BONDING

Atoms bond chemically to form molecules or ions

Coulomb's Law: All bonds occur because of electrostatic attractions. Atoms stick together to form molecules, and atoms and molecules stick together to form liquids and solids because of the negatively charged e- of one atom are attracted to the positively charged nucleus of another atom.

$$\frac{(+q_1)(-q_2)}{r^2}$$

+q ---> magnitude of the positive charge -q ----> magnitude of the negative charge

r ----> distance between the charges

*The bigger charges mean stronger bonds, smaller charges mean weaker bonds;

*Charges close together mean stronger bonds; charges far apart mean weaker bonds.

ex. CaO or KF Which is a stronger bond?

Types of bonding

Bond type	**Happens between**	**Electrons are**
Ionic	Metal & non-metal	Transferred
Covalent	Non-metals	Shared
Polar Covalent	Non-metals	Shared unevenly
Metallic	Metals	pooled

There are general characteristics of each type of bonding:

- **Ionic:** High melting points, most dissolve in water, conduct electricity when dissolved in water, brittle
- **Covalent:** Low melting points, most do not dissolve in water, do not conduct electricity when dissolved in water
- **Polar covalent:** Medium melting points, some dissolve in water, do not conduct electricity when dissolved in water
- **Metallic:** Soft, conduct heat and electricity, do not dissolve in water

IONIC BONDS:

Why are electrons transferred between these two atoms? Why does Na^{o} form Na^{+} ions and not Na^{2+} or Na^{-}? Why does Cl^{o} form Cl^{-} and not Cl^{2-} or Cl^{+} ions?

- The fact is it depends upon an energy change. In order for these ions to form there is a net energy decrease to a more stable energy level. Making a Na^{2+} ion is not possible because it would require to much energy. The same is true for the Cl^{-}. Making a Cl^{-} ion is easy. You would have to force it to become Cl^{2-}.

Two factors affect the energy involved in the formation of an ionic compound.

1. Removal of electrons from the atoms that become cations (eg. Sodium). I.E. is the amount of energy it takes to move an electron out of orbit in a neutral atom and remove it to some infinite point away from the nucleus is the ionization energy.

2. The energy change that accompanies the addition of one or more electrons to the atoms that become anions. (eg. chlorine). This energy is the electron affinity. The ionization energy and the electron affinity are energies associated with the changes of isolated gaseous atoms. A crystal of salt, however, does not consist of isolated atoms. A crystal of salt is a group of ions packed tightly into a regular pattern. This pattern is referred to as a lattice, and it has a lower energy than the isolated ions. To understand this, imagine that we want the vaporize a salt crystal. In order to do this we must add heat energy in order to get the crystal vibrating fast. In the crystal the forces of attraction exceed the forces of repulsion, so to accomplish our vaporization we have to add enough energy to overcome these forces of attraction. This would of course require work, so vaporizing the crystal increases the ions' potential energy and is endothermic. The reverse process - the imaginary process that forms the lattice form from isolated ions - must therefore lead to a lowering of the potential energy of the system and be exothermic. The amount that the energy of the system is lowered because of these mutual attractions of its ions is the lattice energy. **The lattice energy is the major stabilizing factor for ionic compounds.**

   - In almost every case, the energy input required by the ionization energy is larger than the energy recovered by the electron affinity, so the IE and EA combined have a net energy-raising effect. If is were not for the large energy-lowering effect of the lattice energy, formation of ionic compounds would be endothermic and they simply wouldn't be formed.

   - Now why do atoms react? Right from the beginning, you where told that metals tend to form positive ions and non-metals tend to form negative ions. At the left of the period table are the metals - elements with small IE and EA. Relatively little energy is needed to remove electrons from them to produce positive ions. At the upper right of the periodic table are the non-metals - elements with large IE and EA. It is very difficult to remove electrons from these elements, but sizeable amounts of energy are released when they gain electrons. On an energy basis, it is least "expensive" to form a cation from a metal and an anion from a non-metal.

Formation of Ions by the Representative Elements:

What happens when sodium loses an electron? The electronic structure of Na is Na $1s^22s^22p^63s^1$ The electron that is lost is the one least tightly held. For sodium that is the single outer 3s electron. The electronic structure of the Na^+ ion, then is Na^+ $1s^22s^22p^6$ The removal of the first electron from Na does not require much energy because the first IE of Na is so small. For Na 1^{st} IE = 496 kJ/mol

2^{nd} IE = 4563 kJ/mol Therefore, an input of energy equal to the first IE can be easily recovered by the exothermic lattice energy of ionic compounds containing the Na^+ ion. However, removal of a second electron from sodium is very difficult - the second IE of Na is enormous. The amount of energy that must be invested to create a Na^{2+} ion is therefore much greater then the amount of energy that can be recovered by the lattice energy, so overall the formation of a compound containing Na^{2+} is very energetically unfavorable. This is why we never observe compounds that contain this ion, and why sodium stops losing electrons once it has achieved a noble gas configuration. A similar situation exists for other metals too. Consider calcium, for example. We known that this metal forms ions with a 2+ charge. This means that when it reacts, a calcium atom loses its two outermost electrons.

Ca^o $1s^22s^22p^63s^23p^64s^2$ Ca^{2+} $1s^22s^22p^63s^23p^6$

The two 4s electrons of Ca are not held too tightly, so the amount of energy that must be invested to remove them (the sum of the first and second IE) can be recovered easily by the **lattice energy** of a Ca^{2+} compound. For calcium 1^{st} IE = 590 kJ/mol
2^{nd} IE = 1140 kJ/mol 3^{rd} IE = 4912 kJ/mol

- However, the removal of yet another electron from calcium to form Ca^{3+} requires breaking into the noble gas core. A tremendous amount of energy is needed to accomplish this - much more than would be regained by the lattice energy of Ca^{3+} compound. Therefore, a calcium atom loses just two electrons when it reacts. For sodium and calcium, we find that the stability of the noble gas core that lies below the outer shell of electrons effectively limits the number of electrons that they lose, and that the ions that are formed have a noble gas electron configuration.

A similar configuration also tends to be the fate of nonmetals when they form anions. Chlorine and oxygen are typical non-metals that form anions when they react with metals such as sodium or calcium. When a chlorine atom reacts, it gains one electron. For chlorine we have Cl^o $1s^22s^22p^63s^23p^5$ and when an electron is gained, its configuration becomes Cl^- $1s^22s^22p^63s^23p^6$ At this point, electron gain ceases, because if another electron were to be added, it would have to enter an orbital in the next higher shell. With oxygen, a similar situation exists. The formation of the oxide ion, O^{2-}, gives oxygen a noble gas configuration without much difficulty, O^o $1s^22s^22p^4$ becomes O^{2-} $1s^22s^22p^6$ and the large lattice energies of metal oxides leads to stable compounds. However, we never see the formation of O^{3-} because, once again, the last electron would have to enter an orbital in the next higher shell, and this is very energetically unfavourable. The energy factors cause many atoms to form ions that have a noble gas electron configuration. This leads us to the useful generalization that *when they form ions, atoms of most of the representative elements tend to gain or lose electrons until they have obtained a configuration that is that of the nearest noble gas.*

Ions of Transition Metals

The transition elements are metals that form cations when they react. However, the situation is a bit more complex. Many transition elements are able to form more than one cation because they have a partially filled d subshell that is just slightly lower in energy than the outer s subshell. When a transition metal forms a positive ion, it always loses electrons from its outer s subshell first. Once these are gone, any further electron loss takes place from the partially filled d subshell. Iron is a typical example. Its electron configuration is

Fe $[Ar]3d^6 4s^2$

When iron reacts, it loses its 4s electrons fairly easily to give Fe^{2+}. But because the 3d subshell is close in energy to the 4s, it is not very difficult to remove still another electron to give Fe^{3+}.

Fe^{3+} $[Ar]3d^5$

Because so many transition elements are able to form ions in a similar way, the ability to form more than one positive ion is usually cited as one of the characteristic properties of the transition elements. Frequently, one of the ions formed has a 2^+ charge, which arises from the loss of the outer two s electrons. Ions with larger positive charges result when additional d electrons are lost.