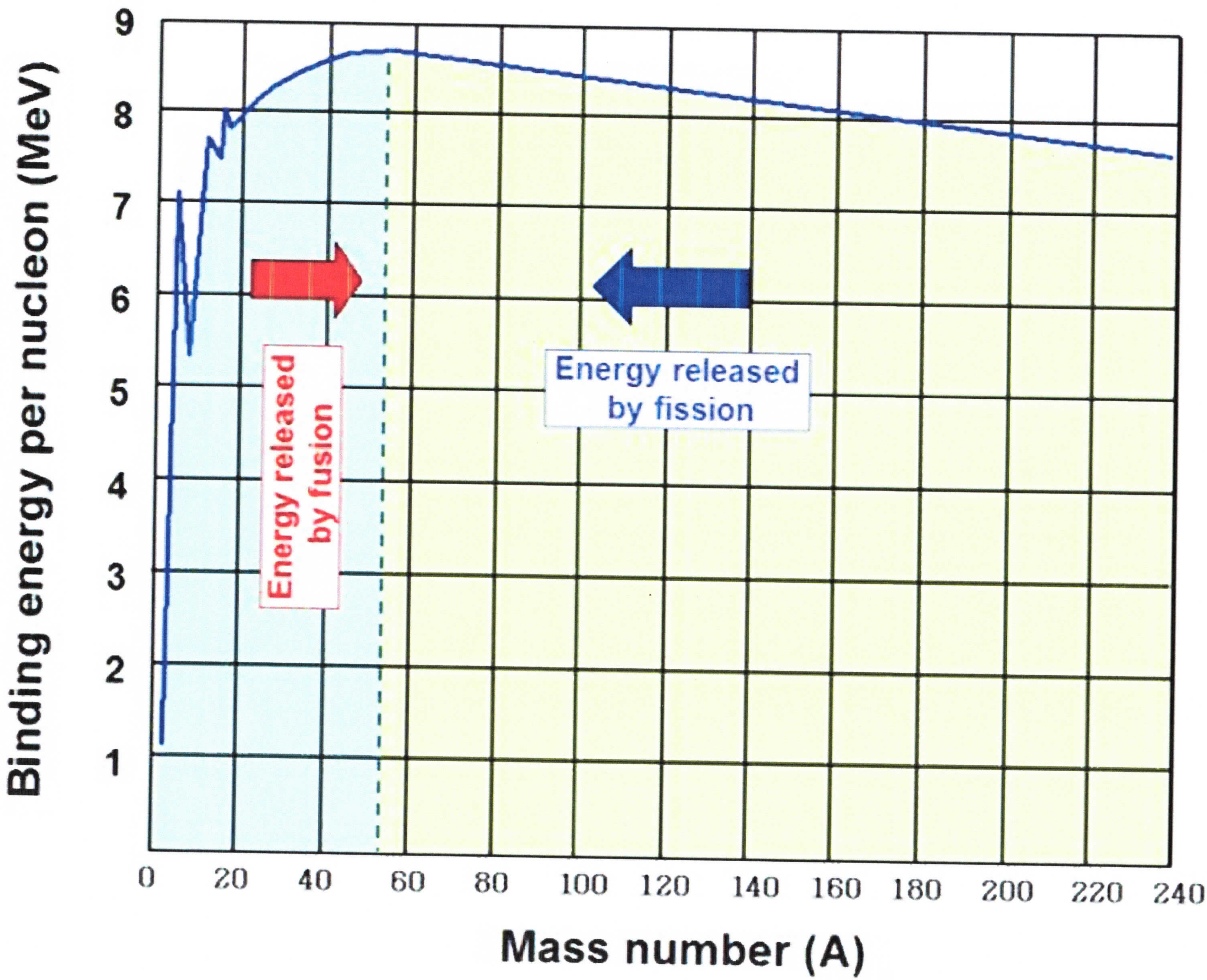
Table of Isotopes (light)

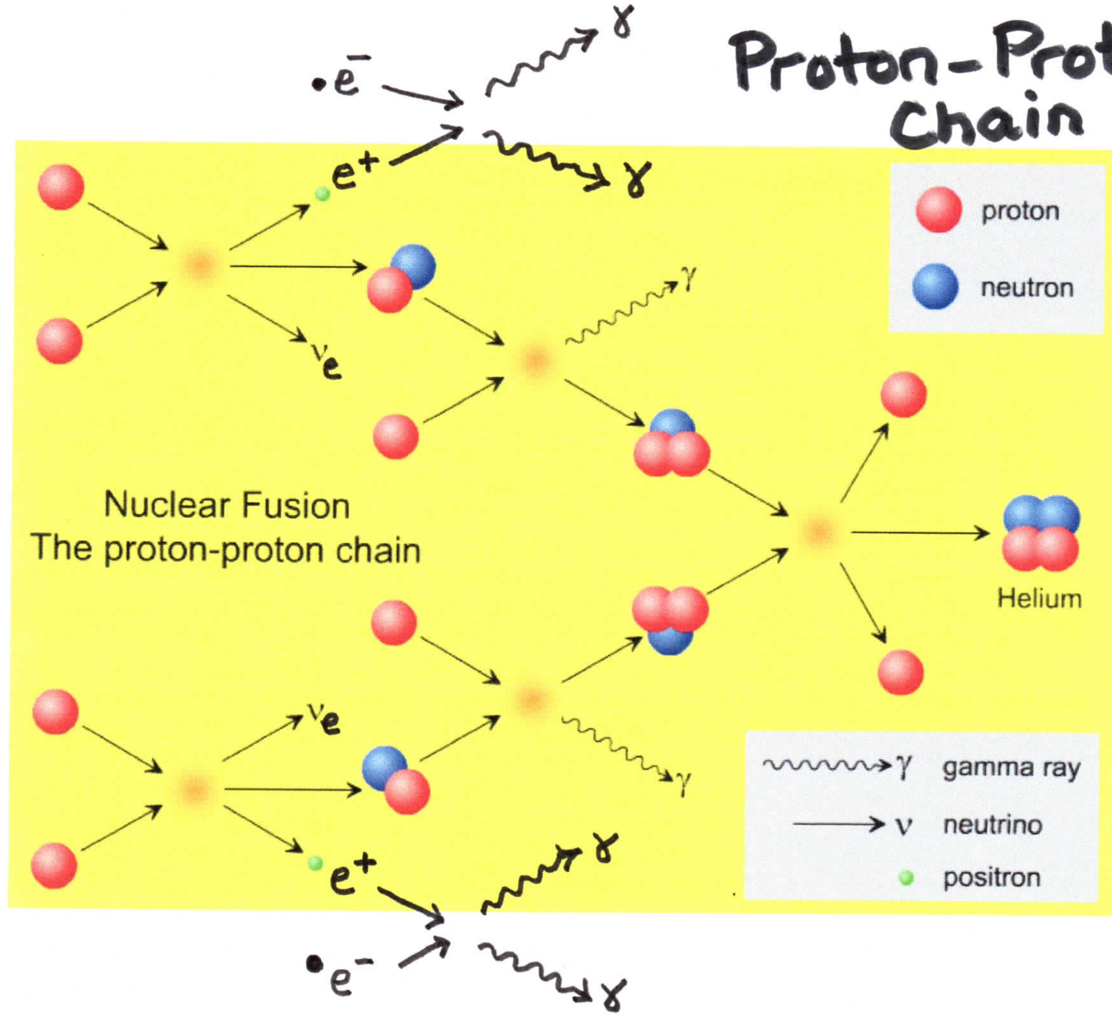
neutral

D	2.014102 u	
T	3.016050 u	12.3 yr (β^-)
^{3}He	3.016030 u	
^{4}He	4.002603 u	
^{6}Li	6.015121 u	
^{7}Li	7.016003 u	53.3 da (EC)
^{7}Be	7.016928 u	
^{8}Be	8.005305 u	10^{-17} s
^{13}C	13.003355 u	
^{14}C	14.003241 u	5730 yr (β^-)
^{13}N	13.005738 u	9.97 min (EC)
^{14}N	14.003074 u	
^{15}O	15.003065 u	122 s (β^+, EC)
^{16}O	15.994915 u	
^{18}O	17.999160 u	

$^{1}H^{+1}$ →	p	1.007276 u
	$e^{\pm}$	.000549 u
$^{2}H^{+1}$ →	d	2.013553 u
$^{4}He^{+2}$ →	α	4.001505 u


Binding energy per nucleon (MeV)
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
180
200
220
240
Mass number (A)
Energy released by fusion
Energy released by fission

Proton-Proton Chain



Proton-Proton Chain

① $p + p \rightarrow {}^2He \rightarrow d + e^+ + \nu_e + Q_1$

② $d + p \rightarrow {}^3He + Q_2$

③ ${}^3He + {}^3He \rightarrow {}^4He + 2p + Q_3$

$Q_1 = .42\,MeV$

$Q_2 = 5.49\,MeV$

$Q_3 = 12.86\,MeV$

$2\times(p + p \rightarrow d + e^+ + \nu_e + Q_1)$

$2\times(d + p \rightarrow {}^3He + Q_2)$

$1\times({}^3He + {}^3He \rightarrow {}^4He + 2p + Q_3)$

$$4p + 2d + 2p + 2\,{}^3He \rightarrow 2d + 2e^+ + 2\nu_e + 2\,{}^3He + {}^4He + 2p + 2Q_1 + 2Q_2 + 1Q_3$$

included

net: $4p \rightarrow {}^4He + 2\nu_e + Q_{net} + 2e^+$

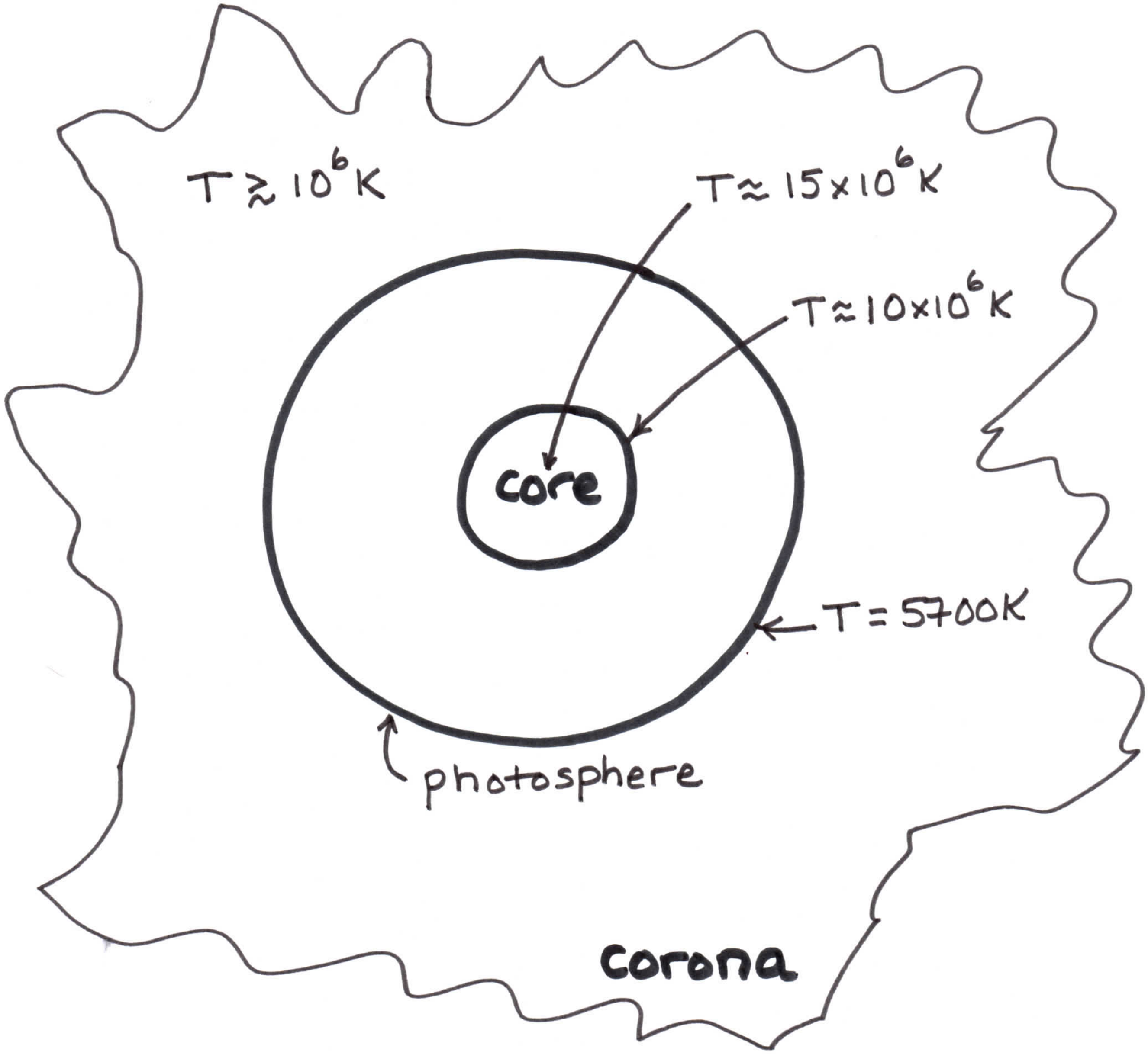
$Q_{net} = 2(.42\,MeV) + 2(5.49\,MeV) + 12.86\,MeV = \underline{24.68\,MeV}$

$2e^+ + 2e^- \rightarrow 2(2\gamma) \leftarrow Q = 2.04\,MeV$

$$\begin{array}{l} \; 4p \rightarrow {}^4He + 2e^+ + 24.68\,MeV \\ +\; 2e^+ + 2e^- \rightarrow 2.04\,MeV \\ \hline \; 4p + 2e^- \rightarrow {}^4He + \underline{26.72\,MeV} \end{array}$$

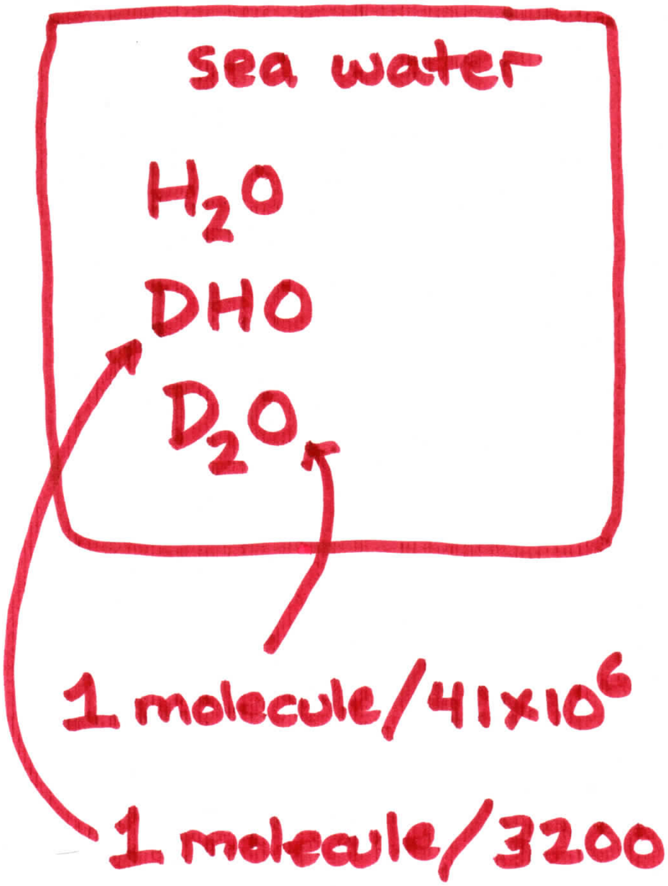
this includes $2 \times \nu_e$

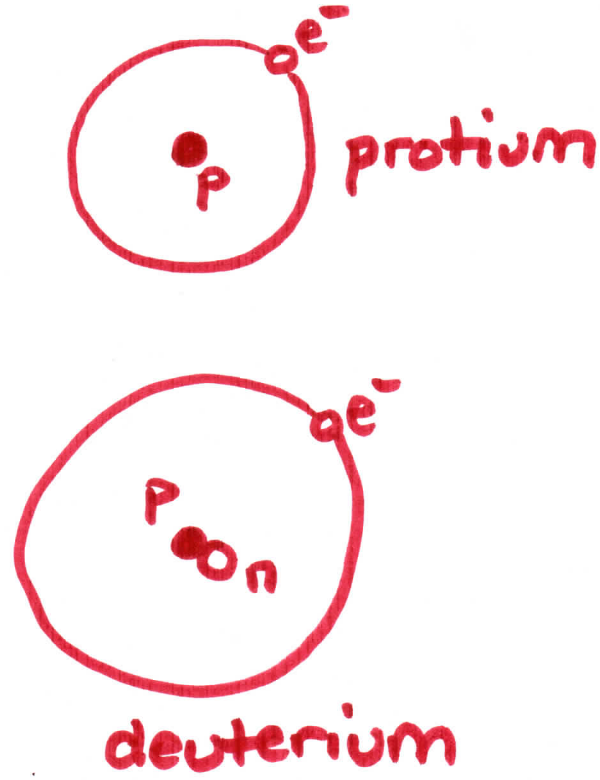
Sun



$T \gtrsim 10^6 K$
$T \approx 15 \times 10^6 K$
$T \approx 10 \times 10^6 K$
core
$T = 5700K$
photosphere
corona

Protium and Deuterium





deuterium accounts for 1 atom out of every 6400 atoms of all hydrogen isotopes in sea water

* 25% of eukaryotic organism's water is D_2O → cell division problems and sterility
* 50% of eukaryotic organism's water is D_2O → death due to cytotoxicity

CNO Cycle

① $p + {}^{12}C \rightarrow {}^{13}N + \gamma_1$

② ${}^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

③ $p + {}^{13}C \rightarrow {}^{14}N + \gamma_2$

④ ${}^{14}N + p \rightarrow {}^{15}O + \gamma_3$

⑤ ${}^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

⑥ $p + {}^{15}N \rightarrow {}^{12}C + {}^{4}\alpha$

Triple-α Process

γ-rays included

$$ {}^{4}_{2}\alpha + {}^{4}_{2}\alpha \rightarrow {}^{8}_{4}Be + Q_1 = -.094 \text{ MeV} $$

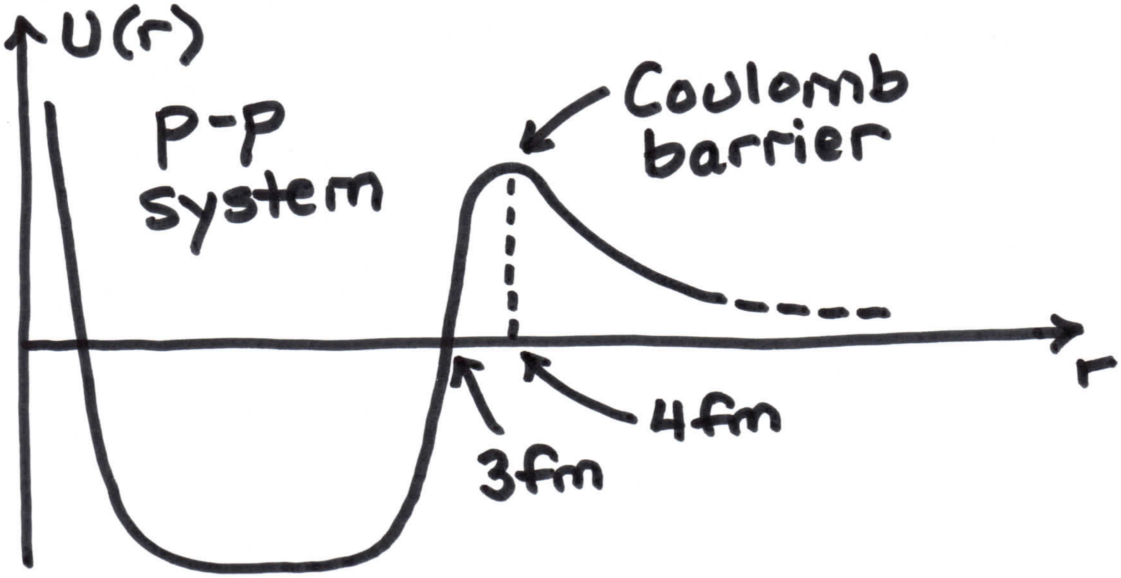
$$ {}^{8}_{4}Be + {}^{4}_{2}\alpha \rightarrow {}^{12}_{6}C + Q_2 = +7.37 \text{ MeV} $$

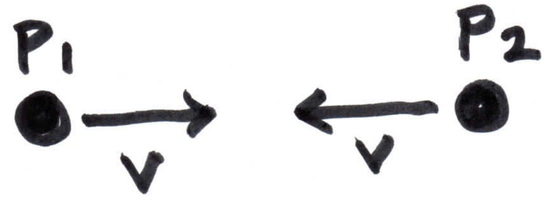
---

net: $3\alpha \rightarrow {}^{12}_{6}C + Q_{net} = 7.27 \text{ MeV}$

occurs in cores of collapsing stars with considerable H → He conversion when T becomes $\approx 10^8$ K

Nuclear Fusion





to overcome Coulomb barrier

$$K_1 + K_2 = \frac{k_e e^2}{a_{min}}$$ ← 4fm

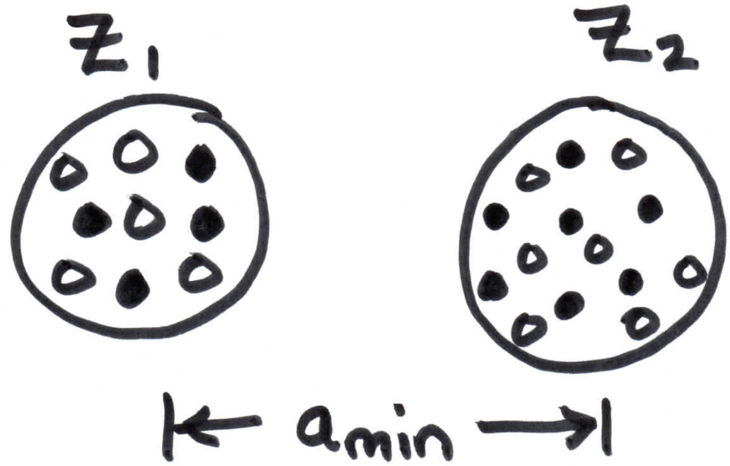
$$\frac{1}{2} m v_{rms}^2 + \frac{1}{2} m v_{rms}^2 = \frac{k_e e^2}{a_{min}}$$

$$\frac{3}{2} k_B T + \frac{3}{2} k_B T = \frac{k_e e^2}{a_{min}}$$

$$T = \frac{k_e e^2}{3 k_B a_{min}} = \frac{9\times10^9 (1.6\times10^{-19})^2}{3(1.38\times10^{-23})(4\times10^{-15})}$$

$$= 1.4\times10^9 \text{ K}$$

Critical Ignition Temperature



$$K_1 = \frac{3}{2} k_B T_c \qquad K_2 = \frac{3}{2} k_B T_c$$

$$K_{total} = 3 k_B T_c = \frac{k_e (Z_1 e)(Z_2 e)}{a_{min}}$$

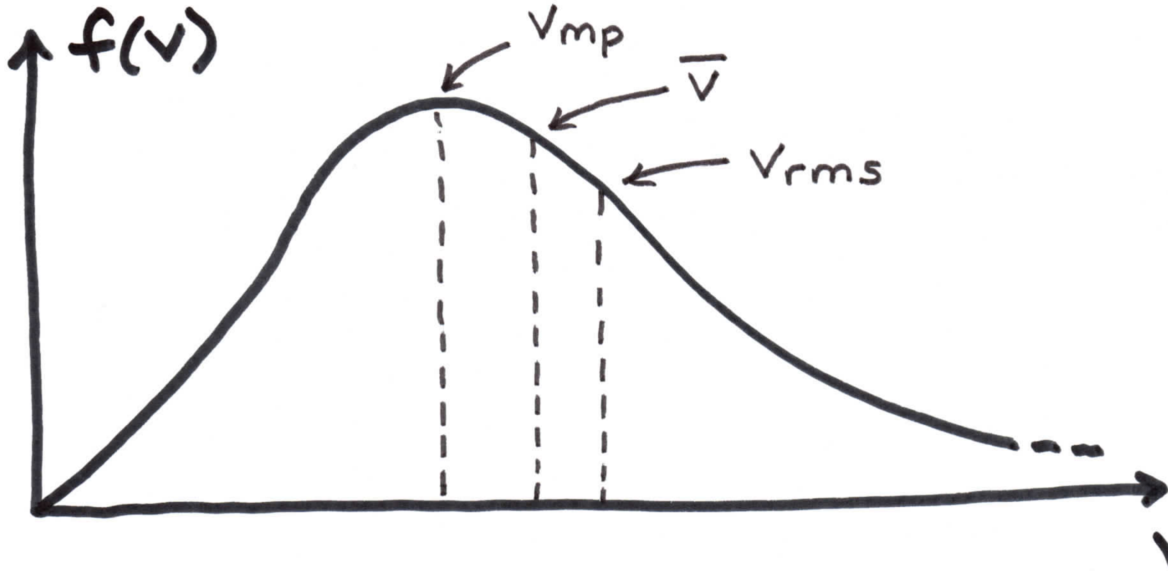
$$T_c = \frac{k_e Z_1 Z_2 e^2}{3 k_B a_{min}}$$

for $d + d \rightarrow {}^3He + n + Q$

$$T_{experimental} = 4 \times 10^8 K$$

$$\Rightarrow a_{min} \approx 14 \text{ fm}$$

Maxwell-Boltzmann Distribution



$$f(v) = \sqrt{\left(\frac{m}{2\pi k_B T}\right)^3}\, 4\pi v^2 \exp\left\{-\frac{mv^2}{2k_B T}\right\}$$

$$v_{mp} = \sqrt{\frac{2k_B T}{m}} \qquad \bar{v} = \sqrt{\frac{8k_B T}{\pi m}} \qquad v_{rms} = \sqrt{\frac{3k_B T}{m}}$$

R♂ R☉

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The Solar Interior