NUCLEAR REACTIONS

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In nuclear physics, a nuclear reaction is the process in which two nuclei or nuclear particles collide to produce products different from the initial particles.

In principle a reaction can involve more than two particles colliding, but because the probability of three or more nuclei to meet at the same time at the same place is much less than for two nuclei, such an event is exceptionally rare.

While the transformation is spontaneous in the case of radioactive decay, it is initiated by a particle in the case of a nuclear reaction. If the particles collide and separate without changing, the process is called an elastic collision rather than a reaction.

Kinetic energy may be released during the course of a reaction (exothermic reaction) or kinetic energy may have to be supplied for the reaction to take place (endothermic reaction). This can be calculated by reference to a table of very accurate particle rest masses as follows.

According to the reference tables, the 63Li nucleus has a relative atomic mass of 6.015 atomic mass units (abbreviated u), the deuteron has 2.014 u, and the helium-4 nucleus has 4.0026 u Thus:

Total rest mass on left side = 6.015 + 2.014 = 8.029 u

Total rest mass on right side = 2 × 4.0026 = 8.0052 u

Missing rest mass = 8.029 - 8.0052 = 0.0238 atomic mass units.

In a nuclear reaction, the total (relativistic) energy is conserved.

The "missing" rest mass must therefore reappear as kinetic energy released in the reaction; its source is the nuclear binding energy.

The following calculations can be used when presenting the point under discussion.

Using Einstein's mass-energy equivalence formula $E = mc^2$, the amount of energy released can be determined. We first need the energy equivalent of one atomic mass unit:

$$1\ \text{u}\ c^2 = (1.66054 \times 10^{-27}\ \text{kg}) \times (2.99792 \times 10^8\ \text{m/s})^2$$

$$= 1.49242 \times 10^{-10}\ \text{kg}\ (\text{m/s})^2 = 1.49242 \times 10^{-10}\ \text{J (Joule)}$$

$$\times (1\ \text{MeV} / 1.60218 \times 10^{-13}\ \text{J})$$

$$= 931.49\ \text{MeV},$$

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Hence, the energy released is

$$0.0238 \times 931\ \text{MeV} = 22.4\ \text{MeV}.$$

If expressed differently, the mass is reduced by 0.3 %, corresponding to 0.3 % of 90 PJ/kg is 300 TJ/kg.

This is a large amount of energy for a nuclear reaction; the amount is so high because the binding energy per nucleon of the helium-4 nucleus is unusually high, because the He-4 nucleus is doubly magic. (The He-4 nucleus is unusually stable and tightly-bound for the same reason that the helium atom is inert: each pair of protons and neutrons in He-4 occupies a filled **1s** nuclear orbital in the same way that the pair of electrons in the helium atom occupy a filled **1s** electron orbital).

Consequently, alpha particles appear frequently on the right hand side of nuclear reactions.

The energy released in a nuclear reaction can appear mainly in one of the three ways:

- kinetic energy of the product particles
- emission of very high energy photons, called gamma rays
- some energy may remain in the nucleus, as a metastable energy level.

When the product nucleus is metastable, this is indicated by placing an asterisk ("*") next to its atomic number. This energy is eventually released through nuclear decay.

A small amount of energy may also emerge in the form of X-rays.

Generally, the product nucleus has a different atomic number, and thus the configuration of its electron shells is wrong.

As the electrons rearrange themselves and drop to lower energy levels, internal transition X-rays (X-rays with precisely defined emission lines) may be emitted.