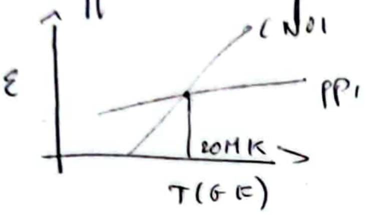
General considerations:

1) H transformed to He: $4H \longrightarrow He$
$4p \longrightarrow {}^4He + 2e^+ + 2\nu_e \quad Q = 26.73\ MeV$

2) pp chains + CNO cycle

3) pp chain v.s. CNO cycle
→ different temperature dependence of reaction rate



→ impact on position of radiative & convective zones

$M < 1.15 M_\odot$ → convective zone @ surface
$M > 1.15 M_\odot$ → core convective zone

4) Final evolution of a close binary system
- H-rich material accreted to the surface of a white dwarf
- thermonuclear runaway
- ejection of a fraction of the accreted material

${}^3He({}^3He,2p){}^4He$ reaction

1) a) $N({}^3He) = \frac{Q}{q_e} = \frac{298\ C}{1.6\ 10^{-19} C} = 1.86\ 10^{21}$ ions

$N({}^3He) = \frac{I \times t}{q_e} = \frac{300\ 10^{-6}\ A \times 11.5 \times 24 \times 3600\ s}{1.6\ 10^{-19} C} = 1.86\ 10^{21}$ ions

b) $N_{detec} = N({}^3He) \times N_{target} \times \sigma \times \varepsilon$
(ions, at/cm², cm², %)

$\Rightarrow \sigma = \frac{N_{detec}}{N_{beam}({}^3He)\ N_{target}\ \varepsilon} = \frac{278}{1.86\ 10^{21} \times 3.19\ 10^{17} \times 0.053}$

(3.19 10^17 ↳ should be 3.9 10^17 (see other page))

$\sigma = 8.84\ 10^{-36}\ cm^2 \Rightarrow \sigma = 8.84\ pb$

c) $S(E) = E\,\sigma(E)\,e^{2\pi\eta} \qquad 2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\frac{M_{amu}}{E(keV)}}$

$M_{amu} = \frac{m({}^3He)\, m({}^3He)}{m({}^3He) + m({}^3He)} = \frac{m({}^3He)}{2} = \frac{3.016029}{2} = 1.5080145\ amu$

$\Rightarrow S(E) = 7.2\ MeV.b$

c) $E_0 = 1.22 (Z_1^2 Z_2^2 \mu_{amu} T_6^2)^{1/3}$ keV $\longrightarrow E_0 = 22.0$ keV

$\Delta = 0.744 (Z_1^2 Z_2^2 \mu_{amu} T_6^5)^{1/6}$ keV $\longrightarrow \Delta = 12.6$ keV

3) a) $S(22\text{ keV}) = S(24.36\text{ keV})$

$\Rightarrow 22\,\sigma(22)\, e^{2\pi\eta(22)} = 24.36 \times \sigma(24.36)\, e^{2\pi\eta(24.36)}$

$\Rightarrow \sigma(E_0 = 22\text{ keV}) = \frac{24.36}{22}\,\sigma(24.36)\, e^{2\pi\eta(24.36) - 2\pi\eta(22\text{ keV})}$

$\sigma(E_0 = 22\text{ keV}) = 0.217\,\sigma(24.36)$

$\sigma(E_0 = 22\text{ keV}) = 1.92$ pb

b) $N_{detec} \propto \sigma$

$\Rightarrow \frac{N(22)}{\sigma(22)} = \frac{N(24.36)}{\sigma(24.36)}$

$\Rightarrow N(22) = N(24.36)\,\frac{\sigma(22)}{\sigma(24.36)}$

$\Rightarrow N(22) = 60$ coincident events

4) Non resonant reaction $\Rightarrow \langle\sigma v\rangle = 4.33\,10^5 \frac{\tau^2 e^{-\tau}}{Z_1 Z_2 \mu_{amu}} S(E_0)$ $cm^3 mol^{-1} s^{-1}$ (S in keV b)

$\tau = 42.46 (Z_1^2 Z_2^2 \mu_{amu} / T_6)^{1/3}$

$\tau = 49.10$

$\langle\sigma v\rangle = 5.89\, 10^{-10}\ cm^3 mol^{-1} s^{-1}$

$^{25}Al(p,\gamma)$ reaction

1) non resonant + resonant mechanisms

2) $Q = (m_p + m_{25Al} - m_{26Si})\,u = 5.514$ MeV

3) a) $E_0 \pm \Delta E/2 \Rightarrow E_x = Q + E_0 \mp \Delta/2$

$\Rightarrow E_x \in [5.730 ; 5.960]$ MeV

b) $E_x = 5890$ keV $\Rightarrow E_R = 376$ keV || $E_x = 5946$ keV $\Rightarrow E_R = 432$ keV

$E_x = 5929$ keV $\Rightarrow E_R = 415$ keV

c) entrance channel

- $\vec{S} = \vec{s}(p) + \vec{s}(^{25}Al)$

  $\vec{S} = \vec{1/2} + \vec{5/2}$

$\Rightarrow 2 \leq s \leq 3$

- $\pi_R = \pi(p) \cdot \pi(^{25}Al) \cdot (-1)^{\ell}$

  $\pi_R = + \quad + \quad (-1)^{\ell}$

  $\pi_R = (-1)^{\ell}$

- $J_R = s + \ell$

$E_x = 5890$ keV, $J^{\pi} = 0^{+} \Rightarrow \ell = 2$

$E_x = 5929$ keV, $J^{\pi} = 3^{+} \Rightarrow \ell = 0$

$E_x = 5946$ keV, $J^{\pi} = 0^{+} \Rightarrow \ell = 2$

$E_x = 5929$ keV resonance is the most likely to contribute because of lower centrifugal barrier

1) a) 2 possibilities

$N(^3He) = \frac{Q}{e} = \frac{298\,C}{1.6\,10^{-19}\,C} = 1.86\,10^{21}$ incident ions

$N(^3He) = \frac{I}{e} \times \Delta t = \frac{300\,10^{-6}}{1.6\,10^{-19}} \times 11.5 \times 24 \times 3600 = 1.86\,10^{21}$

b) $N_{coinc} = N_{incident} \times N_{target} \times \sigma \times \varepsilon$

$\Rightarrow \sigma = \frac{278}{1.86\,10^{21} \times 3.9\,10^{17} \times 5.3\,10^{-2}} = 7.2\,10^{-36}\,cm^2 = 7.2\,pb$

c) $S(E) = \sigma(E) \times E \times e^{2\pi\eta}$ with ~~η~~ $2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\frac{\mu_{amu}}{E_{keV}}}$

$2\pi\eta = 31.29 \times 2 \times 2 \times \sqrt{\frac{\mu_{amu}}{24.36}}$ $\mu = \frac{m_1 m_2}{m_1 + m_2} = \frac{m^2}{2m} = \frac{m}{2}$

$2\pi\eta = 31.140793$

~~$\Rightarrow S(24.36) = 5461.8\,pb.keV \simeq 5.5\,nb.keV$~~

$\Rightarrow S(24.36) = 7.2\,10^{-12} \times 24.36 \times e^{31.140793}$

$S(24.36) = 5865\,keV.b$

2) $E_0 = 1.22\,(Z_1^2 Z_2^2 \mu_{amu} T_6^2)^{1/3} = 22\,keV$

$\Delta = 0.749\,(Z_1^2 Z_2^2 \mu_{amu} T_6^5)^{1/6} = 12.6\,keV$

$\Rightarrow 22 \pm 6.3\,keV$

3) a) $S(22) = S(24.6)$ $\Rightarrow \sigma(22) \times 22 \times e^{2\pi\eta(22)} = \sigma(24.6) \times 24.6\, e^{2\pi\eta(24.6)}$

$\Rightarrow \sigma(22) = \sigma(24.6)\, \frac{24.6}{22}\, e^{2\pi[\eta(24.6) - \eta(22)]}$

$\Rightarrow \sigma(22) = \sigma(24.6)\, \frac{24.6}{22} \left(e^{31.140793 - 32.768531}\right)$

$\sigma(22) = 0.22\,\sigma(24.6)$

b) $N_{coinc}(22) = 0.22\, N_{coinc}(24.6)$

$N_{coinc}(22) = 61$ evts

4) $\langle\sigma v\rangle = 4.33\,10^{+5}\, \frac{\tau^2 \exp(-\tau)}{Z_1 Z_2 \mu_{amu}} \times S_0$

$\tau = 41.1$

$\langle\sigma v\rangle =$ ~~$7.98\,10^{-34}$~~ $5.09\,10^{-10}\,cm^3\,s^{-1}$