Fusion

universe initially all hydrogen

Need neutrons to form heavier elements

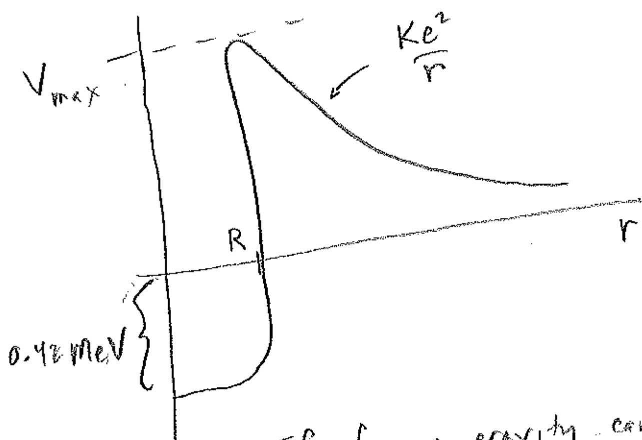
$p + p \longrightarrow d + e^+ + \nu_e$

$Q = 2\,[\,1u + \Delta(^1H) - m_e\,] - [\,2u + \Delta(^2H) - m_e\,] - m_e$

$\quad = 2\Delta(^1H) - \Delta(^2H) - 2m_e$

$\quad = 0.420$ MeV $\qquad \Rightarrow E_\nu(max) = 0.42$ MeV

Reaction is allowed but Coulomb barrier

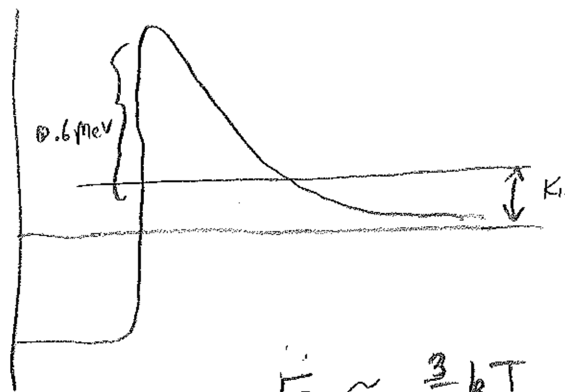


$R \sim 2r_0 \sim 2.4$ fm

$V_{max} = \frac{Ke^2}{R} = \frac{1.44\text{ MeV fm}}{2.4\text{ fm}} = 0.6$ MeV

If force of gravity can compress balls of hydrogen to high enough temps to allow protons to get close enough (despite EM repulsion) the weak force allows $p \rightarrow n + e^+ + \nu_e$ at which point the strong force binds p & n into d, releasing energy

[delicate interplay of all 4 forces allows us to exist]



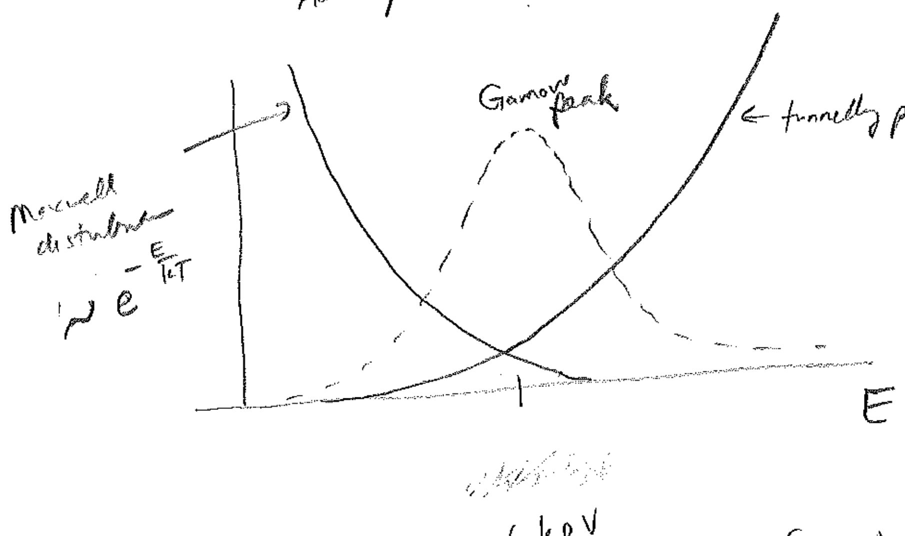
$$\bar{E} \sim \frac{3}{2}kT$$

$T \sim 15.8$ million K $\Rightarrow \frac{3}{2}\left(\frac{1.5E7}{3E2}\right)\frac{1}{40}\,eV = 2$ keV

(would need $T \sim 5\times10^{9}$ K to overcome barrier)

but protons have a Maxwellian distribution (tail)

Also protons can tunnel through barrier



$E_G \sim 0.49$ MeV

[Clayton, p. 192]
Pcl Astro

Even if proton tunnels through barrier prob that weak interaction will occur is 10^{-20}.
usually elastic scattering (via strong force) of pp occurs

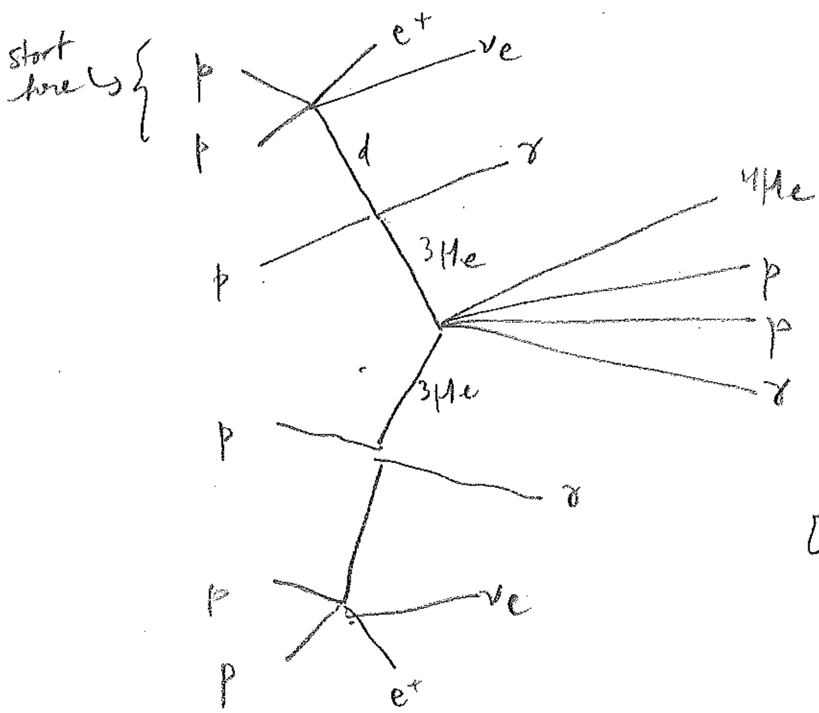
[Next step:]

$p + d \rightarrow {}^3He + \gamma$

${}^3He + {}^3He \rightarrow {}^4He + p + p + \gamma$

[85%
Carroll & Ostlie say 69%
p. 345]

Altogether



[Then add in two places:

Total pp cycle: $6p + 2e^- \rightarrow {}^4He + 2p + 7\gamma + 2\nu_e$

- How much energy does this release? [HW]
- Some goes into ν, which escape [HW]
- The rest heats the sun & is eventually radiated away about 26.2 MeV per helium nucleus formed or 6.5 MeV per proton consumed.
  (more efficient than fission on a mass basis
  ↳ ≈ 0.7 MeV per nucleon)