

# PERIODIC PROPERTIES

## IONIC COMPOUNDS

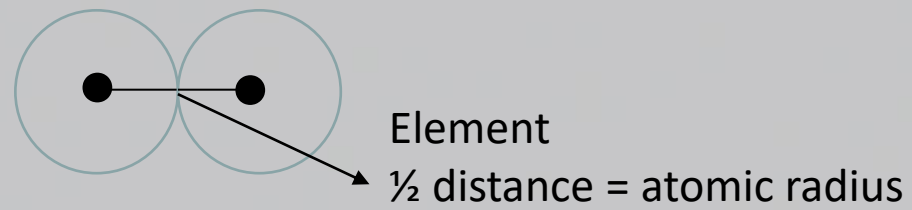
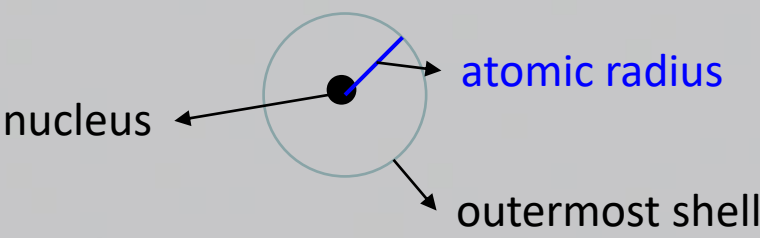
### Lecture 3



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# PERIODIC PROPERTIES: ATOMIC RADII



Size increases down a group  
Shell gets bigger

|    |                     |
|----|---------------------|
| Li | [He]2s <sup>1</sup> |
| Na | [Ne]3s <sup>1</sup> |
| K  | [Ar]4s <sup>1</sup> |
| Rb | [Kr]5s <sup>1</sup> |

Size decreases across a period (L to R)  
Shell is the same  
but nuclear charge increase pulling in shell

|    |                                     |            |
|----|-------------------------------------|------------|
| Al | [Ne]3s <sup>2</sup> 3p <sup>1</sup> | 13 protons |
| Si | [Ne]3s <sup>2</sup> 3p <sup>2</sup> | 14 protons |
| P  | [Ne]3s <sup>2</sup> 3p <sup>3</sup> | 15 protons |
| S  | [Ne]3s <sup>2</sup> 3p <sup>4</sup> | 16 protons |



NF<sub>3</sub> (stable) vs NCl<sub>3</sub> (unstable) ???

# REAL NUMBERS

| Wavelength<br>$\lambda$ , (nm) | Frequency<br>$\nu$ , (Hz, s <sup>-1</sup> ) | $n_1$ | $n_2$ |
|--------------------------------|---------------------------------------------|-------|-------|
| 94                             | $3.20 \times 10^{15}$                       | 1     | 6     |
| 95                             | $3.16 \times 10^{15}$                       | 1     | 5     |
| 97                             | $3.08 \times 10^{15}$                       | 1     | 4     |
| 103                            | $2.92 \times 10^{15}$                       | 1     | 3     |
| 122                            | $2.47 \times 10^{15}$                       | 1     | 2     |
| 410                            | $7.31 \times 10^{14}$                       | 2     | 6     |
| 434                            | $6.91 \times 10^{14}$                       | 2     | 5     |
| 486                            | $6.17 \times 10^{14}$                       | 2     | 4     |
| 657                            | $4.57 \times 10^{14}$                       | 2     | 3     |
| 1094                           | $2.74 \times 10^{14}$                       | 3     | 6     |
| 1282                           | $2.34 \times 10^{14}$                       | 3     | 5     |
| 1876                           | $1.60 \times 10^{14}$                       | 3     | 4     |
| 2626                           | $1.14 \times 10^{14}$                       | 4     | 6     |
| 4053                           | $7.40 \times 10^{13}$                       | 4     | 5     |

$$c = \lambda \times \nu = 3 \times 10^8 \text{ m/s}$$

$$\nu = R_h \times \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$R_h = 3.29 \times 10^{15} \text{ s}^{-1}$$

Rydberg constant



# REAL NUMBERS

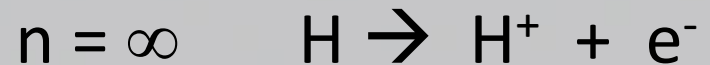
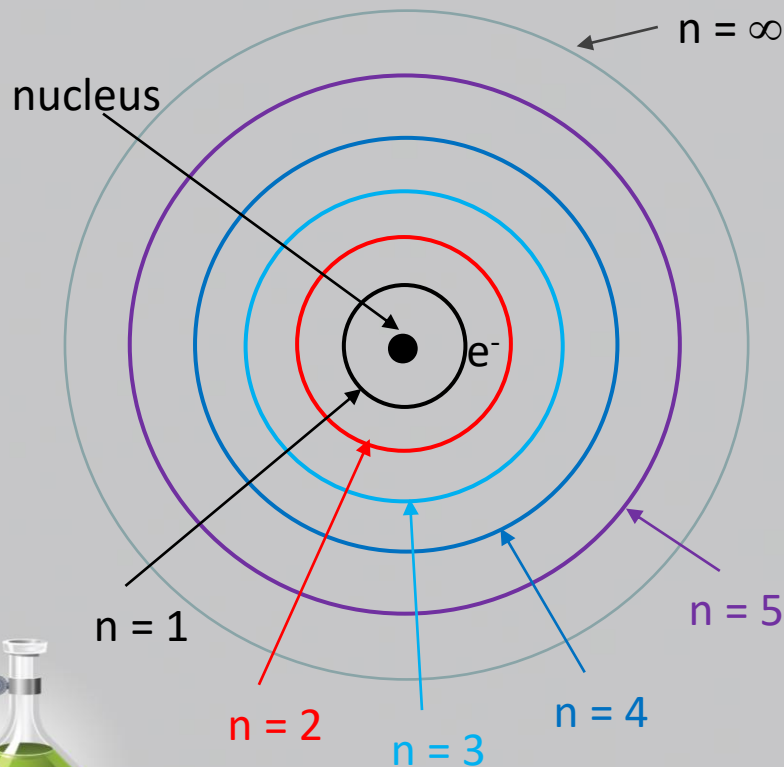
$$E = h \times \nu$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$\nu = R_h \times \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$R_h = 3.29 \times 10^{15} \text{ s}^{-1}$$

$$E = h \times R_h \times \left( \frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$



$$E = 2.18 \times 10^{-18} \text{ J} \times \left( \frac{1}{1^2} - \frac{1}{\infty^2} \right)$$

$$E = 2.18 \times 10^{-18} \text{ J}$$

**IONISATION ENERGY**



# PERIODIC PROPERTIES: IONISATION ENERGY (IE)

- ionization energy - an indicator of the reactivity of an element
- the greater the ionization energy, **the more difficult it is to remove an electron**
- elements with a low ionization energy tend to be reducing agents and form cations



**IE decreases down a group**

Shell gets bigger

Electrons further away from nucleus

More shielded

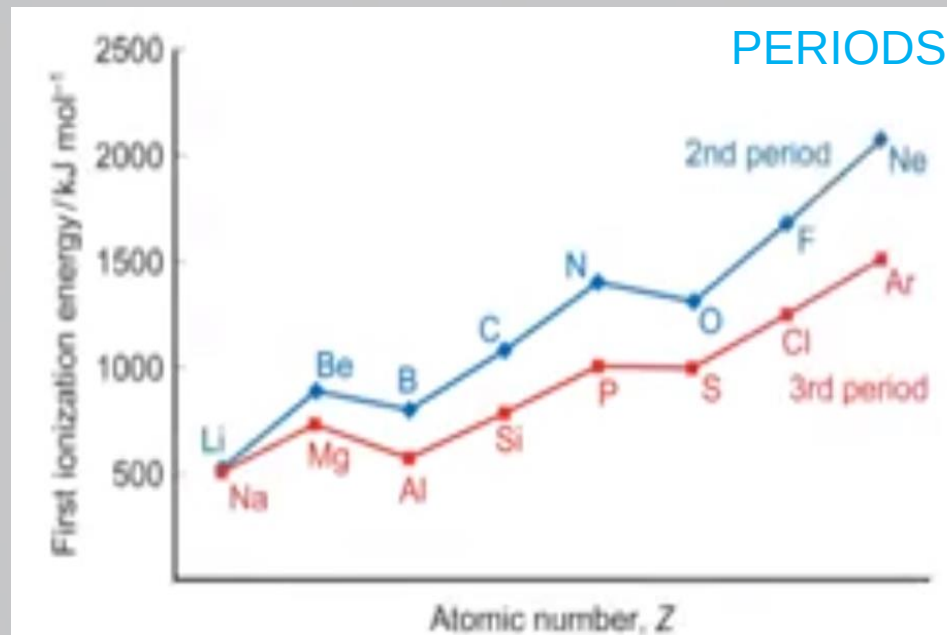
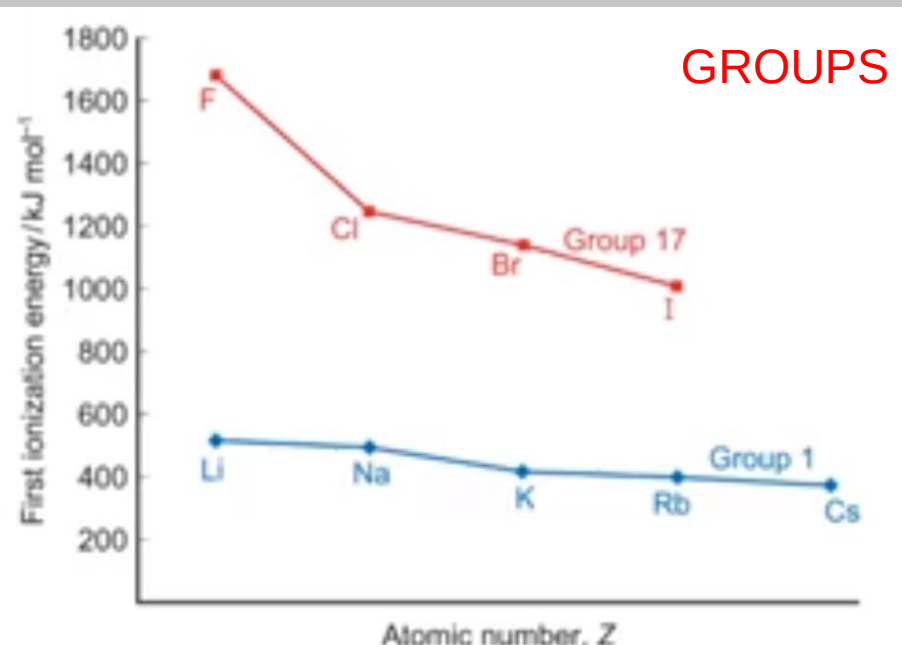
Electrons held less strongly

**IE increases across a period (L to R)**

Shell is the same

Nuclear charge increases pulling in shell

Electrons held more strongly



# IONISATION ENERGY (IE)



IE increases across a period (L to R)

Expected:  $Li < Be < B < C < N < O < F < Ne$

Actual:  $Li < B < Be < C < O < N < F < Ne$

|    | Atom                                | Atom <sup>+</sup>                   |                          |                      |
|----|-------------------------------------|-------------------------------------|--------------------------|----------------------|
| Li | [He]2s <sup>1</sup>                 | [He]                                | make full filled 1s      | easy                 |
| Be | [He]2s <sup>2</sup>                 | [He]2s <sup>1</sup>                 | break filled 2s          | harder than expected |
| B  | [He]2s <sup>2</sup> 2p <sup>1</sup> | [He]2s <sup>2</sup>                 | make only filled 2s      | easier than expected |
| N  | [He]2s <sup>2</sup> 2p <sup>3</sup> | [He]2s <sup>2</sup> 2p <sup>2</sup> | break half-filled 2p     | harder than expected |
| O  | [He]2s <sup>2</sup> 2p <sup>4</sup> | [He]2s <sup>2</sup> 2p <sup>3</sup> | make only half filled 2p | easier than expected |
| Ne | [He]2s <sup>2</sup> 2p <sup>6</sup> | [He]2s <sup>2</sup> 2p <sup>4</sup> | break filled 2p          | very hard            |



Same trend but much smaller from Na to Ar period

# IONISATION ENERGIES (IE)

- 1<sup>st</sup> Ionisation Energy :  $A(g) \rightarrow A^+(g) + e^-$   
Increase across with zig-zag
- 2<sup>nd</sup> Ionisation Energy :  $A^+(g) \rightarrow A^{2+}(g) + e^-$   
All higher than the 1<sup>st</sup> IE for a given atom.  
Noble gas configuration the hardest from which to remove electron.  
Alkali metals have highest 2<sup>nd</sup> IE
- 3<sup>rd</sup> Ionisation Energy :  $A^{2+}(g) \rightarrow A^{3+}(g) + e^-$   
All higher than the 2<sup>nd</sup> IE for a given atom  
Noble gas configuration the hardest from which to remove electron.  
Alkaline earth metals have highest 3<sup>rd</sup> IE

| Element | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ | $I_8$ |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|
| H       | 1312  |       |       |       |       |       |       |       |
| He      | 2372  | 5251  |       |       |       |       |       |       |
| Li      | 520   | 7298  | 11815 |       |       |       |       |       |
| Be      | 900   | 1757  | 14849 | 21007 |       |       |       |       |
| B       | 801   | 2427  | 3660  | 25026 | 32827 |       |       |       |
| C       | 1086  | 2353  | 4620  | 6223  | 37831 | 47277 |       |       |
| N       | 1402  | 2856  | 4578  | 7475  | 9445  | 53267 | 64360 |       |
| O       | 1314  | 3389  | 5300  | 7469  | 10990 | 13327 | 71331 | 84078 |
| F       | 1681  | 3374  | 6050  | 8408  | 11023 | 15164 | 17868 | 92038 |
| Ne      | 2081  | 3952  | 6122  | 9371  | 12177 | 15238 | 19999 | 23070 |
| Na      | 496   | 4562  | 6910  | 9543  | 13354 | 16613 | 20117 | 25496 |
| Mg      | 738   | 1451  | 7733  | 10543 | 13630 | 18020 | 21711 | 25661 |
| Al      | 578   | 1817  | 2745  | 11577 | 14842 | 18379 | 23326 | 27466 |
| Si      | 787   | 1577  | 3232  | 4356  | 16091 | 19806 | 23780 | 29287 |
| P       | 1012  | 1907  | 2914  | 4964  | 6274  | 21267 | 25431 | 29872 |
| S       | 1000  | 2252  | 3357  | 4556  | 7004  | 8496  | 27107 | 31720 |
| Cl      | 1251  | 2298  | 3822  | 5159  | 6540  | 9362  | 11018 | 33604 |
| Ar      | 1521  | 2666  | 3931  | 5771  | 7238  | 8781  | 11995 | 13842 |
| K       | 419   | 3052  | 4420  | 5877  | 7975  | 9590  | 11343 | 14944 |
| Ca      | 590   | 1145  | 4912  | 6491  | 8153  | 10496 | 12270 | 14206 |

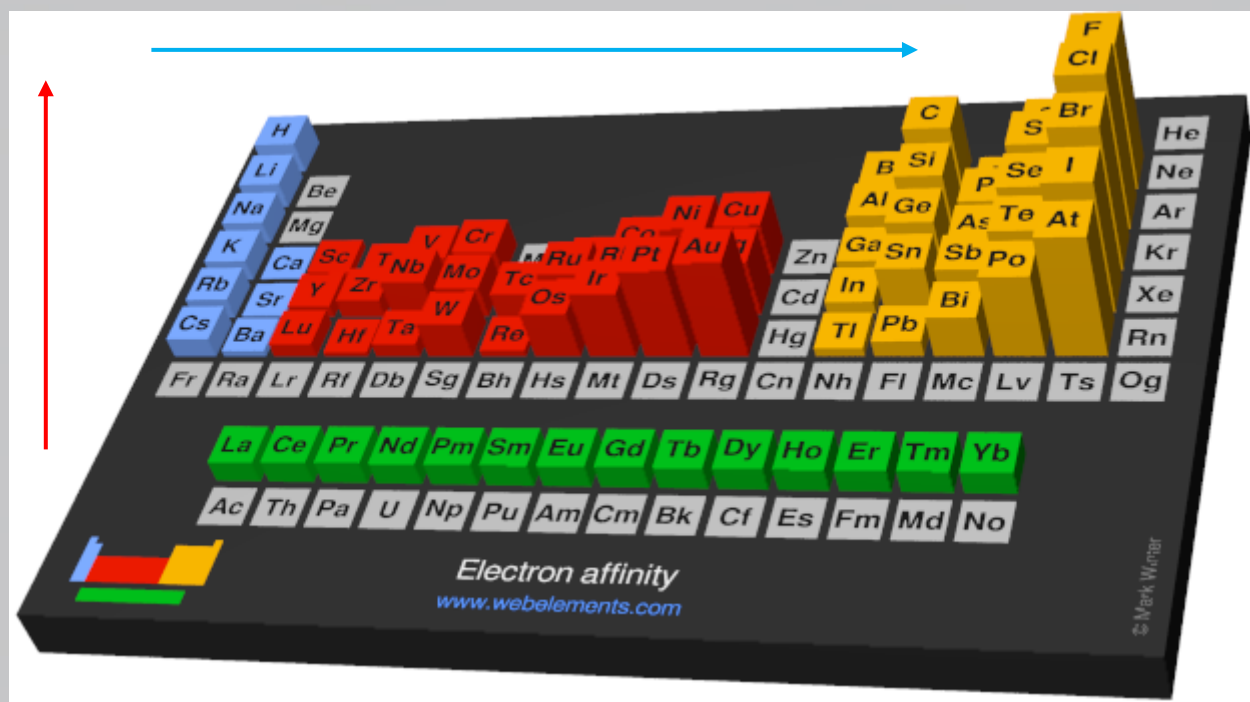


# ELECTRON AFFINITY

the amount of energy liberated when an electron is added to a neutral atom to form a negatively charged ion.

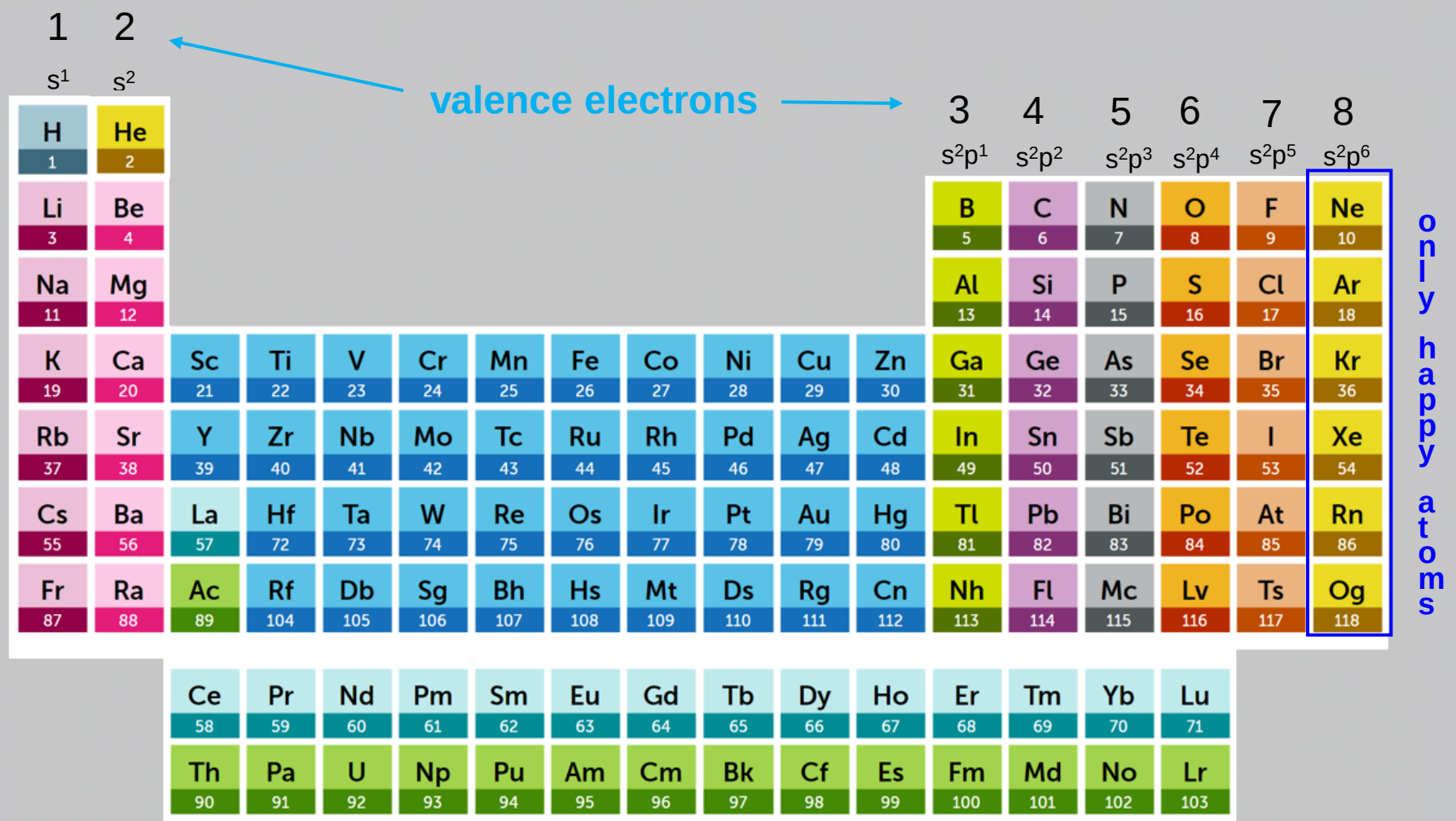


Electron affinity **increases upward for the groups and from left to right across periods** because the electrons added to energy levels become closer to the nucleus, thus a stronger attraction between the nucleus and its electrons.



The electron affinities of atoms are difficult to measure, hence values are available for only a few chemical elements, chiefly the halogens.

# MAKING CATIONS: Happy atoms



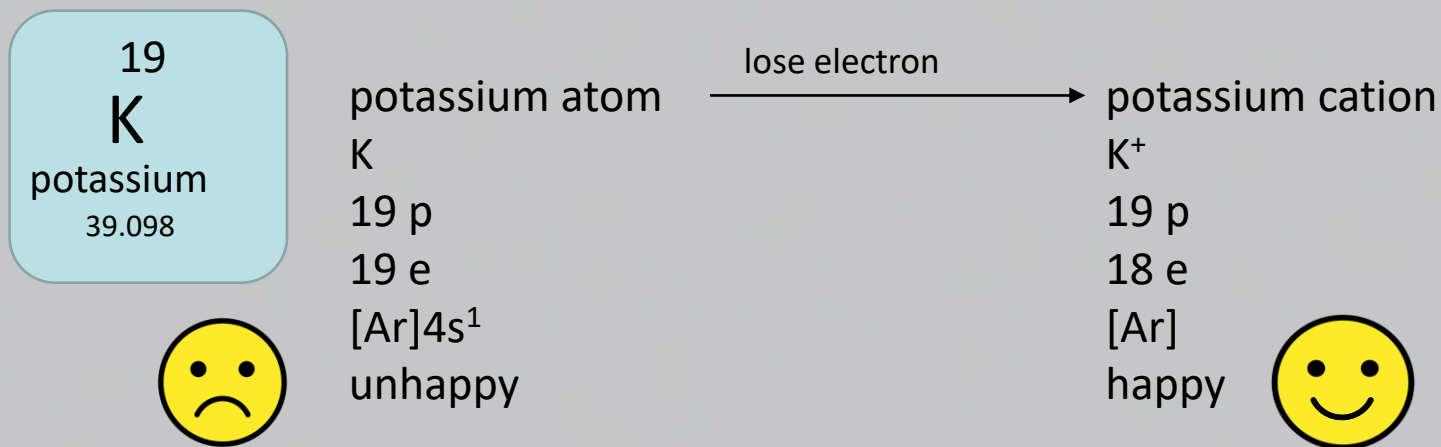
# Unhappy atoms:

happiness = same number of electrons as a noble gas

1. Lose electron(s)                      main group (s and p block), d block METALS
2. Gain electron(s)                      main group (p block) NON-METALS, some METALLOIDS
3. Share electrons (Covalent) main group (s and p block) NON-METALS, METALLOIDS

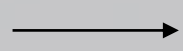


# MAKING CATIONS: Lose electron(s)



Akali metals

[noble gas]ns<sup>1</sup>



[noble gas]

Li becomes Li<sup>+</sup>

lithium cation

[He]

Na becomes Na<sup>+</sup>

potassium cation

[Ar]

etc

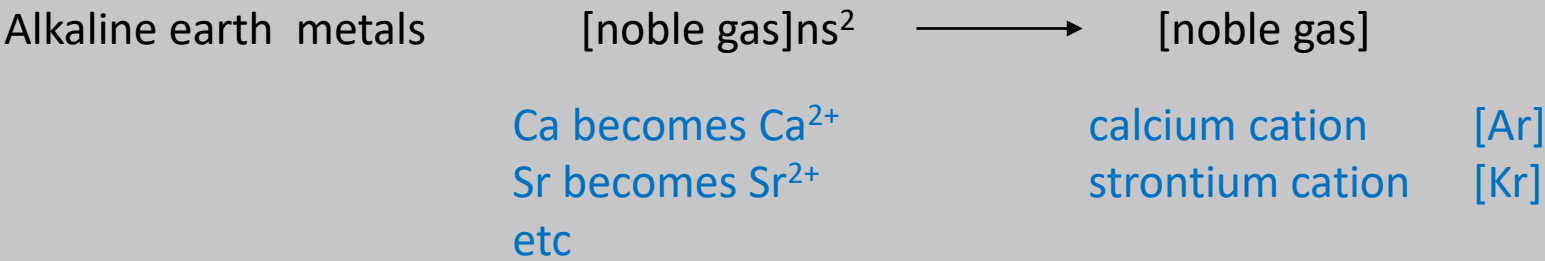
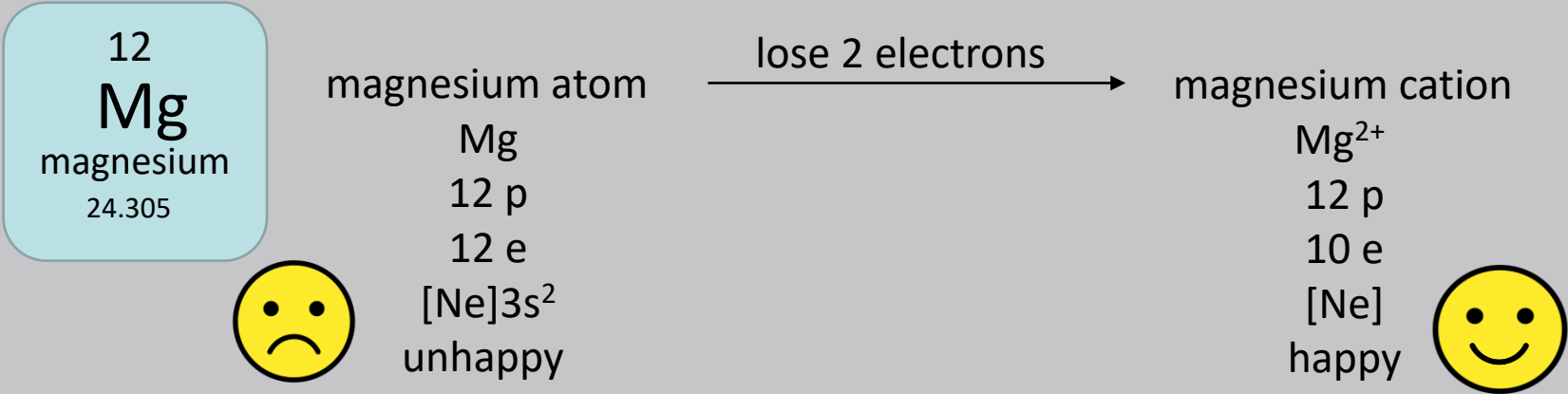
## Potassium salts in explosives:

**KNO<sub>3</sub> salpetre** - **not explosive**, unless in presence of reducing agents (S, charcoal-based compounds - blackpowder).

**KClO<sub>3</sub>, KClO<sub>4</sub>** - **very powerful oxidising agent**. When heated, it decomposes to produce oxygen which fuels the flame of the lit firework, increasing the temperature of the firework even further.



# Lose electron(s)



## Magnesium salts in explosives:

**MgCl<sub>2</sub>** and **Mg(ClO<sub>3</sub>)<sub>2</sub>** – mix of non- and oxidising Mg salts, may explode when heated or react explosively with hydrocarbons (fuels) and ignite combustibles (wood, paper, oil, clothing, etc.)



Lose electron(s)

13

Al

aluminium

26.982



aluminium atom  
Al  
13 p  
13 e  
[Ne] 3s<sup>2</sup> 3p<sup>1</sup>  
unhappy

lose 3 electrons

aluminium cation  
Al<sup>3+</sup>  
13 p  
10 e  
[Ne]  
happy



Boron group metals

[noble gas]ns<sup>3</sup>



[noble gas]

Ga becomes Ga<sup>3+</sup>(Ga<sup>+</sup>)  
In becomes In<sup>3+</sup> (In<sup>+</sup>)  
etc

gallium cation [Ar]  
indium cation [Kr]

‘INERT EFFECT’ d and f block reduce (shield) effect of nucleus

Aluminum powder in explosives:

Al powders- high heat of reaction and energy content; when added to fuel increases the speed of detonation



# Lose electron(s)

## Metal atoms like to lose electrons

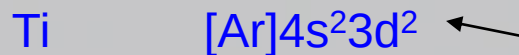
|          |             |             |             |             |          |          |          |
|----------|-------------|-------------|-------------|-------------|----------|----------|----------|
| 1        | 2           | 3           | 4           | 5           | 6        | 7        | 8        |
| $s^1$    | $s^2$       | $s^2p^1$    | $s^2p^2$    | $s^2p^3$    | $s^2p^4$ | $s^2p^5$ | $s^2p^6$ |
| Li<br>3  | Be<br>4     |             |             |             |          |          |          |
| Na<br>11 | Mg<br>12    | Al<br>13    |             |             |          |          |          |
| K<br>19  | Ca<br>20    | Ga<br>31    |             |             |          |          |          |
| Rb<br>37 | Sr<br>38    | In<br>49    | Sn<br>50    |             |          |          |          |
| Cs<br>55 | Ba<br>56    | Tl<br>81    | Pb<br>82    | Bi<br>83    |          |          |          |
| Fr<br>87 | Ra<br>88    | Nh<br>113   | Fl<br>114   | Mc<br>115   |          |          |          |
| +1       | +2<br>or +1 | +3<br>or +1 | +4<br>or +2 | +5<br>or +3 |          |          |          |



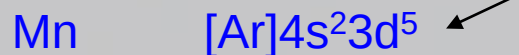
# Transition metal cations

d-block  $4s^2 3d^n$

All except Sc group make 2+ cations: LOSE THE 4s ELECTRONS FIRST !!!



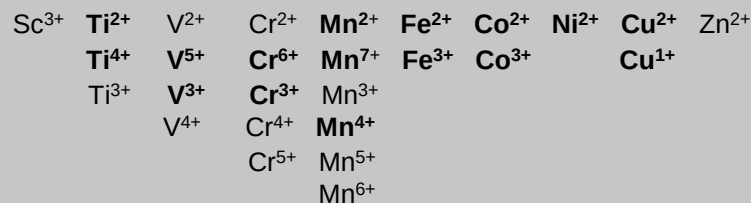
Early TM can lose all electrons down to Noble Gas  
Up to 5 from the d as well as two valence electrons



Late TM can lose two valence electrons and go to  $d^5$



|          |           |           |           |           |           |           |           |           |           |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Sc<br>21 | Ti<br>22  | V<br>23   | Cr<br>24  | Mn<br>25  | Fe<br>26  | Co<br>27  | Ni<br>28  | Cu<br>29  | Zn<br>30  |
| Y<br>39  | Zr<br>40  | Nb<br>41  | Mo<br>42  | Tc<br>43  | Ru<br>44  | Rh<br>45  | Pd<br>46  | Ag<br>47  | Cd<br>48  |
| La<br>57 | Hf<br>72  | Ta<br>73  | W<br>74   | Re<br>75  | Os<br>76  | Ir<br>77  | Pt<br>78  | Au<br>79  | Hg<br>80  |
| Ac<br>89 | Rf<br>104 | Db<br>105 | Sg<br>106 | Bh<br>107 | Hs<br>108 | Mt<br>109 | Ds<br>110 | Rg<br>111 | Cn<br>112 |



# IONIC COMPOUNDS: Gain electron(s)

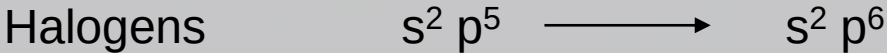
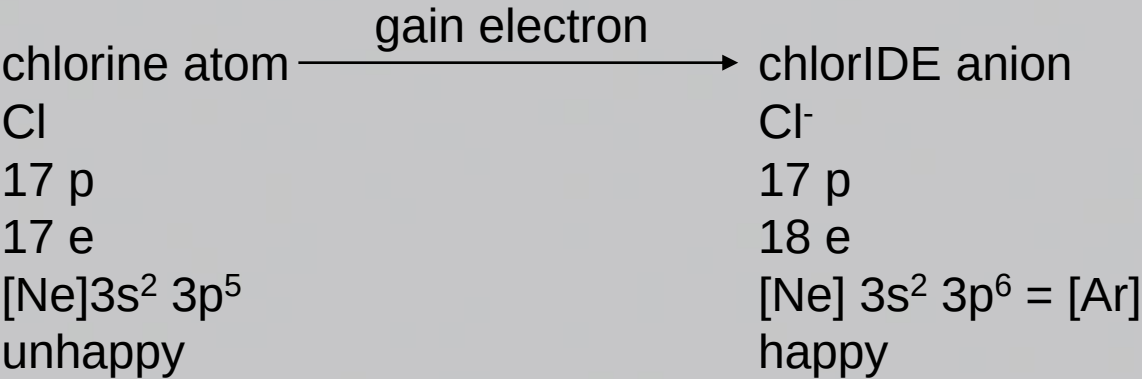
Non-metal (and some metalloid) atoms like to gain electrons

17

Cl

chlorine

35.453



Br becomes Br<sup>-</sup>

I becomes I<sup>-</sup>

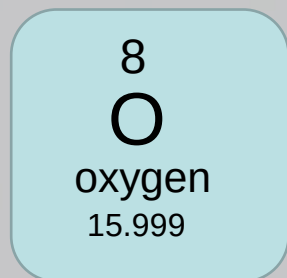
etc

bromide anion

iodide anion



## Gain electron(s)



oxygen atom  
O  
8 p  
8 e  
[He] 2s<sup>2</sup> 2p<sup>4</sup>  
unhappy

gain 2 electrons

oxide anion  
O<sup>2-</sup>  
8 p  
10 e  
[He] 2s<sup>2</sup> 2p<sup>6</sup> = [Ne]  
happy



Oxygen group      s<sup>2</sup> p<sup>4</sup>      →      s<sup>2</sup> p<sup>6</sup>

O becomes O<sup>2-</sup>      oxide anion  
S becomes S<sup>2-</sup>      sulfide anion  
etc

Toxic oxides are formed during basic explosive reactions between  
nitrogen, oxygen and carbon → NO<sub>x</sub>, CO



# Gain electron(s)

Non-metal (and some metalloid) atoms like to gain electrons

| 1              | 2              | 3                             | 4                             | 5                             | 6                             | 7                             | 8                             |
|----------------|----------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| s <sup>1</sup> | s <sup>2</sup> | s <sup>2</sup> p <sup>1</sup> | s <sup>2</sup> p <sup>2</sup> | s <sup>2</sup> p <sup>3</sup> | s <sup>2</sup> p <sup>4</sup> | s <sup>2</sup> p <sup>5</sup> | s <sup>2</sup> p <sup>6</sup> |
|                |                |                               | C<br>6                        | N<br>7                        | O<br>8                        | F<br>9                        | Ne<br>10                      |
|                |                |                               |                               | P<br>15                       | S<br>16                       | Cl<br>17                      | Ar<br>18                      |
|                |                |                               |                               | As<br>33                      | Se<br>34                      | Br<br>35                      | Kr<br>36                      |
|                |                |                               |                               | Sb<br>51                      | Te<br>52                      | I<br>53                       | Xe<br>54                      |
|                |                |                               |                               |                               |                               | At<br>85                      | Rn<br>86                      |
|                |                |                               |                               |                               |                               | Ts<br>117                     | Og<br>118                     |
|                |                |                               | +3                            | -4                            | -3                            | -2                            | -1                            |



# CATION AND ANION SIZE

## Cations are smaller than their atoms

- a) Fewer electrons for same nuclear attraction
- b) main group – smaller shell

Na  $1s^2 2s^2 2p^6 3s^1$   
11 protons, 11 electrons

Na<sup>+</sup>  $1s^2 2s^2 2p^6$   
11 protons, 10 electrons

## Anions are bigger than their atoms

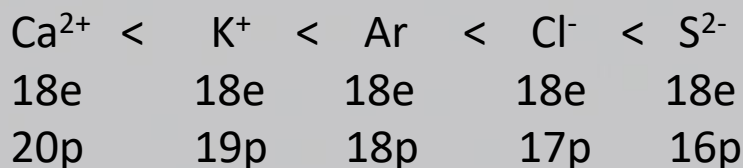
- a) More electrons for same nuclear attraction
- b) main group – larger shell

S  $[\text{Ne}] 3s^2 3p^4$   
16 protons, 16 electrons

S<sup>2-</sup>  $[\text{Ne}] 3s^2 3p^6$   
16 protons, 18 electrons

## ISOELECTRONIC SERIES – same number of electrons

Size **INCREASES** as ions become **LESS POSITIVE** (MORE NEGATIVE)



# POLYATOMIC IONS

Have to be memorised (unfortunately)

More than one atom.

Oxyanions with root and "ate":

|           |                     |
|-----------|---------------------|
| borate    | $\text{BO}_3^{3-}$  |
| carbonate | $\text{CO}_3^{2-}$  |
| chlorate  | $\text{ClO}_3^-$    |
| chromate  | $\text{CrO}_4^{2-}$ |
| nitrate   | $\text{NO}_3^-$     |
| phosphate | $\text{PO}_4^{3-}$  |
| sulfate   | $\text{SO}_4^{2-}$  |

Names of other oxyanions with atoms in the same group:

|           |                    |          |                     |                        |
|-----------|--------------------|----------|---------------------|------------------------|
| carbonate | $\text{CO}_3^{2-}$ | silicate | $\text{SiO}_3^{2-}$ |                        |
| chlorate  | $\text{ClO}_3^-$   | bromate  | $\text{BrO}_3^-$    | iodate $\text{IO}_3^-$ |
| phosphate | $\text{PO}_4^{3-}$ | arsenate | $\text{AsO}_4^{3-}$ |                        |
| sulfate   | $\text{SO}_4^{2-}$ | selenate | $\text{SeO}_4^{2-}$ |                        |



Same root atom  
but different number of oxygens

one more than -ate = per\_\_ate

one less than -ate = \_\_ite

two less than -ate = hypo\_\_ite

chlorate  $\text{ClO}_3^-$

perchlorate  $\text{ClO}_4^-$

chlorite  $\text{ClO}_2^-$

hypochlorite  $\text{ClO}^-$

sulfate  $\text{SO}_4^{2-}$

sulfite  $\text{SO}_3^{2-}$

# POLYATOMIC IONS

Hydrogen-containing oxyanions

Add 'hydrogen' before the name

carbonate  $\text{CO}_3^{2-}$   
hydrogen carbonate (bicarbonate)  $\text{HCO}_3^-$

phosphate  $\text{PO}_4^{3-}$   
hydrogen phosphate  $\text{HPO}_4^{2-}$   
dihydrogen phosphate  $\text{H}_2\text{PO}_4^-$

## Polyatomic CATIONS

ammonium ion  $\text{NH}_4^+$

hydronium ion  $\text{H}_3\text{O}^+$



Have to be memorised (unfortunately)

|              |                              |
|--------------|------------------------------|
| azide        | $\text{N}_3^-$               |
| cyanide      | $\text{CN}^-$                |
| dichromate   | $\text{Cr}_2\text{O}_7^{2-}$ |
| hydroxide    | $\text{OH}^-$                |
| oxalate      | $\text{C}_2\text{O}_4^{2-}$  |
| permanganate | $\text{MnO}_4^-$             |
| peroxide     | $\text{O}_2^{2-}$            |
| superoxide   | $\text{O}_2^-$               |
| thiocyanate  | $\text{SCN}^-$               |
| thiosulfate  | $\text{S}_2\text{O}_3^{2-}$  |
| triiodide    | $\text{I}_3^-$               |

# NAMING AND FORMULAS

**CATION** first, then **ANION**, if needed put the polyatomic ion in brackets

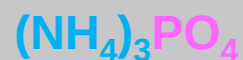
Calcium nitrate



Aluminium carbonate

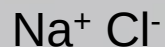


Ammonium phosphate

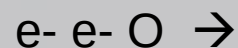
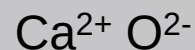


# IONIC COMPOUNDS

Metal + Non-Metal → IONIC COMPOUND



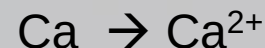
sodium chloride



calcium oxide



calcium chloride



calcium nitride

