# He fusion

At $10^7$K, $-\frac{Z_1 Z_2}{T_7^{1/2}} \approx -4$, yet does not happen

$$^4_2\text{He} + ^4_2\text{He} \rightarrow ^8_4\text{Be}^* \rightarrow 2\,^4_2\text{He}$$

↳ unstable, less bound than $2\,^4_2$He by ~100 keV. Decays in few $10^{-16}$ s

Compare w/ duration of scattering

$$T \sim 10^8\text{K} \Rightarrow v \approx \sqrt{\frac{\frac{3}{2}kT}{\frac{1}{2}m_p 4}} \approx 800\ \text{km/s} \Rightarrow t_{scat} \approx \frac{1\,\text{fm}}{v} \approx 10^{-21}\,\text{s}$$

⇒ still increases chance for another reaction by $10^5$

$$^4_2\text{He} + ^8_4\text{Be} \rightarrow ^{12}_6\text{C} + \gamma \qquad \text{final rate} \propto \rho^2 X^3_{He}$$

↓ triple alpha

With sufficient $^{12}_6$C

$$^{12}_6\text{C} + ^4_2\text{He} \rightarrow ^{16}_8\text{O} + \gamma \quad \text{common}$$

$$^{16}_8\text{O} + ^4_2\text{He} \rightarrow ^{20}_{10}\text{Ne} + \gamma \quad \text{rarer (beyond: v. rare)}$$

⇒ final products: $^{12}_6$C & $^{16}_8$O

Also $^{14}_7\text{N} + ^4_2\text{He} \rightarrow ^{18}_9\text{F}$

$$^{18}_9\text{F} + e^- \rightarrow ^{18}_8\text{O} + \nu_e$$

$$^{18}_8\text{O} + ^4_2\text{He} \rightarrow ^{22}_{10}\text{Ne} + \gamma$$

Also $^{14}_7\text{N} \rightarrow ^{22}_{10}\text{Ne}$

↓ extra neutrons

# C fusion

$^{12}_{6}C + {}^{12}_{6}C \rightarrow {}^{24}_{12}Mg^{*}$

$\rightarrow {}^{24}_{12}Mg + \gamma$ UNLIKELY EXO

$\rightarrow {}^{23}_{12}Mg + n$ " ENDO.

$\rightarrow {}^{23}_{11}Na + p$ $P \sim 0.5$ EXO

$\rightarrow {}^{20}_{10}Ne + \alpha$ $\sim 0.5$

$\rightarrow {}^{16}_{8}O + 2\alpha$ ENDO

p, $\alpha$ at high T → immediate reactions

Also chain $^{12}_{6}C(p,\gamma)^{13}_{7}N(e^{+}\nu)^{13}_{6}C(\alpha,n)^{16}_{8}O$

↑ extra neutron!

Also $^{22}_{10}Ne(\alpha,n)^{25}_{12}Mg$

Net produce $^{16}_{8}O$ & $^{20}_{10}Ne$

Next, for fusion $^{16}_{8}O + {}^{16}_{8}O \rightarrow {}^{32}_{16}S^{*} \rightarrow {}^{32}_{16}S + \gamma$ UNLIKELY

$^{31}_{15}P + p$

$^{31}_{16}S + n$ UNLIKELY

lots of sec. reactions

$^{28}_{14}Si + \alpha$

end up w/ a lot of $^{28}_{14}Si$

$^{24}_{12}Mg + 2\alpha$

# Ne burning / Si burning

As T↑, γ more energetic & can unbind nuclei

For $^{20}_{10}Ne$, happens <u>before</u> Oxygen fusion

$$^{20}_{10}Ne + \gamma \leftrightarrows {}^{16}_{8}O + \alpha$$

But some $^{20}_{10}Ne + \alpha \rightarrow {}^{24}_{12}Mg + \gamma$

Net: $2\,{}^{20}_{10}Ne + \gamma \rightarrow {}^{16}_{8}O + {}^{24}_{12}Mg + \gamma$

=

At $T_9 \simeq 3$, $^{28}_{14}Si + \gamma \rightarrow$ ... p, n, α

lots of reactions

build up to $^{56}_{28}Fe$

VERY MESSY

$T_9 \gtrsim 5$: breakup Fe →

one reason for blip