13.18, 13.25, 15.8, 15.10

18) calculate Q $(7.016004u - 3.016029u - 4.002603u) \times 931.5 \frac{MeV}{u}$

$= -2.45\,MeV$ need a 2.45 MeV γ to break this apart

$\gamma \to \overset{1}{e^+}\overset{2}{e^-}$?

$E_i = E_f$

$E_\gamma = E_1 + E_2$

$\vec{p}_i = \vec{p}_f$

$\vec{p}_\gamma = \vec{p}_1 + \vec{p}_2$

$$0 = E_\gamma^2 - p_\gamma^2 c^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 \quad (\text{let } c = 1)$$

$$= E_1^2 + 2E_1E_2 + E_2^2 - p_1^2 - 2\vec{p}_1\cdot\vec{p}_2 - p_2^2$$

$$= m_1^2 + m_2^2 + 2E_1E_2 - 2\vec{p}_1\cdot\vec{p}_2$$

For massive particles $E_1E_2 > p_1p_2$

massless $|E_1E_2| = |p_1p_2|$

25) calculate Q

answers in back of book

$$\left\{\begin{array}{ll} = ① & Q_1 = m(^{12}C) + m(^1H) - m(^{13}N) \\ = ② & Q_2 = m(^{13}N) - m(^{13}C) - m(e^+) \\ = ③ & Q_3 = m(^{13}C) + m(^1H) - m(^{14}N) \\ = ④ & Q_4 = m(^{14}N) + m(^1H) - m(^{15}O) \\ = ⑤ & Q_5 = m(^{15}O) - m(^{14}N) - m(e^+) \\ = ⑥ & Q_6 = m(^{15}N) + m(^1H) - m(^{12}C) - m(^4He) \end{array}\right.$$

$$Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 = 4m(^1H) - 2m(e^+) - m(^4He)$$

so must be same

15.8 $\quad {}^{7}Be + e^- \to {}^{7}Li + \nu_e$ (electron capture)

$Q = (7.016929u - 7.016004u)\, 931.5\frac{MeV}{u}$

$= 0.862\ MeV$

$\nu_e + {}^{37}_{17}Cl \to {}^{37}_{18}Ar + e^-$ (Argon needs the electron for m_{Ar})

$Q = (36.965903u - 36.966776u)\, 931.5\frac{MeV}{u}$

$= -0.813\ MeV$

so the ν_e has barely enough energy

15.10 $\quad {}^{4}He + {}^{4}He \to {}^{8}Be$

$Q = (2(4.002603u) - 8.005305u)\, 931.5\frac{MeV}{u}$

$= -92.2\ keV$

If we assume a 2 state system

treat 2 states as ${}^{4}He + {}^{4}He$ and ${}^{8}Be$

with $\Delta E = 92.2\ keV$

$$\frac{P(Be)}{P(He+He)} = \frac{e^{-\Delta E/k_B T}}{g(He+He)} \quad \text{assuming } g(He+He) = 1 = g(Be)$$

For 1 Be atom, $\# He = e^{\Delta E/k_B T} = N^{-1} = (2.25\times10^{-5})^{-1}$

The number of ways we can form 2 He atoms is $\frac{N(N-1)}{2} = g(He)$

(even though the Be state is unstable, the He are moving fast and colliding so often, the Be has a chance to stick around a while.

$t_{collision} \sim 10^{-21}s \qquad t_{Be} \sim 10^{-16}s$)

estimate for the relative amount

$$\frac{\# Be}{\# He} = \frac{e^{-\Delta E/k_B T}}{(e^{\Delta E/k_B T})^2/2} = 2\left(e^{-3(92.2\times10^3 eV)/(8.617\times10^{-5} eV/K\, 10^8 K)}\right)$$

$= 1.14\times10^{-14}$ (# I saw in a book was $\sim 10^{-10}$)

We could say the $\frac{dN_{Be}}{dt} = 0 = R - \lambda N$
$\uparrow$ rate of creation

and from our discussion of the sun, we know

$$\frac{R}{V} = \frac{n_{He}^2}{2} v\sigma$$

so we end up with

$$\frac{n_{He}^2}{2} v\sigma = \lambda n_{^8Be}$$

$$\frac{n_{He}^2}{n_{^8Be}} = 2\left(\frac{\lambda}{v\sigma}\right)$$

$$\frac{N_{He}^2}{N_{^8Be}} = V\,2\left(\frac{\lambda}{v\sigma}\right)$$

$$\frac{N_{^8Be}}{N_{He}^2} = \frac{1}{V}\left(\frac{v\sigma}{2\lambda}\right)$$

$$= ?\, e^{-\Delta E/k_BT} \;?\;?$$

so, actually, we're stuck!
we need to know $\langle v\sigma \rangle$, Volume ...
As it is, we've cheated by saying there was
1 Be atom at equilibrium!!