Group IV: Neutron Capture

Profile : Neutron Capture

Nuclear reactions are physical processes in which **two nuclides** (atomic nuclei) react or fuse with each other. One nuclear reaction of particular importance in nuclear astrophysics is neutron capture. Here, one of the two reactants is a **Neutron**. An example of neutron capture is the following reaction with natural gold (Au-197):

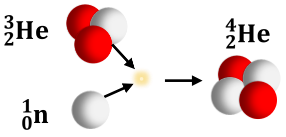
$$^{197}_{79}\mathrm{Au} + ^{1}_{0}\mathrm{n} \rightarrow ^{198}_{79}\mathrm{Au} + \gamma$$

The nuclide Au-197 absorbs a neutron, creating a new isotope. This isotope Au-198 is in a highly excited state, and emits its excess energy in the form of a gamma quantum (= **photon**, γ). Nuclear reactions usually require energy to be added to make the reaction possible. However, unlike other nuclear reactions, neutron capture is possible at very low kinetic energies of the neutron. One can also calculate the released energy ΔE in a nuclear fusion like neutron capture:

$$\text{Rest Energy Parent Nuclide} + \text{Energy Neutron}$$
$$= \text{Rest Energy Daughter Nuclide} + \text{released Energy}$$

Or as formula:

$$\mathrm{E_0(X) + E(n) = E_0(Y) + \Delta E}$$



Helium-3 is stable, but can react with a free neutron to produce Helium-4, which has a higher binding energy.

In a Nutshell

- ✓ The overall reaction is generally $^{A}_{Z}\mathbf{X} + ^{1}_{0}\mathbf{n} \rightarrow ^{A+1}_{Z}\mathbf{Y} + \boldsymbol{\gamma}$
- ✓ Occurs at: **Free Neutrons**
- ✓ Radiation released: **Photons**

Expert Task | Nuclear Waste

A significant proportion of nuclear waste from nuclear reactors is produced by neutron capture in nuclear reactors. In this process, the original nuclear fuel (usually Uranium) reacts with free neutrons to produce radioactive isotopes with even higher mass numbers. An example of this is neutron capture with **U-238** (Uranium isotope, which even occurs naturally in small quantities).

a) Set up the reaction equation and use conservation of mass number and proton number and the nuclide table to determine the daughter nucleus (The formula in the Nutshell box can help you).

b) Calculate the energy released ΔE. Use the following values:
$\mathrm{E_0(U\text{-}238) = 221{,}70\ GeV}$ $\mathrm{E_0(U\text{-}239) = 222{,}63\ GeV}$ $\mathrm{E(n) = 1{,}16\ GeV}$

Home Group Task

What to explain:

- Choose any stable nuclide and write down the reaction equation for neutron capture. Using the equation, briefly summarize neutron capture and its properties.
- Explain how to calculate the energy released in a fusion reaction.

What you have to find out:

- Why can neutron capture occur at particularly low kinetic energies? Ask group 3 and find out what the "Problem" is in nuclear fusion and what the Coulomb barrier is.