Essentials of Chemistry 2:

Subatomic Particles, Ions and Bonds

Atoms are made up of smaller particles, called **subatomic particles** (meaning “within the atom”). Some of these particles have a **charge**. Charge is a quality that causes some things to be attracted to others, similar to the way magnets are naturally attracted to some metals. Particles that have similar charges (both positive or both negative) are repelled from each other, and particles with opposite charges are attracted to each other. The numbers of each of the particles in an atom tells you how it interacts in reactions.

Protons are large, heavy subatomic particles (…well, heavy for a subatomic particle, anyway) with a positive charge. The number of protons in an atom is called its **atomic number**, and it determines which element that atom is. All atoms that have an atomic number of 6 (i.e., that have 6 protons) are carbon atoms.

Neutrons are also large and heavy subatomic particles, but they do not have a charge (“Neutron” has the same root word as “neutral”). They are clustered together with the protons in the centre of an atom to form the **nucleus** of an atom. It is very difficult to remove protons and neutrons from the nucleus of an atom. Because protons and neutrons have approximately the same mass, the total number of these particles in an atom is called the **mass number** of the atom. It is possible for atoms of an element to have a different number of neutrons (but always the same number of protons). These varieties are called **isotopes** and are distinguished by their mass numbers.

One familiar example of an isotope is carbon-14. Most carbon atoms have six neutrons, but a small percentage of naturally occurring carbon atoms have eight. Carbon-14 (6 protons + 8 neutrons = 14 as a mass number) is used in radiocarbon dating to determine the age of any organic (living) matter, e.g. fossils.

There are also small, light subatomic particles called **electrons**. Electrons have negative charges, and they **orbit** the nucleus. Unlike planets, electrons do not move in defined circular or elliptical paths; they move randomly and can be found anywhere near the nucleus. The areas near the nucleus where they are most likely to be found are called **orbitals**. Because electrons are lighter and are outside the nucleus, they can be removed from or added to an atom much more easily than protons or neutrons. When an atom has the same number of protons as electrons, the positive and negative charges balance (since the charge on each is the same strength), and we say that the atom is **neutral**. If not, the atom has become an **ion**.

An ion is any atom or group of bonded atoms that has an imbalance of charge. If electrons are added to an atom, then it has more negative charges than positive ones, and the atom has an overall negative charge. Negative ions are called **anions**. Many students get confused by this. Although something has been added to the atom it ends up with a negative charge because the only thing that can be added is an electron, which has a negative charge itself.

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If electrons are removed from an atom, then it has more positive charges than negative ones, and the atom has an overall positive charge. Positive ions are called **cations**.

The sharing or exchanging of electrons is what forms bonds between atoms. Bonds and ions form to provide the most stability for the atoms involved. Only the electrons on the outside layer of an atom (the **valence** electrons) can be involved in bonding. Atoms are at their most stable when they have a low-energy configuration of their electrons. The best configuration for an atom or ion is one where it has eight valence electrons, which is called an **octet**. This configuration only happens in neutral atoms for the **noble gases**, (the rightmost column of the periodic table). For all other atoms, this will mean either a surplus of positive or negative charge, or a sharing of electrons with another nearby atom. The tendency to have a positive or negative charge and the way an atom shares electrons in a molecule are determined by the **electronegativity** of each element. Each element has an electronegativity between 0.5 and 4.0, and you can look these up on the periodic table. Elements on the left side of the table tend to have low values, and elements on the right tend to have high values.

If the difference between the electronegativities of two bonded atoms is less than 1.7–1.9, then the bond formed is a **covalent** bond. In a covalent bond, electrons are shared between the atoms. This sharing is not necessarily equal; electrons will be found closer to the atom with the higher electronegativity. Substances with covalent bonds exist as molecules, and they're called covalent substances. Water is an example.

If the difference between electronegativities is greater than 1.7–1.9, then the bond is an **ionic** bond: instead of sharing, the electrons transfer completely to the atom with the higher electronegativity. Substances with ionic bonds form crystals. They are called ionic substances. Table salt ($NaC\ell$, sodium chloride) is an example. In formulas for ionic substances, the positive cation is always listed first.

Elements on the far right side of the periodic table tend to form anions. They usually need only one or two electrons to complete their octets, so they have high electronegativities and tend to receive electrons in ionic bonds. Elements from the far left side tend to form cations. They usually have one or two valence electrons which if lost, allow the electrons in the next layer down to form a complete octet. Elements on both ends of the table tend to form ions with highly predictable charges, while elements near the middle of the table can have a couple of commonly-occurring charges.

Consider beryllium chloride. Beryllium has two valence electrons. (We can tell this because it is in Group 2 in the table, and it is the second element in its row.) It's easier to remove two valence electrons than to add six, so when beryllium forms an ion, it has a charge of 2+: Be^{2+}. For similar reasons, chlorine forms an anion with a charge of 1−: $C\ell^{-}$. (Since chlorine has 7 valence electrons, it only needs one more electron to complete its octet.) For the ionic compound beryllium chloride, it takes two chlorine atoms to accept the two electrons donated by one beryllium atom. The formula is $BeC\ell_2$. Note that the subscripts do *not* indicate the charge on each ion — it would be wrong to write that the ions involved were Be^{+} and $C\ell^{2-}$. Be^{+} and Cl^{2-} would not be stable ions as they break the octet rule. An ion that is unstable won't exist in nature, so the only ions beryllium and chlorine ever form are Be^{2+} and $C\ell^{-}$. On the other hand, copper, which is near the centre of the periodic table, has two common, stable ions: Cu^{+} and Cu^{2+}.