Lifetimes and Carbon Dating

$$-\frac{dN}{dt} = \lambda N$$

$$N(t) = N_0 e^{-\lambda t}$$

$$\tau = \frac{1}{\lambda}$$

$$t_{1/2} = \tau \ln 2$$

$$p + \text{nucleus} \rightarrow n + X$$

p ↑ cosmic; nucleus ↑ atmosphere

$$n + {}^{14}N \rightarrow p + {}^{14}C$$

$${}^{14}C \rightarrow {}^{14}N + e^- + \bar{\nu}_e$$

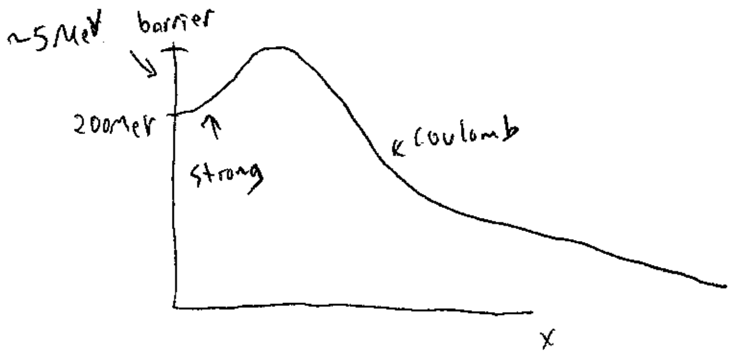
$$t_{\frac{1}{2}} = 5730\,y$$

Ratio of ^{12}C to ^{14}C is 1.3×10^{-12}, which is maintained in living organisms

Nuclear Fission

Heavy nuclei decay into two lighter nuclei

Fission Barrier



$n + {}^{235}U \rightarrow {}^{236}U^* \rightarrow$ fission

↑ excited state ~~that~~ is larger than barrier

chain reaction

$n + {}^{235}U \rightarrow {}^{236}U^* \rightarrow {}^{90}Kr + {}^{143}Ba + 3n$

more efficient when n is 'slow'. produced neutrons are typically too fast to initiate fission. they can be slowed down by interactions with water

In class problem

find the energy relevsed in the reaction

$$n + {}^{235}U \rightarrow {}^{236}U^{*} \rightarrow {}^{90}Kr + {}^{143}Ba + 3n$$

the inconning neutron has $E_K = 0.01$ eV

Solution

$$Q = m_n c^2 + M_U c^2 + E_K - m_{Kr} c^2 - m_{Ba} c^2 - 3(m_n) c^2$$

$$= 0.9396 \text{ GeV} + 218.8968 \text{ GeV} - 83.7418 \text{ GeV} - 133.1020 \text{ GeV} - 3(.9396 \text{ GeV})$$

$$= 174 \text{ MeV}$$

$$1 \text{ W} = 174 \times 10^6 \text{ eV} \times \frac{1.6 \times 10^{-19} \text{ J}}{1 \text{eV}} \cdot \text{Rate}$$

$$\text{Rate} \sim 10^{11} \text{ s}^{-1}$$

Compare to

$$2H_2 + O_2 \rightarrow 2H_2O + (5.7 \text{ eV})$$

Fusion

$$d + t \rightarrow \alpha + n$$

$$^{2}H + ^{3}H \rightarrow ^{4}He + n$$

$$Q = m_d c^2 + m_t c^2 - m_\alpha c^2 - m_n c^2$$

$$= 17.6 \text{ MeV}$$

Neutrino production in the sun

$$p + p \rightarrow d + e^+ + \nu_e$$

$$p + e^- + p \rightarrow d + \nu_e$$

$$^{7}Be + e^- \rightarrow ^{7}Li + \nu_e$$

$$^{7}Be + e^- \longrightarrow ^{7}Li^* + \nu_e$$

$$^{8}B \longrightarrow ^{8}Be + e^+ + \nu_e$$

$$^{3}He + p \rightarrow \alpha + e^+ + \nu_e$$

Detecting neutrinos

$$\nu_e + ^{37}Cl \rightarrow e^- + ^{37}Ar$$

Neutrino flux expected on earth is 10^{15} $m^{-2} s^{-1}$

Observed flux is less.

This is thought to happen from 'neutrino oscillation' between 'flavors'

$$\nu_e \longleftrightarrow \nu_\mu$$

ν_μ not detected

Possible if neutrinos have mass, Estimated mass ~ 0.1 eV

Nuclear spin

^3He → protons must have opposite spin from pauli exclusion - these add to zero
spin comes from remaining neutron

$s = \frac{1}{2}$

^4He both proton and neutron pairs add to zero

$s = 0$

ground state electronic spin is $s = 0$

Total spin of the atom comes from nuclear spin

^3He is a fermion

^4He is a Boson

Magnetic moment

$$\mu_p = \frac{e\hbar}{2m_p} g_p \qquad g_p = 2.79$$

$$\mu_N = \frac{e\hbar}{2m_p}$$

$$\mu_p = 2.79 \, \mu_N$$

$$\mu_n = -1.91 \, \mu_N$$

Radiation through Matter

Bethe-Block eq.

$$\frac{dE}{dx} = - \frac{C Z \rho}{A \beta^2} \left[\ln\left(\frac{2 m \gamma^2 \beta^2 c^2}{I} \right) - \beta^2 \right]$$

$$C = 0.0307 \text{ MeV } m^2/kg$$

approximation

$$-\left(\frac{dE}{dx}\right) \approx \left(0.2 \text{ MeV } m^2/kg\right) \rho$$

Radiation Units and doses

activity - becquerel $1 Bq = 1$ decay/s - SI unit

curie $1 Ci = 3.7 \times 10^{10}$ Bq

~ activity of 1g of radium

'radiation absorbed dose' - energy absorbed per mass of medium ~~particle~~

gray $1 Gy = \frac{1 J}{Kg} = 6.25 \times 10^{12}$ MeV/kg - SI Unit

For damage done to biological entities

'radiation dose equivalent'

sievert $1 Sv = (1 Gy) \times Q$ -

radiation	Q
γ	1
e	1
p (10 MeV)	1
p (1 GeV)	2
n (thermal)	3
n (fast)	10
α	20

typical Background ~ 1 mSv /year

1-5 Sv - sickness, death