Chapter 11: Atoms and Molecules

Atoms are considered to be the building blocks of matter, i.e. the world around us, but they themselves are made of more fundamental particles, electrons, protons and neutrons.

Electrons, Protons and Neutrons

- The electrons and protons have electric charge and there are strong electrical forces between electric charges. The neutron is neutral, i.e. not charged. There are two types of electric charge, positive and negative. The electron is negative and the proton is positive. Like electric charges repel each other and unlike charges attract each other, so a proton attracts an electron, but two electrons repel each other.
- The charge on the electron is exactly equal in magnitude to the charge on the proton, but opposite in sign. Therefore the total charge of an electron plus a proton is zero, i.e. they cancel.
- The mass of a proton is very close to that of a neutron and it is approximately one atomic mass unit, a.m.u., which is 1.66x10^{-27} kg. An electron has a mass that is about 0.0005 a.m.u., or almost 2000 times smaller than the proton's mass.

Atoms

- The protons and neutrons are found in the nucleus of the atom, and the electrons are in a "cloud" about the nucleus.
- The nuclei are very small, ranging between 2x10^{-14} m and 2x10^{-15} m in diameter. The electron cloud is much larger, about 2x10^{-10} m in diameter. It is the size of the electron cloud that determines the diameter of an atom, but the nucleus contains most of its mass. It would take about four or five billion atoms lined up edge to edge to stretch one meter. Atoms are very small but nuclei are much smaller!
- Neutral atoms have the same number of electrons and protons.
- Atoms are usually grouped into elements, i.e. according to the number of protons in the nucleus. The number of protons in the nucleus is the Atomic Number. All atoms of the same element have the same chemical properties.
- The atomic mass number of an atom is the number of protons plus the number of neutrons in the atom. It is approximately the mass in a.m.u.
- Atoms with the same atomic number can have different atomic mass numbers. Atoms having the same atomic number but different mass numbers are said to be isotopes of the same element. There are three isotopes of the element hydrogen (atomic number 1). The have mass numbers 1, 2 and 3. (These are often written \(^1\)H, \(^2\)H, \(^3\)H and called hydrogen, deuterium, and tritium. The superscript on the left side of the H is the mass number.) Most elements have more than one isotope.
- An atom with a mass number of 14 and an atomic number of 6 would have 6 protons and 8 neutrons in its nucleus. (It is called carbon-14 or \(^{14}\)C, and it is radioactive.)
Radioactivity

- Some nuclei are not stable but will change into other nuclei. This is called radioactive decay. For instance carbon-14, 6 protons + 8 neutrons, changes by emitting an electron from the nucleus, which converts a neutron into a proton. It becomes nitrogen-14, 7 protons + 7 neutrons. (This process where a nucleus emits an electron as a neutron converts to a proton is called beta decay or $\beta^-$ decay. In $\beta^-$ decay the mass number stays the same, but the atomic number increases by 1. There is also a $\beta^+$ decay where a proton emits a positron, an anti-electron, and converts into a neutron. In the $\beta^+$ decay the mass number stays the same, but the atomic number decreases by 1. Both $\beta^-$ and $\beta^+$ decays are lumped together as different types of beta decay.)

- Atoms with atomic numbers 84 or larger all have unstable nuclei. A common, but not the only type, of decay here is alpha decay. In alpha decay the nucleus emits an alpha particle which is a helium nucleus of 2 protons and 2 neutrons. For example, $^{238}$U has an atomic number of 92, so its nucleus contains 92 protons and $238-92 = 146$ neutrons. When it undergoes alpha decay its nucleus loses 2 protons and 2 neutrons, so the atomic number of the resulting nucleus is $92 - 2 = 90$ and the mass number is $238 - 4 = 234$. This new atom is thorium-234, which is also radioactive and undergoes beta decay like carbon-14 does.

- When radioactive nuclei decay, the resulting nucleus is often in an excited state and it then decays to the ground state by emitting a gamma ray, a highly energetic photon. This emission of a gamma ray does not change either the mass number or the atomic number.

- There are other more esoteric types of radioactive decay, but these two, beta decay and alpha decay coupled with the possible emission of a gamma ray, are the most common.