li | 4 Be | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne | 11 Na | 12 Mg | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 Ds | 111 Rg | 112 | (113) | 114 | (115) | 116 | (117) | (118) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <table border="1"> <tbody> <tr> <td>58 Ce</td> <td>59 Pr</td> <td>60 Nd</td> <td>61 Pm</td> <td>62 Sm</td> <td>63 Eu</td> <td>64 Gd</td> <td>65 Tb</td> <td>66 Dy</td> <td>67 Ho</td> <td>68 Er</td> <td>69 Tm</td> <td>70 Yb</td> <td>71 Lu</td> </tr> <tr> <td>90 Th</td> <td>91 Pa</td> <td>92 U</td> <td>93 Np</td> <td>94 Pu</td> <td>95 Am</td> <td>96 Cm</td> <td>97 Bk</td> <td>98 Cf</td> <td>99 Es</td> <td>100 Fm</td> <td>101 Md</td> <td>102 No</td> <td>103 Lr</td> </tr> </tbody> </table> | | | | | | | | | | | | | | | | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |
| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Some Groups in the Periodic Table

Alkali Metals



- Group 1A
- +1 charge
- Highly reactive

Alkali Earth Metals

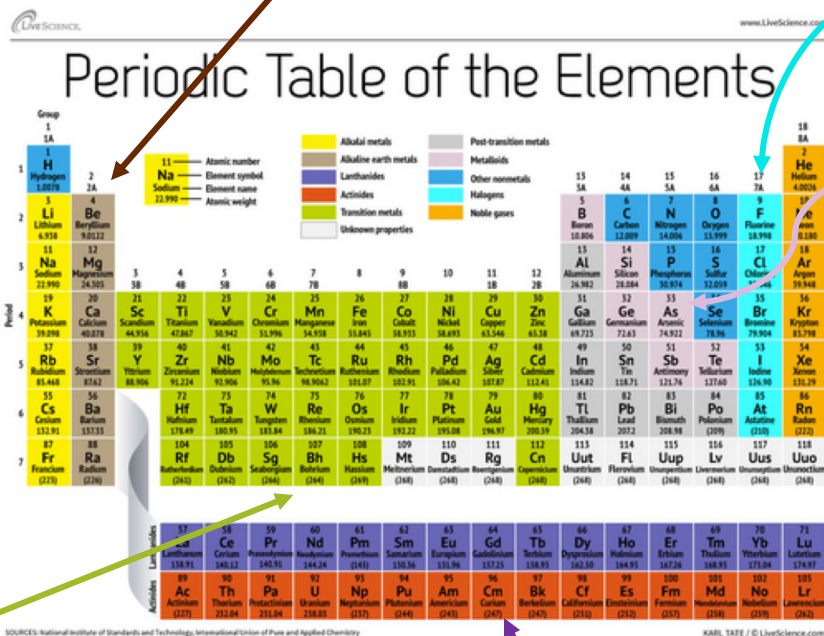


- Group 2A
- +2 charge
- Reactive

Halogens



- Group 7A
- -1 charge
- Highly reactive if single atoms
- Diatomic molecules

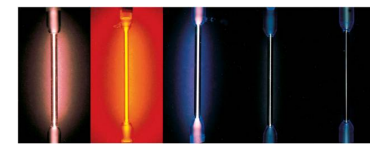


Metalloids

- Some characteristics of metals, some of nonmetals
- semiconductors



Silicon (Si)



Lithium (Li) Neon (Ne) Argon (Ar) Krypton (Kr) Xenon (Xe)

Noble Gases

- Group 8A
- + charge (if charged)
- Inert (least reactive)

Lanthanides & Actinides

- Bottom of table
- Very reactive
- + charge
- Often radioactive

Transition metals

- Center of table
- Varying (+) charge
- Use Roman numerals



Valence and Core Electrons

Valence electrons:

- Highest energy shell (largest principle quantum #, n)
- Furthest from nucleus
- Outermost electrons
- Available for bonding
 - Determine the behavior of the atom

Core electrons

- Located on the inside in inner shells.
- Principal quantum number is lower

Example

Oxygen, O

$$Z = 8$$

valence electrons

$$e^- = 6$$

Core electrons

$$e^- = 2$$

Valence e⁻



TABLE 8.1

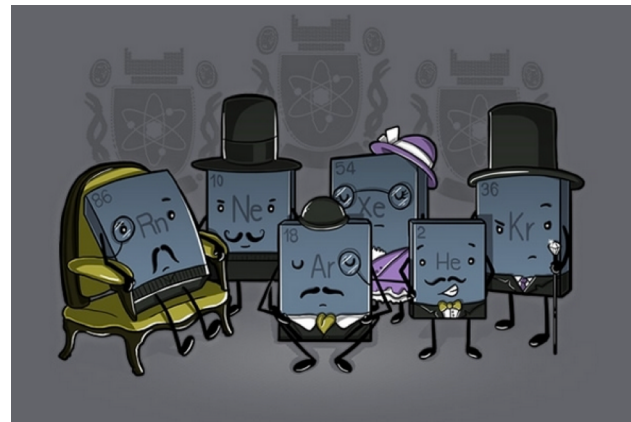
Electron Configurations of Group 1A and Group 2A Elements

| Group 1A | Group 2A |
|------------------------|------------------------|
| Li [He]2s ¹ | Be [He]2s ² |
| Na [Ne]3s ¹ | Mg [Ne]3s ² |
| K [Ar]4s ¹ | Ca [Ar]4s ² |
| Rb [Kr]5s ¹ | Sr [Kr]5s ² |
| Cs [Xe]6s ¹ | Ba [Xe]6s ² |
| Fr [Rn]7s ¹ | Ra [Rn]7s ² |

Effect of Valence Electrons on Elements

Octet Rule:

- Elements most stable with 8 valence electrons ($2s + 6p$)
- Noble gases have 8 valence electrons
 - No e^- want to be added or removed
 - Why they are so unreactive
- Main group elements form ions to become isoelectronic with the noble gases
 - Same electron configuration
- He & H follow duet rule
 - $2 e^-$; too small for $8e^-$



Main Group elements – gain or lose s & p e^- to get 8
Transition metals – all form cations – remove e^- from s orbital before d orbital (ie $4s$ e^- lost before $3d$ e^-)

Periodic Properties in Main Group Elements

Table of Pauling Electronegativity Values

| IA | | | | | | | | | | VIII | | | | | | | | | | VIIIA | | | | | | | | | | |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|----|----|----------------|------------------------|------------------------|-----------------------|-----------------------|------------------------|-----------------|--|--|--|--|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | | | | | | | | | | |
| 1 H 2.1 | | | | | | | | | | | | | | | | | | | | 2 He | | | | | | | | | | |
| IIA | | | | | | | | | | | | III A | IV A | V A | VIA | VII A | | | | | | | | | | | | | | |
| 3 Li 1.0 | 4 Be 1.5 | | | | | | | | | | | | | | | | | | | | 5 B 2.0 | 6 C 2.5 | 7 N 3.0 | 8 O 3.5 | 9 F 4.0 | 10 Ne | | | | |
| 11 Na 0.9 | 12 Mg 1.2 | | | | | | | | | | | | | | | | | | | | 13 Al 1.5 | 14 Si 1.8 | 15 P 2.1 | 16 S 2.5 | 17 Cl 3.0 | 18 Ar | | | | |
| IIB | | IIIB | IVB | VB | VIB | VII B | VIII | | | IB | IIB | | | | | | | | | | | | | | | | | | | |
| 19 K 0.8 | 20 Ca 1.0 | 21 Sc 1.3 | 22 Ti 1.5 | 23 V 1.6 | 24 Cr 1.6 | 25 Mn 1.5 | 26 Fe 1.8 | 27 Co 1.8 | 28 Ni 1.8 | 29 Cu 1.9 | 30 Zn 1.6 | 31 Ga 1.6 | 32 Ge 1.8 | 33 As 2.0 | 34 Se 2.4 | 35 Br 2.8 | 36 Kr | | | | | | | | | | | | | |
| 37 Rb 0.8 | 38 Sr 1.0 | 39 Y 1.2 | 40 Zr 1.4 | 41 Nb 1.6 | 42 Mo 1.8 | 43 Tc 1.9 | 44 Ru 2.2 | 45 Rh 2.2 | 46 Pd 2.2 | 47 Ag 1.9 | 48 Cd 1.8 | 49 In 1.8 | 50 Sn 1.8 | 51 Sb 1.9 | 52 Te 2.1 | 53 I 2.5 | 54 Xe | | | | | | | | | | | | | |
| 55 Cs 0.7 | 56 Ba 0.9 | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl 1.8 | 82 Pb 1.9 | 83 Bi 1.9 | 84 Po 2.0 | 85 At 2.2 | 86 Rn | | | | | | | | | | | | | |
| 87 Fr 0.7 | 88 Ra 0.9 | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 | 111 | 112 | 114 | | 116 | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|------------------|------------------|------------------|
| Lanthanides | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| Actinides | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

Trends in the Periodic Table

Effective Nuclear Charge (Z_{eff})

- The attractive force felt by an electron in an atom
- Takes into account two things:
 - The actual nuclear charge (Z)
 - The repulsive effects of the other electrons (referred to as **shielding** effects)
 - Most shielding is due to core electrons
- Depends on size of nucleus & energy level

Periodic Table of the Elements

The image shows a standard periodic table of elements, color-coded by groups. A legend at the top identifies various categories: Alkali metals (yellow), Alkaline earth metals (orange), Transition metals (green), Post-transition metals (light blue), Metalloids (purple), Other nonmetals (pink), Noble gases (grey), and Unknown properties (dark grey). Two blue arrows point from text annotations to specific elements: one points to Francium (Fr) at the bottom left, and another points to Fluorine (F) at the top right.

Fluorine:
Valence electrons
experience high Z_{eff}

Francium:
Valence electrons
experience low Z_{eff}

Trends in the Periodic Table

When looking at trends, consider 3 things:

- Amount of positive charge in nucleus (Z)
- Distance of the electron from the nucleus (Energy level)
- Number of other electrons between the electron in question and the nucleus (Shielding)



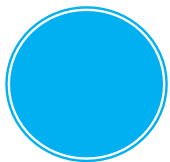
Lithium

- 3 protons
- 2nd energy level
- 2 core electrons

Fluorine



- 9 protons
- 2nd energy level
- 2 core electrons



Rubidium

- 37 protons
- 5th energy level
- 36 core electrons

Iodine

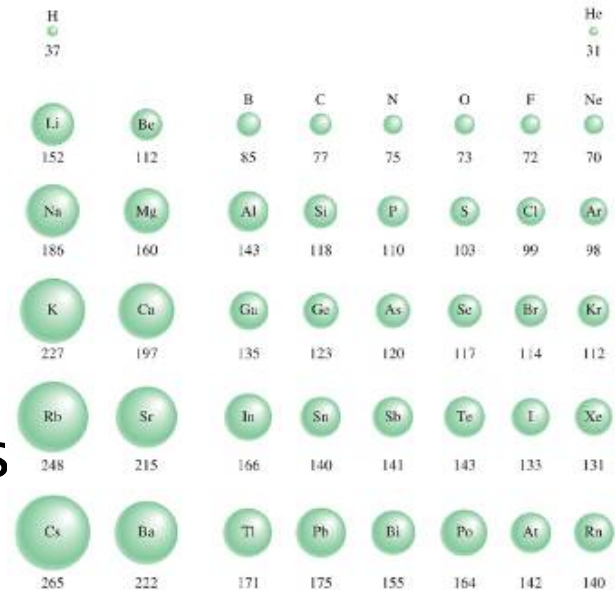


- 53 protons
- 5th energy level
- 46 core electrons

Atomic Radius

Atomic radius increases from top to bottom in a group/column

- Electrons are shielded from nucleus
- Previous shells blocks attraction
- Effective nuclear charge decreases
- Large size difference between shells



Atomic radius decreases from left to right across a row/period

- Little shielding as all electrons in same shell
- Effective nuclear charge higher as protons added
- Electrons pulled closer to nucleus

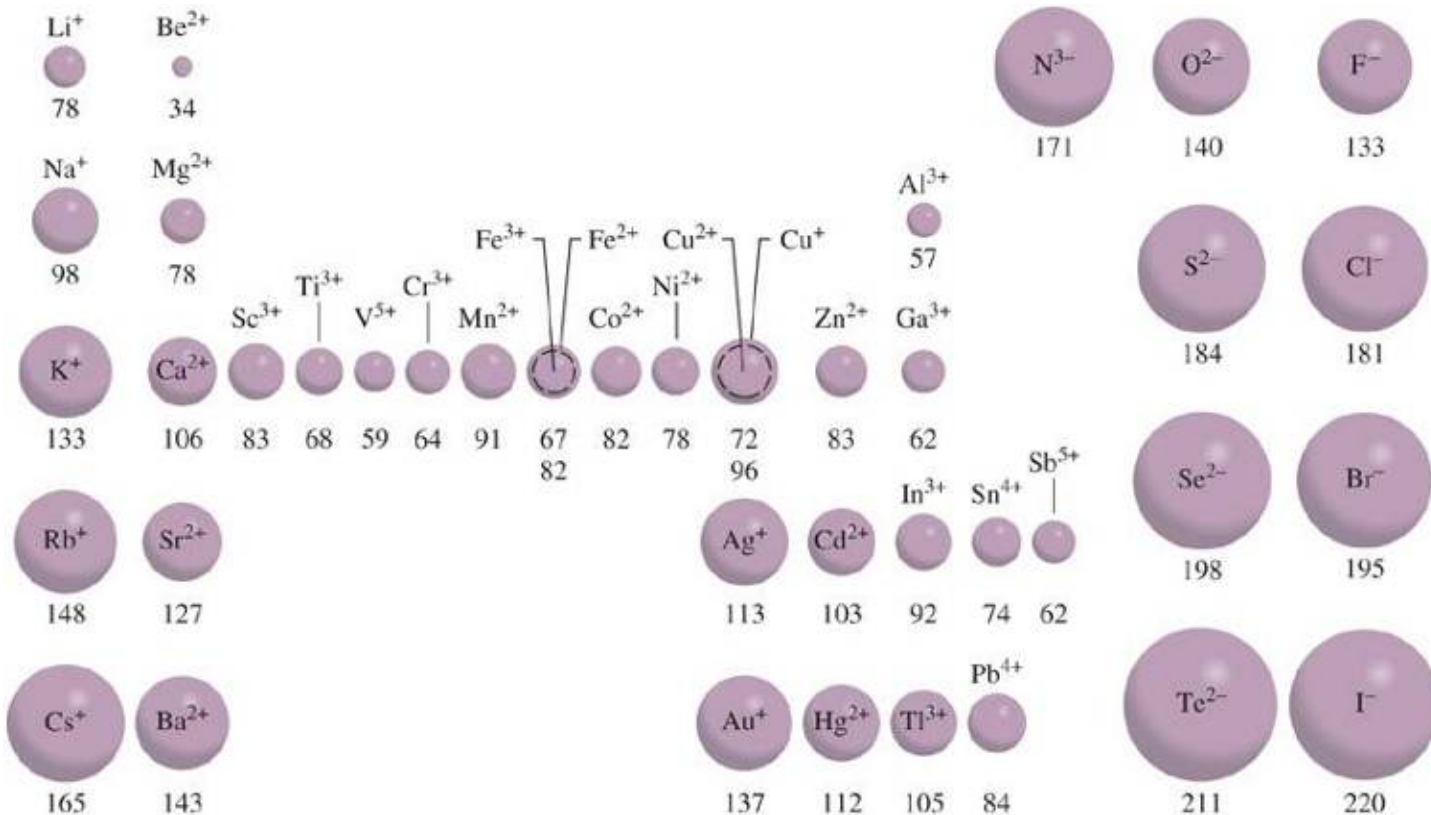
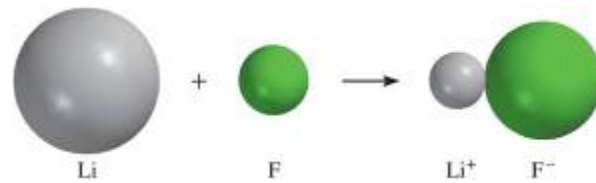
Ionic Radius

Anions larger than atoms

Cations smaller than atoms

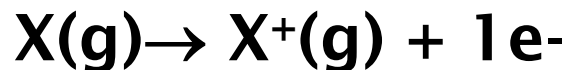
- Low effective nuclear charge
- More electrons
- More repulsion

- High effective nuclear charge
- Fewer electrons
- Less repulsion



Ionization Energy

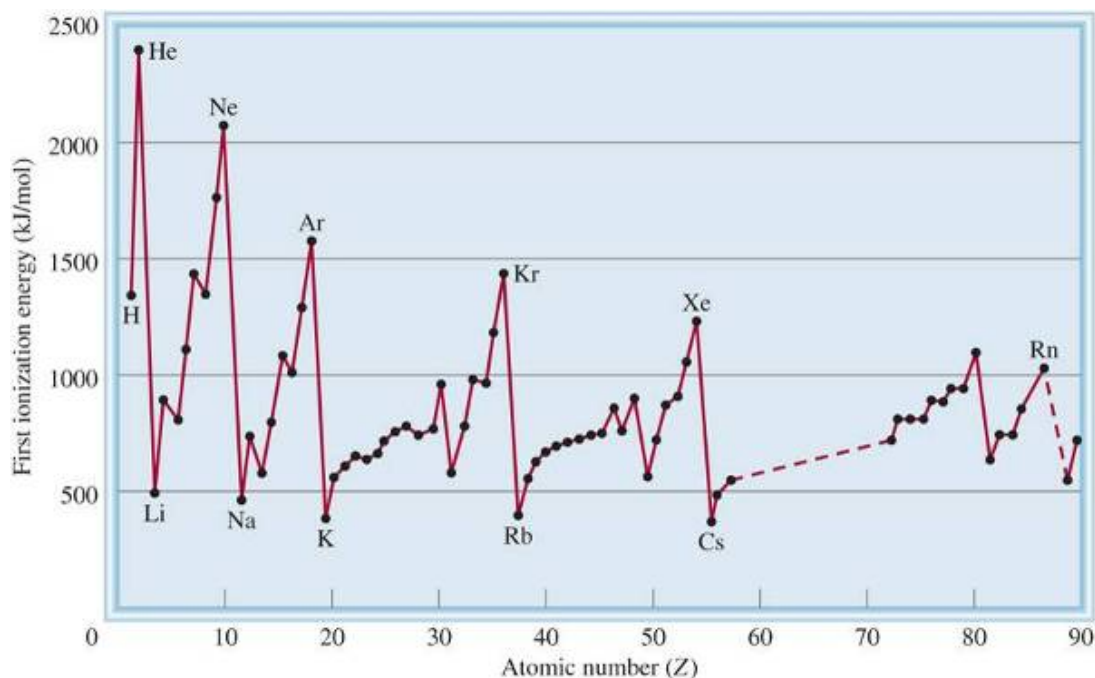
Energy needed to remove an e⁻ from a gaseous atom or ion



Endothermic Process

Decreases top to bottom: Bigger atom = more shielding

Increases from left to right: Atoms want to gain electrons



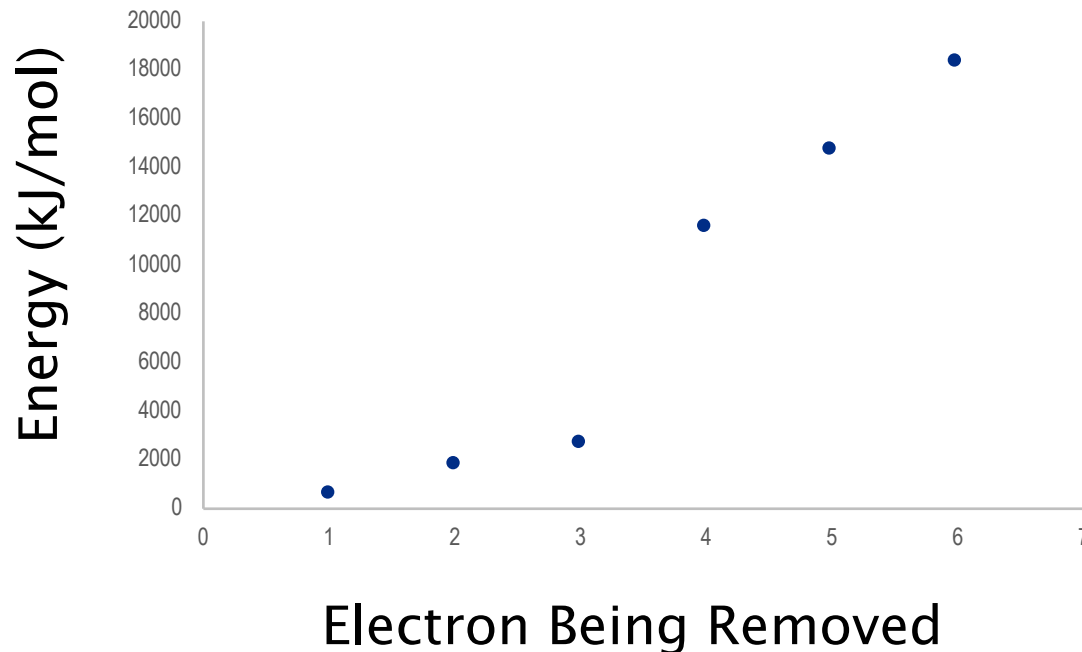
Ionization Energy con't

3rd ionization energy > 2nd > 1st:

- takes less energy to remove the first electron
- 2nd , 3rd , 4th , etc. electrons are held more strongly

Very large jump once all valence e⁻ have been removed

Ionization Energies of Aluminum



Elemental 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 |

Electron Affinity

Energy released when an e^- is added to a gaseous atom



- Decreases top to bottom
- Increases left to right
- Fluorine at top right
 - small atom
 - limited shielding
 - nucleus relatively large compared to overall size

Exothermic Process

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 |

2nd electron affinities lower: Ion is already negative – doesn't want to add more negative charges

Electronegativity: measure of attraction for e^- in a chemical bond
– follows similar trend; F has greatest electronegativity

Trends in the Periodic Table

- 1.) Which has the highest ionization energy: nitrogen, phosphorus, arsenic, or antimony?
- 2.) Which atom is smaller, potassium, calcium, iron, or arsenic?
- 3.) Which is the largest ion, K^+ , Ca^{2+} , Se^{2-} , Br^- ?
- 4.) Which has the highest electronegativity, fluorine, chlorine, bromine, or iodine?