Nuclear Chemistry

Nuclide Symbols

Most elements in the periodic table have more than one form. These forms are known as **isotopes** or **nuclides**. Each nuclide has a unique symbol that shows us which particular isotope it is. The symbols have the following form:

$${}^{A}_{Z}E$$

Where Z is the atomic number (number of protons), A is the mass number (number of protons and neutrons) and E is the one or two letter symbol for the element. The three isotopes of Hydrogen can be represented as:

$${}^{1}_{1}H \quad {}^{2}_{1}H \quad {}^{3}_{1}H$$

The latter two are also known as Deuterium (D) and Tritium (T).

Type of radiation

There are three kinds of radiation. The first is α (alpha) radiation. It is comprised of helium-4 nuclei. It is the weakest type of radiation and can be stopped by paper or clothing. The second is β (beta) radiation and consists of fast moving electrons. It requires a few inches of wood or Lucite to block it. The third type of radiation is the most energetic and is called γ (gamma) radiation. This is composed of high-energy photons (particles of light) and requires several inches of lead or concrete to block it.

In addition to the types of radiation we see here there are a few other types of particles that are encountered in nuclear chemistry.

Type of particle	Symbol
Positron	β^{+} or ${}^{0}_{1}e$ or ${}^{0}_{1}\boldsymbol{b}$
Neutrino	ν
Proton	p or ${}^{1}_{1}p$
Neutron	n or ${}^{1}_{0}n$

All of these can appear in a nuclear reaction.

Balancing nuclear reactions

If you can add and subtract, you can balance a nuclear reaction. The main thing is that the numbers on top on both sides must add up to the same number. Also, the numbers on the bottom on both sides must add up to the same number. Keeping this in mind we can then balance nuclear reactions such as

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + \underline{\qquad}$$

The top numbers on the left add up to 18. This means that the top number on the last term on the right must be 1 (18-17). The bottom numbers on the left add up to 9 so the bottom number on the last term on the right must also be 1 (9-8). That means that the last term must be a proton, or a hydrogen nucleus.

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

Energies involved in nuclear reaction

The energies involved in nuclear reaction are much larger than those involved in chemical reaction. The reason for this is that the law of conservation of mass must be modified to include energy. We do this because Einstein's Theory of Relativity shows that mass and energy are equivalent ($E = mc^2$). We can convert one into the other. When a nuclear reaction takes place, some of the mass in the reactant is converted into energy. Therefore, the products have a very slightly lower mass than the reactants. The difference in mass can be calculated and then, from that, the energy. Looking at the above nuclear reaction:

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

we can calculate the total mass on each side using the masses of the isotopes:

On the left side:

14.003074 amu + 4.00260 amu = 18.005674 amu

On the right side:

16.999131 amu + 1.007825 amu = 17.999135 amu

The difference is:

$17.999135 \text{ amu} - 18.005674 \text{ amu} = -6.539\times10^{-3} \text{ amu}$

This mass difference can the be converted into energy:

$$E = \left(-6.539\times10^{-3} \text{ amu} \times \frac{1.00 \text{ g}}{6.022\times10^{23} \text{ amu}} \times \frac{1 \text{ kg}}{10^{3} \text{ g}} \right) \times \left(2.998\times10^{8} \text{ m s}^{-1}\right)^{2}$$
$$= -9.760\times10^{-13} \text{ J}$$

This is the energy release per atom. If one mole of nitrogen-14 reacts the total energy is the number above time Avogadro's number:

$$E = -9.760\times10^{-13} \times 6.022\times10^{23} = -5.877\times10^{11}\text{ J}$$

This amount of energy is far larger than the amount of energy from any chemical reaction (usually about $10^{5 \text{ or } 6}$ Joules).

Decay Kinetics

Nuclear decay always follows first order kinetics (rate = k N_a, N_a is the original number of atoms present). As a result the half-life of any nuclear decay is a constant. This means that if we know the half-life of a particular isotope, we can calculate how long it has been decaying. This has useful applications in the dating of fossils and rocks. It is the primary means by which we know how long humans have been on this continent and how old the Earth is. The integrated rate law for this applies:

$$\ln\frac{N_t}{N_0} = -kt$$

k can be calculated from the half-life:

$$k = \frac{\ln 2}{t_{1/2}}$$

The problems for nuclear decay are the same as the first order kinetics problems from chapter 13.