Ionization energy is the amount of energy required to remove an electron from a given chemical species. Reduction Potential is a measurement of the amount of force required for a chemical species to gain electrons. The ionization energy is a single step process and follows a constant trend by decreasing down a period within a group. Standard reduction potential is more closely related to a multistep process known as solvation. Solvation upon how easily a solute can break its own bonds, how easily the solute can break its bonds, and how much easily the solute can attract the solvent toward it self in order to form and ionic compound. is depend and upon the polarity of the molecules within the solution. As we will see, some species will have lower ionization energies as well as having higher reduction potential when compared to species of the same period.

Contrasting two metrics of Ionization

Contrast the trend of ionization energy (Table A2) and Standard Reduction Potential (Table P1) of the alkali metals

There is irregular variation in electrode potential due to irregular variation in ionization enthalpy, sublimation energy and energy of hydration.

Ionization Energy

Ionization energy (IE) is the amount of energy needed to tear an electron away from a species; this value is measured in kJ/mol. Ionization energy is related to the amount of electrons in the outer shell as well as the size of the molecule. Larger molecules have lower ionization energies a the outer shells are shielding the nucleus from the outer electron, hence disrupting their charge. Having less valence electrons also decreases the amount of energy required for ionization as atoms want a full electron shell (discussed elsewhere) and with the shielding from the inner shells, the outer electrons tend to be further away from the atom, making them more likely to come into contact with outer molecules and be ripped away with relative ease. It is important to note that ionization energy is in reference to reactions in a gaseous state.

Alkali metals have one electron in their valance shell. These atoms have a strong desire to get rid of that electron so they can attain a more energetically stable noble gas configuration. An alkali metal such as potassium favors becoming an ion and losing its electron so it will have the noble gas configuration of Argon. Since potassium wants to lose its one valance electron, potassium has a small ionization energy: 419 kJ/mol. All the alkali metals exhibit similar behaviors in this respect so they all have relatively small ionization energies.

Consider fluorine as opposed to potassium. A single fluorine atom has the electron configuration: [He] 2s²3p⁵, and a total of seven valence electrons. Fluorine atoms have a strong desire to gain just one more electron so they’ll have a full octet; conversely fluorine atoms do not want to lose any electrons because that pushes them farther away from the possibility of attaining an octet. It requires significantly less energy for fluorine to gain one atom to attain the noble gas configuration of neon than to remove seven electrons to have helium’s configuration. Fluorine is going to “hold on” to its seven electrons tightly so it requires a large amount of energy to take one of those electrons away. Fluorine has a high ionization energy: 1681 kJ/mol. Similarly, all the halogens have relatively high ionization energies.

Ionization energy is also related to atomic radii. They are inversely related so as ionization energy increases, atomic radius
Atoms with many electrons get bigger as the electrons become more shielded from the nucleus. Shielding occurs when the electrons closer in to the nucleus get in the way of the outer electrons being able to “see” the nucleus. These electrons feel the positive influence of the nucleus less strongly so they tend to reside farther out from the nucleus, rendering a very large atom. The farther out an electron is, the easier it becomes to remove it, and less energy is required to do so. Cesium has 55 electrons, and only one in its valence shell. This last electron is very far away from the nucleus; so Cesium has corresponding low ionization energy. Ionization energy decreases as you move down a group. This is a result of the atomic radii and shielding effects. As you go across a period ionization energies increase. This is due to the increasing number of valence electrons and decreasing shielding and radii. The graph below shows these trends. Note: the lanthanides, hydrogen and helium, and radioactive elements have been excluded from the graph. The graph contrasts the high ionization energies of the noble gases to the low ionization energies of alkali metals and the decreasing trend within each group. 

**Reduction Potential**

Reduction-oxidation reactions: These reactions involve the transfer of electrons from one species to another (remember: OIL RIG). The oxidized species is called the reducing agent. Atoms that are good reducing agents, good at being oxidized, are atoms that easily give up electrons. Alkali and alkali earth metals have small ionization energies so they are good reducing agents. Similarly, the reduced species is called the oxidizing agent. Good oxidizing agents, atoms who are good at being reduced, easily gain electrons. Halogens have high ionization energies and really want to gain electrons; therefore they are good oxidizing agents. 

**Oxidation-Reduction Reactions**

Reduction potential: a measure of a species’ tendency to be reduced, gaining electrons. Reduction potentials are an intrinsic property unique to each atom and ion. If reduction potentials are experimentally determined under standard conditions (1 M concentration, 1 bar pressure, 25°C) then they are called Standard Electrode Reduction Potentials (SRP). SRP are measured in Volts and denoted by $E^\circ_{\text{cell}}$. The Standard Hydrogen Electrode potential is arbitrarily set at 0 and all other SRP are relative to this value.

**Gibbs Energy**

Gibbs energy, $\Delta G^\circ$, is a measure of how much energy, in kJ, a system has available to use. Under standard conditions Gibbs energy is denoted by $\Delta G^\circ$. $\Delta G^\circ$, is the thermodynamic connection between standard reduction potential and spontaneity of a reaction. The equation $\Delta G^\circ = -nFE^\circ$ can be used to calculate Gibbs energy for a reaction from a standard reduction potential; where $n$ is the number of moles of electrons transferred, $F$ is Faraday’s constant $=96485$ C/mol e⁻, and $E^\circ_{\text{cell}}$ is the standard reduction potential for a given reaction.

- **If $\Delta G^\circ < 0$** the reaction is spontaneous.
- **If $\Delta G^\circ > 0$** the reaction is not spontaneous.
- **If $\Delta G^\circ = 0$** the reaction is at equilibrium.

The magnitude of $\Delta G^\circ$ is also important. ***If the value is highly negative then the reaction is highly spontaneous,***
as opposed to a slightly negative value where the reaction is spontaneous, but less so. If \( \Delta G \)° is a large positive value, that reaction is not spontaneous at all. Gibb's Free Energy

**Relationship Across a Period**

a. \( \text{Li}^{+} (aq) + e^- \rightarrow \text{Li}(s) \)
   
   IE=522 kJ/mol
   
   \( E^*= -3.040 \) V
   
   \( \Delta G \)°=-nF(-3.040)>0

Since \( \Delta G \)°>0 this reaction is not spontaneous. The actual math is unnecessary in this instance because it is known that a negative number multiplied by another negative number will be positive. This is to be expected because lithium prefers to be in its ionized form without its last electron. The low ionization energy value confirms this. Because \( E^* \) is a large negative value, \( \Delta G \)° will be largely positive indicating that the reaction is highly non-spontaneous and unlikely to occur naturally.

b. \( \text{F}_2(g) + 2e^- \rightarrow 2\text{F}^-(aq) \)
   
   IE=1681 kJ/mol
   
   \( E^*= +2.866 \) V
   
   \( \Delta G \)°=-nF(+2.866)<0

Since \( \Delta G \)°<0 this reaction is spontaneous. Again, the math is unnecessary in this case because a negative number times a positive number will be negative. This result is expected because fluorine atoms really want to gain electrons. This is confirmed by the high ionization energy. Because \( E^* \) is a large positive value, \( \Delta G \)° will be largely negative indicating that the reaction is highly spontaneous and very likely to occur.

These reactions show how groups on the left side of the periodic table, alkali metals, do not want to be reduced and their reduction reaction is highly non-spontaneous. Alkali earth metals’ reduction is also undesired and non-spontaneous, but less so near the nitrogen family where reduction becomes favored. The oxygen family has a strong desire to be reduced, so their reduction reactions are spontaneous, but the halogens have an even stronger desire to be reduced. A similar trend should hold true for all the other periods.

**References**


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