Nuclear reactions

proton-proton chain (p-p chain)

I $\quad {}^1H + {}^1H \rightarrow {}^2H + e^+ + \nu_e + 1.18\ \text{MeV}$

II $\quad {}^1H + {}^2H \rightarrow {}^3He + \gamma + 5.49\ \text{MeV}$

III $\quad {}^3He + {}^3He \rightarrow {}^4He + {}^1H + {}^1H + 12.85\ \text{MeV}$

Notation. ^2_1H

Number of nucleons A

Nucleon is sum of neutrons N and protons Z, so

$$A = Z + N$$

Chemical element

Number of protons Z

Superfluous because the chemical element is in a 1:1 correspondence with Z.

Hydrogen means $Z=1$

Helium means $Z=2$

Lithium means $Z=3$

etc.

Sometimes you will find

p instead of ^1H (proton) protium

d instead of ^2H (deuteron ~~deuterion~~) deuterium

Isotope: same number of protons but different number of neutrons, e.g.

^2H also written as ^2_1H

^1H

~~^3He also written ^3_2He~~

$^3He \qquad {}^3_2He$

$^4He \qquad {}^4_2He$

Isotone Same number of neutrons but different number of protons

neutrons

$7 < {}^{12}_{5}B$

$7 < {}^{13}_{6}C$

Isobar Same number of nucleons (protons + neutrons)

${}^{40}_{18}Ar \quad {}^{40}_{19}K \quad {}^{40}_{20}Ca$

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weak nuclear force

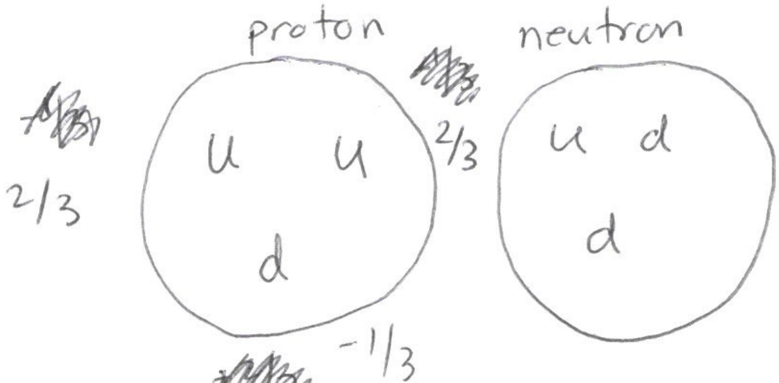
Emission of neutrinos is a telltale of weak interaction

$$\text{I} \quad {}^{1}H + {}^{1}H \longrightarrow {}^{2}H + e^{+} + \nu_e$$

$$p + p \longrightarrow d + e^{+} + \nu_e$$

Can you create and atom with ~~2 hydrogens~~ 2 protons and no neutrons?

☆ Why or why not?



$$q_p = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = \frac{3}{3} = 1$$

$$q_n = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = \frac{0}{3} = 0$$

just like electrons can absorb energy in an atom and move to a higher energy orbital so can the proton absorb energy

$$m_p = 1.672 \times 10^{-27}\ \text{kg} = 938.27\ \frac{\text{MeV}}{c^2}$$

$$m_n = 1.674 \times 10^{-27}\ \text{Kg} = 939.56\ \frac{\text{MeV}}{c^2}$$

* If the neutron is more massive, which one is more stable? The mean life time of
The proton! a neutron is 881 s (free neutron)

In addition to quantum tunneling of the Coulomb interaction (which occurs with low probability to begin with) a weak interaction is necessary to "flip" one of the up quarks into a down quark.

β^+ decay only occur within a nucleus, the two protons form a "nucleus" for a short time with quantum tunnel

$$\Delta q = -1/3 - 2/3 = -1$$

In order to conserve charge, a positron is emitted along with a neutrino

Although a nucleus with two protons is not stable, a nucleus with 1 proton and 1 neutron IS stable.

The antielectron annihilates with an electron right away producing 2 γ rays. The neutrino interacts very weakly, so it essentially escapes.

Reaction I occurs very rarely, about once evere 10^{10} years. (in the sun)

The mass of an up quark is $2.2^{+0.5}_{-0.4} \frac{MeV}{c^2}$, the mass of a down quark is $4.7^{+0.5}_{-0.3} \frac{MeV}{c^2}$, so

Proton

$$2\left(2.2 \frac{MeV}{c^2}\right) + \left(4.7 \frac{MeV}{c^2}\right) = 9.1 \frac{MeV}{c^2}$$

But $m_p = 938 \frac{MeV}{c^2}$ where is all the 'extra' mass coming for??

For neutron

$$\left(2.2 \frac{MeV}{c^2}\right) + 2\left(4.7 \frac{MeV}{c^2}\right) = 11.6 \frac{MeV}{c^2}$$

But $m_n = 939 \frac{MeV}{c^2}$

From the strong force binding energy!

Reaction II: $^1H + {}^2H \longrightarrow {}^3He + \gamma + 5.49\ MeV$

does not require weak interaction, Coulomb barrier not that high, so it happens once every 1 s (in the sun)

A consequence of this is that deuterium does not exist in the core of stars. The ratio of deuterium to hydrogen in the universe is 26 in 1 million. In the earth's oceans it is 156 per 1 million (1 in 6,410). All remain from Big Bang.

III $^3He + {}^3He \rightarrow {}^4He + {}^1H + {}^1H + 12.85\,MeV$

Occurs once every 300,000 years or so.

Although another path exists

$${}^2_1H + {}^1_1H \rightarrow {}^3_2He + \gamma$$

69%

$${}^3_2He + {}^3_2He \rightarrow {}^4_2He + 2\,{}^1_1H$$

31%

$${}^3_2He + {}^4_2He \rightarrow {}^7_4Be + \gamma$$

99.7%

$${}^7_4Be + e^- \rightarrow {}^7_3Li + \nu_e$$

$${}^7_3Li + {}^1_1H \rightarrow 2\,{}^4_2He$$

0.3

$${}^7_4Be + {}^1_1H \rightarrow {}^8_5B + \gamma$$

$${}^8_5B \rightarrow {}^8_4Be + e^+ + \nu_e$$

$${}^8_4Be \rightarrow 2\,{}^4_2He$$

I + II
I + II
> III

each time this occurs, 4 protons are converted into a ^4He nucleus, $2\nu_e$, photons, and kinetic energy. Adding all the energies,

Get the 0.7% from here.

you get 26.73 MeV, the mass of ^4He is $25.71\,\frac{MeV}{c^2}$, $2(0.511\,MeV)$ annihilation of existing e^-, 25.71 MeV.