Nuclear Reactions

During his investigations on the scattering of alpha particle by nuclei, Rutherford noticed that certain light elements could be disintegrated by these alpha particles. In 1919, he placed an alpha particle source inside a box that could be filled with various gases. A zinc sulphide screen was placed outside the box to detect scintillations. When the box was filled with nitrogen, scintillations were seen on the screen. These scintillations could not have been produced by alpha particles since the distance between the source and the screen was greater than the range of alpha particles in the gas. Rutherford concluded that the particles were protons ejected by the impact of the alpha particles on nitrogen nuclei. This, now famous, nuclear reaction can be written

$$^{14}_{7}\mathrm{N}\ (\text{nitrogen}) + {}^{4}_{2}\mathrm{He}\ (\text{alpha}) \rightarrow [{}^{18}_{9}\mathrm{F}]^{*}\ (\text{fluorine}) \rightarrow {}^{17}_{8}\mathrm{O}\ (\text{oxygen}) + {}^{1}_{1}\mathrm{H}\ (\text{proton})$$

This transmutation [1] of nitrogen into oxygen was the first artificially induced nuclear reaction (notice that radioactive decay is also nuclear reaction but it occurs naturally). Nuclear reactions involve the absorption of a bombarding particle by the nucleus of the target material. Absorption of the bombarding particle first produces an excited compound nucleus (fluorine in the above example) which then decays to yield the final products. The main interactions of interest occur when the bombarding particles are alpha particles, protons, deuterons, neutrons, light nuclei, and photons. The nuclear reaction can be represented as

$$X + a \rightarrow [\text{compound nucleus}]^{*} \rightarrow Y + b$$

Where X is the target nucleus, a the bombarding particle, Y the product nucleus, and b the emitted particle. In condensed form this reaction can be written as

Target (projectile, emission) Product

or X (a,b)Y

since the total charge Z and the total number of nucleons must be the same before and after the reaction, it is customary to include these in the reaction as shown in the transmutation reaction with nitrogen above.

Two basic types of nuclear reactions can be distinguished i.e. *scattering* and *reaction*. In scattering reactions the projectile interacts with the nucleus and transfers some of its energy. Elastic scattering is said to occur if the nucleus is left in its ground state. Inelastic scattering occurs when the nucleus is left in an excited state. In a reaction, the projectile is fully absorbed into the target nucleus and forms a short-lived compound nucleus in an excited state. The nucleus can de-excite by, for example, the emission of a photon or by fissioning.

[1] "Don't call it transmutation…. they'll have our heads off as alchemists", Ernest Rutherford, 1902