

## 1.2: Fundamental Properties - Ionization Energy

The ionization energy (IE), or more properly the ionization enthalpy, is defined as the energy required to loose an electron from a gaseous atom or ion.



Each subsequent ionization energy is greater than the previous one because of the increase in charge on the ion. For example, for any given atom or ion the 1st ionization energy is less than the 2nd ionization energy, and so on. This is shown in Table 1.2.1.1.

Table 1.2.1.1: The first three ionization energies for aluminum.

Ionization	Ionization energy (kJ/mol)
$Al^0 \rightarrow Al^+ + e^{-}$ (1.2.2)	548
$Al^+ \rightarrow Al^{2+} + e^{-}$ (1.2.3)	1823
$Al^{2+} \rightarrow Al^{3+} + e^{-}$ (1.2.4)	2751

How does the ionization energy vary with elements in the periodic table? If we consider the 1<sup>st</sup> ionization potential of the elements in a particular group of the periodic table we note that there is a decrease in ionization potential as you go down the Group. The reason for this trend is due to the increased shielding of the outer shell electrons ( $ns^1$ ) by the completed (filled) inner shells. The  $ns^1$  electron thus exhibits a lower effective nuclear charge and makes it easier to remove. For example, Table 1.2.1.2 shows the 1<sup>st</sup> ionization potential for the Group 1 alkali metals.

Table 1.2.1.2: Variation of the first ionization potential ( $M^0 \rightarrow M^+$ ) for the Group 1 (IA) elements.

Element	Ionization energy (kJ/mol)
Li	526
Na	502
K	425
Rb	409
Cs	382

In contrast, to individual Groups, moving across a particular Period results in a general increase in the ionization potential as is shown in Figure 1.2.1.1. The lack of additional screening of filled shells across the Period means that the ionization energy for the outer shell electrons is dominated by the increase in nuclear charge (number of protons) with increased atomic number.

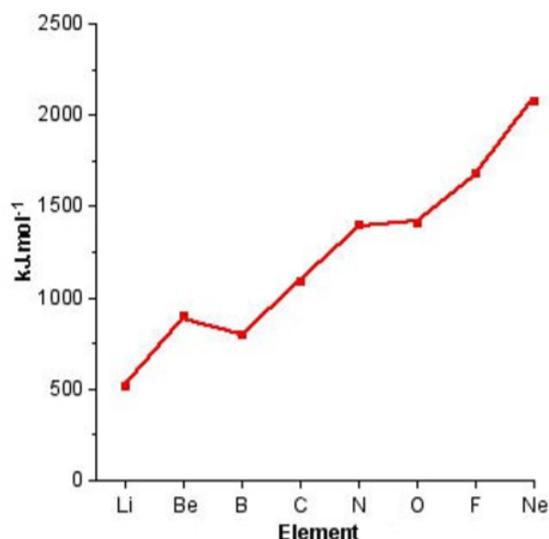


Figure 1.2.1: Plot of the first ionization potential for the elements Li to Ne.

From Figure 1.2.1.1 it can be seen that the Periodic trend is not linear, there are significant steps in the plot. Boron, for example, has a lower first ionization potential than beryllium, why? A consideration of the electron configuration for the elements provides in answer (Figure 1.2.1.2). Beryllium has a  $2s^2$  outer shell configuration, while boron has a  $2s^2 2p^1$  configuration. The  $2p^1$  electron is easy to remove because it exhibits increased shielding from the nucleus due to the filled  $2s$  orbital.

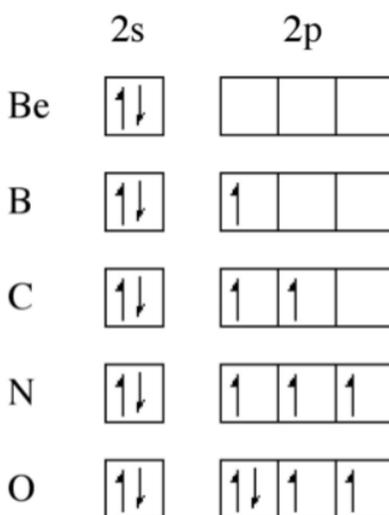


Figure 1.2.2: Outer shell electron configuration of beryllium through oxygen.

As we move from, boron to nitrogen, the  $2p$  shell is filled (Figure 1.2.1.2) without additional shielding and the effect of the increased nuclear charge dominates. Finally, the  $2p^4$  configuration for oxygen (Figure 1.2.1.2) results in an electron pair, which repel each other, thus making it easier to remove an electron (lower ionization potential) than expected from the increased nuclear charge. From Figure 1.2.1 we can see that the effect of electron pairing is less than that of a filled shell.

The trend for the  $2^{\text{nd}}$  ionization potential is similar, but different, to that of the  $1^{\text{st}}$  ionization potential. As may be seen in Figure 1.2.1.3 the steps observed for the  $1^{\text{st}}$  ionization energy plot (i.e., between Be/B and N/O have moved one element to the right). A view of the electron configuration for the  $E^+$  ions (Figure 1.2.1.4) shows that the rationale for the trend in the  $1^{\text{st}}$  ionization potential trends still applies but to the ion of the element to the right in the Periodic table. Now  $B^+$  has a  $2s^2$  outer shell configuration, while  $C^+$  has a  $2s^2 2p^1$  configuration. A similar plot for the  $3^{\text{rd}}$  ionization energy would move the steps another element to the right.

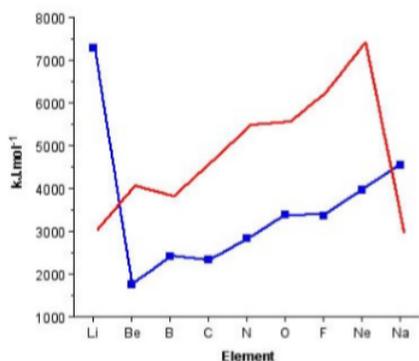


Figure 1.2.3: A plot of 2<sup>nd</sup> ionization energy (enthalpy) for elements Li to Na (blue with square data points) showing the relative trend to the 1<sup>st</sup> ionization potential (red line not to scale).

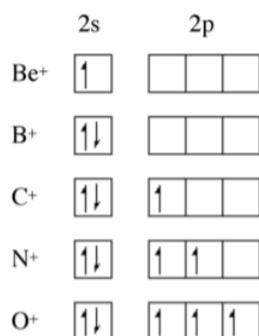


Figure 1.2.4: Outer shell electron configuration of E<sup>+</sup> for beryllium through oxygen.

The other observation to be made from Figure 1.2.1.3 is the very large 2<sup>nd</sup> ionization potential for lithium associated with the ionization of Li<sup>+</sup> to Li<sup>2+</sup>. The large increase is due to the removal of an electron from the filled 1s<sup>2</sup> shell.

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