Ionization Energies

When an electron moves between energy levels the resulting change in energy, ΔE, is always given by the following equation

$$\Delta E = E_2 - E_1$$

where E_2 is the electron's final energy and E_1 is its initial energy. Of particular interest to us is the change in energy when an electron moves to a distance that is infinitely far away from the nucleus; this is called the ionization energy (IE).

Questions to Consider

Do you expect an ionization energy to have a positive value or a negative value? Explain your reasoning.

The ionization energy is positive because E_2 is zero (a free electron's energy) and E_1 is negative (the energy of attraction between electron and nucleus).

Suppose an electron has a potential energy of -2.31×10^{-18} J. What is the electron's IE? Explain your reasoning.

The ionization energy will be $+2.31 \times 10^{-18}$ J because the electron's final energy when it is a free electron is 0 J.

Is the IE for an electron that is 500 pm away from a nucleus larger, smaller or identical to the IE for an electron that is 1000 pm away from the same nucleus? Explain your reasoning.

It will be larger. Because the electron's potential energy is inversely proportional to distance, the closer the electron is to the nucleus, the more negative its potential energy.

If the two ionization energies are not identical, how many times greater is the larger of the two ionization energies? Explain your reasoning.

It will be twice as large since it is twice as close to the nucleus.

Which do you expect to have the larger IE, a hydrogen atom, H, or a helium ion, He^+? Explain your reasoning? Have you made any assumption(s) in reaching your answer? If so, what are they.

The helium ion will have the larger IE because its nucleus has a +2 charge, which is twice that of the hydrogen atom. We must, of course, assume that the electron is at the same distance in both cases, or that the difference in distances is not siginficant relative to the difference in charge of the nuclei.

Ionization energies are obtained experimentally by bombarding atoms in the gas-phase with a beam of fast-moving particles. If the particle's KE is less than the electron's IE, nothing happens when it collides with the atom; however, when the particle's KE matches or exceeds the electron's IE, the collision ejects the electron from the atom. Thus, ionization energies can be measured by slowly increasing the particle beam's KE and looking for the precise energy where an electron is ejected from the atom. For a H atom, the reaction is

$$H(g) \rightarrow H^{+}(g) + e^{-}$$

and the IE is 2.178×10^{-18} J. Usually, ionization energies are reported with units of kJ/mol. What is the IE for H in these units? ($N_A = 6.022 \times 10^{23}$ mol^{-1})

$$2.178 \times 10^{-18} \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times \frac{6.022 \times 10^{23}}{\text{mol}} = 1312 \text{ kJ/mol}$$

Suppose you have an atom with many electrons, each at a different distance from the nucleus. Does every electron in the atom have the same ionization energy? Explain your reasoning. If the IEs are not the same, which electron – the one closest to the nucleus or the one furthest from the nucleus – has the lowest IE? Explain your reasoning.

They will have different IE's because the electron's potential energy is inversely proportional to its distance from the nucleus. The electron with the lowest IE, therefore, is the one furthest form the nucleus.

Suppose that several electrons in an atom are equidistant from the nucleus. Do you expect these electrons to have identical or different ionization energies? Explain your reasoning.

Yes. Each electron experiences the same charge on the nucleus and is the same distance from the nucleus; thus, they have the same potential energy and the same IE.

Suppose that two electrons have identical ionization energies. Based on our current model, will removing one of the electrons affect the other electron's ionization energy?

At this point, our model suggests that there is no difference in the ionization energies as removing one electron does not appear to change either the charge on the nucleus or the distance between the second electron and the nucleus. Later, we will see that this isn't true, which means that our understanding needs some additional work.