Title: Cosmology Lecture (230418)

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Collection: Cosmology (2022/2023)

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Big Bang Nucleosynthesis

hot, dense $\Longrightarrow$ high rate Γ

naively expect ^{56}Fe

actually: mostly H, He

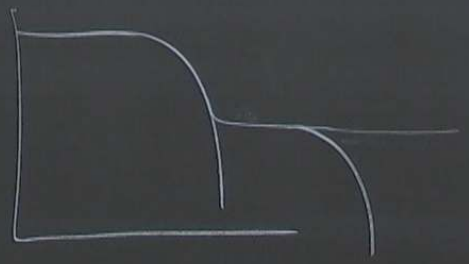
$p + e^- \longrightarrow n + \nu_e$

$p + e^- \rightarrow n + \nu_e$

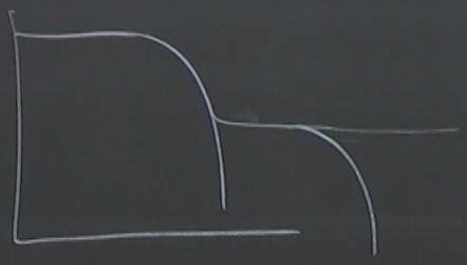
$\frac{n_n}{n_p} \simeq e^{-\frac{\Delta m}{T_F}} \approx 0.2$

$\Delta m = m_n - m_p \simeq 1.3\,\text{MeV}$

$T_F \simeq 0.8\,\text{MeV}$



$\frac{n_n}{n_p}$



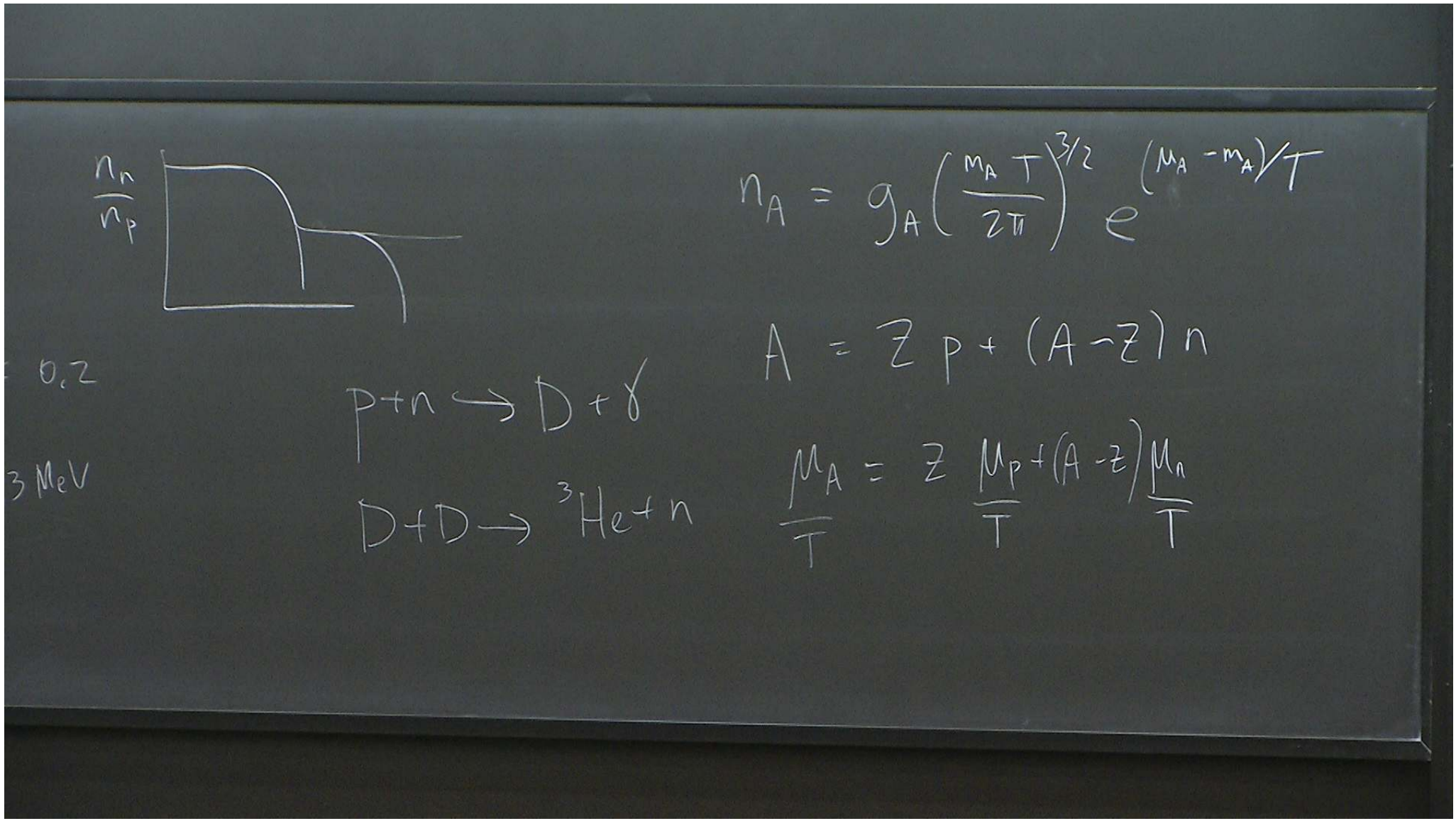
$$n_A = g_A \left(\frac{m_A T}{2\pi}\right)^{3/2} e^{(\mu_A - m_A)/T}$$

.2

eV

$p + n \rightarrow D + \gamma$

$D + D \rightarrow {}^3He + n$


$\frac{n_n}{n_p}$
$n_A = g_A \left(\frac{m_A T}{2\pi}\right)^{3/2} e^{(\mu_A - m_A)/T}$
$A = Z\,p + (A-Z)\,n$
$p + n \rightarrow D + \gamma$
$D + D \rightarrow {}^3He + n$
$\frac{\mu_A}{T} = Z\frac{\mu_p}{T} + (A-Z)\frac{\mu_n}{T}$
0.2
3 MeV

$T_f \simeq 0.8\ \mathrm{MeV}$

$$e^{\frac{\mu_A}{T}} = \left[e^{\mu_p/T}\right]^Z \cdot \left[e^{\mu_n/T}\right]^{A-Z}$$

$$n_A = \frac{g_A}{2^A}\left(\frac{m_A T}{2\pi}\right)^{3/2}\left(\frac{m_N T}{2\pi}\right)^{-3A/2} n_p^{\,Z}\, n_n^{\,A-Z}\, e^{\left[Z m_p + (A-Z) m_n - m_A\right]/T}$$

$T_f \simeq 0.8\ \mathrm{MeV}$

$$e^{\frac{\mu_A}{T}} = \left[e^{\mu_p/T}\right]^Z \cdot \left[e^{\mu_n/T}\right]^{A-Z}$$

$$n_A = \frac{g_A}{2^\Lambda}\left(\frac{m_A T}{2\pi}\right)^{3/2}\left(\frac{m_N T}{2\pi}\right)^{-3A/2} n_p^{\,Z}\, n_n^{\,A-Z}\, e^{\overbrace{\left[Z m_p + (A-Z) m_n - m_A\right]}^{B_A}/T} \Rightarrow$$

$$m_A \approx A\, m_N$$

$$\overbrace{\left[Z m_p + (A-Z) m_n - m_A\right]}^{B_A} / T \Rightarrow \frac{g_A}{2^A} A^{3/2} \left(\frac{m_N T}{2\pi}\right)^{\frac{3}{2}(1-A)} n_p^Z \, n_n^{A-Z} \, e^{B_A/T}$$

$$n_N = n_p + n_n + \sum_i (A n_A)_i \qquad \sum_i X_i = 1$$

$$X_A = \left(\frac{g}{2}\right)^A A^{5/2} n_N^{A-1} \left(\frac{m_N T}{2\pi}\right)^{\frac{3}{2}(1-A)} X_p^Z X_n^{A-Z} e^{B_A/T}$$

$$n_N = n_\gamma \eta$$

$$n_\gamma = \frac{2\zeta(3)}{\pi^2} T^3$$

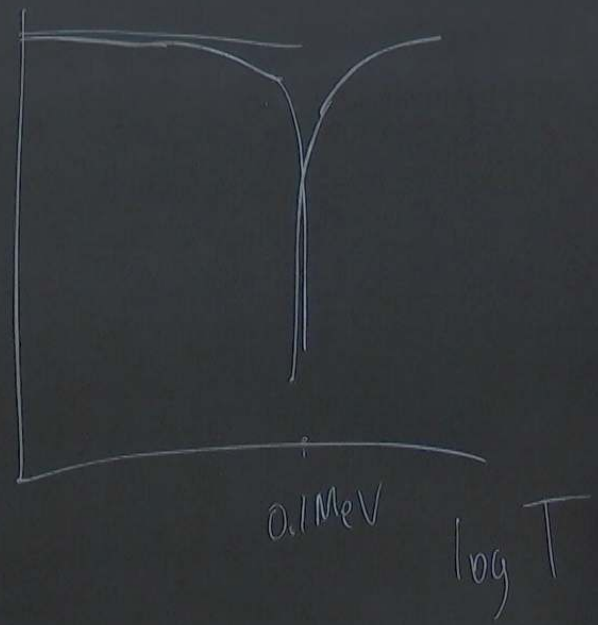
$$\left(\frac{T}{m_N}\right)^{\frac{3}{2}(A-1)} X_p^{\,Z}\, X_n^{\,A-Z}\, \eta^{A-1}\, e^{B/T}$$

$$\frac{1}{\eta} = 2 \cdot 10^9$$

A	B_A
$D = {}^2H$	2.2 MeV
${}^4He$	28 MeV
${}^{12}C$	92 MeV

$T \sim 1\,\mathrm{MeV}$

$\eta^3 \sim 10^{-28}$ $\quad e^{B/T} \sim 10$

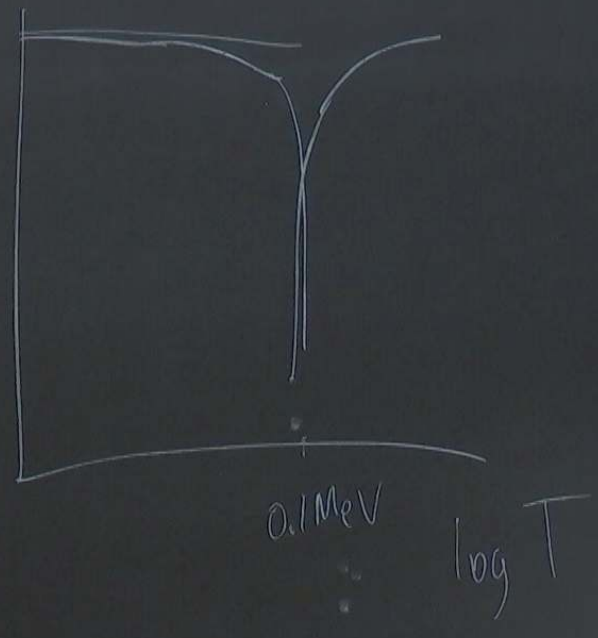


$T \sim 1\,\mathrm{MeV}$

$\eta^3 \sim 10^{-28}$ $\quad e^{B/T} \sim 10$

$\frac{n_n}{n_p} \sim \frac{1}{7}$ at $T \sim 0.1\,\mathrm{MeV}$

free n decay



$$\left(\frac{I}{m_N}\right)^{\frac{3}{2}(A-1)} X_p^{\,Z}\, X_n^{\,A-Z}\, \eta^{A-1}\, e^{B/T}$$

$$\frac{1}{\eta} = 2 \cdot 10^9$$

$$3\,{}^4He \rightarrow {}^{12}C$$

A	B_A
$D = {}^2H$	2.2 MeV
${}^4He$	28 MeV
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$T \sim 1\,\mathrm{MeV}$

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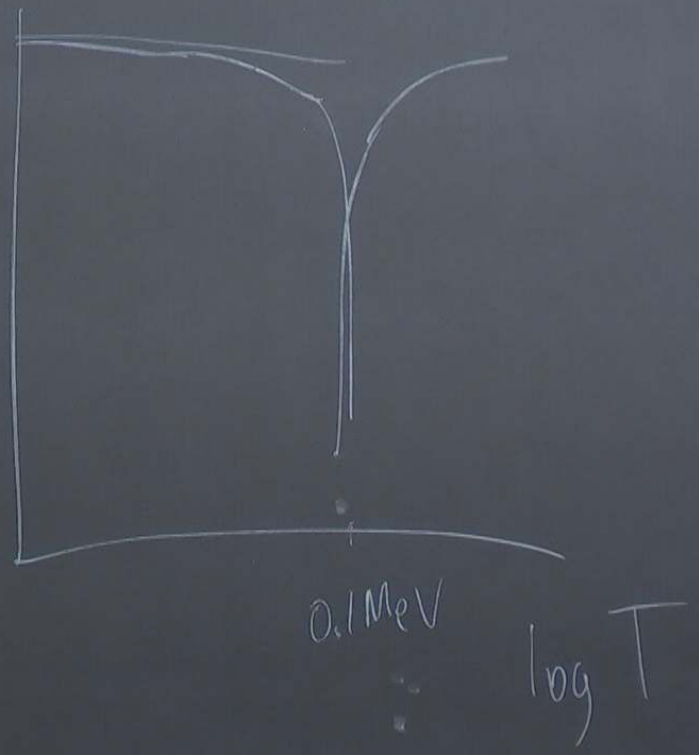
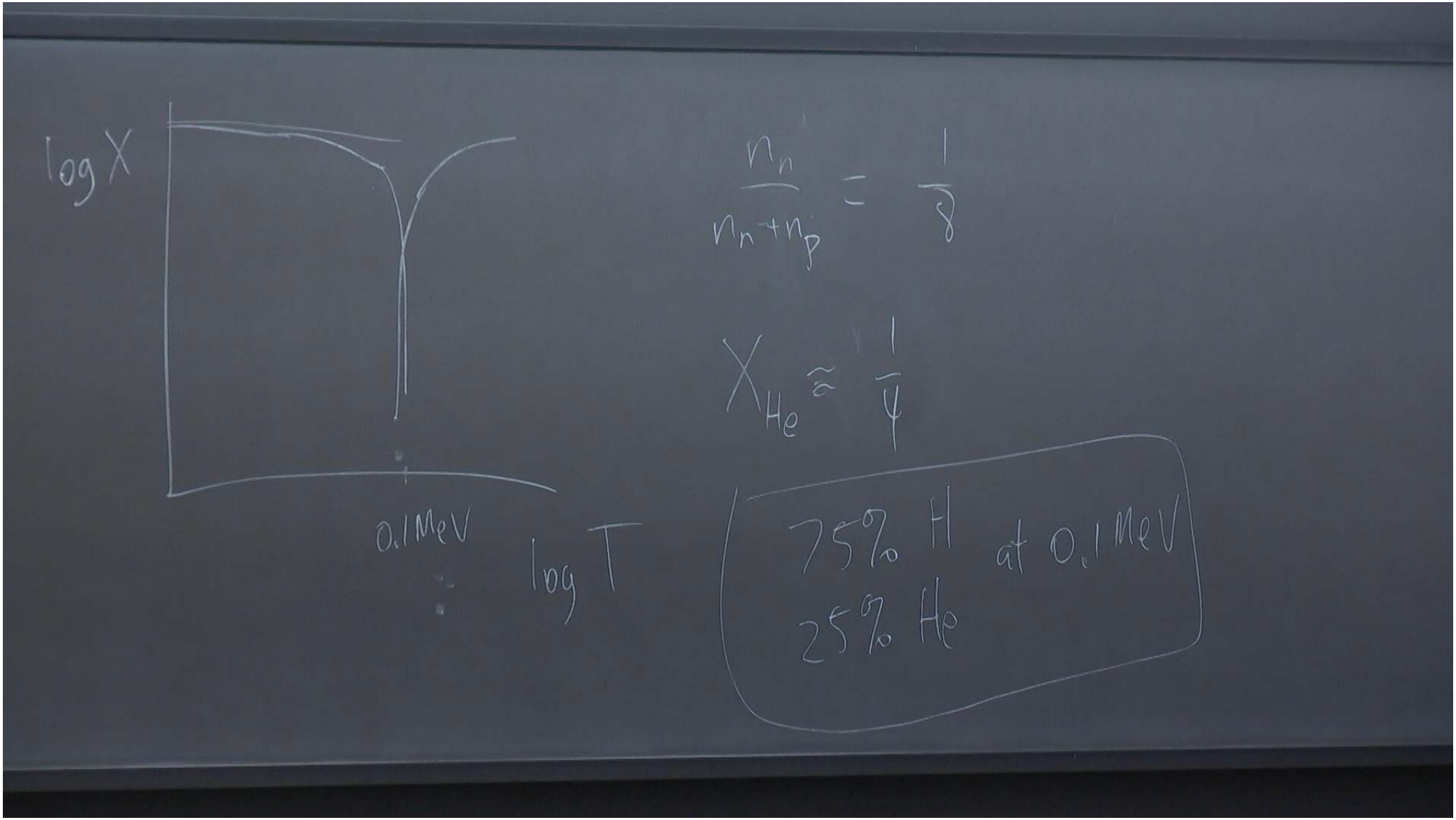
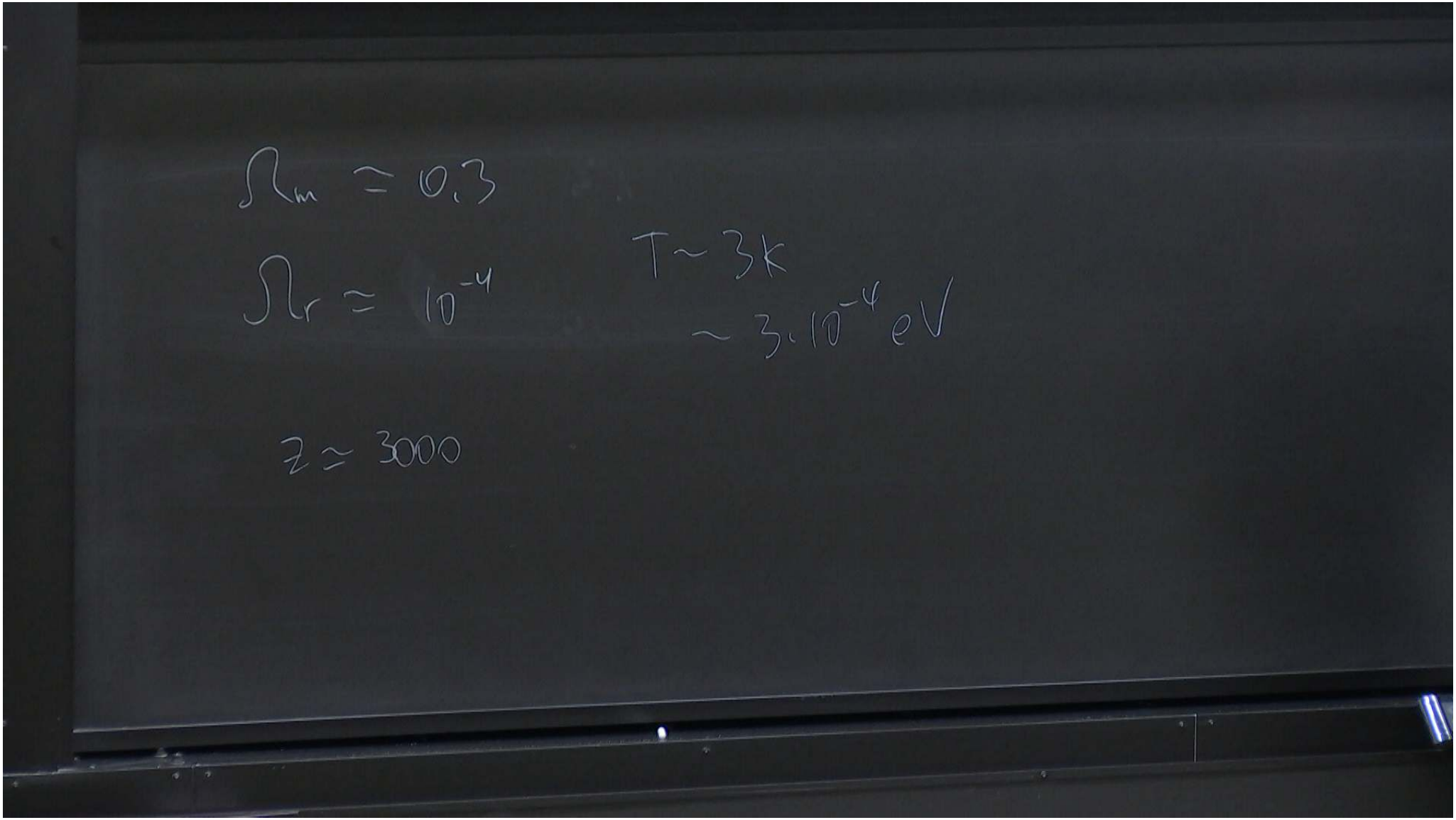
free n decay




log X
0.1MeV
log T
$\frac{n_n}{n_n + n_p} = \frac{1}{8}$
$X_{He} \approx \frac{1}{4}$
75% H at 0.1 MeV
25% He


$\Omega_m \simeq 0.3$
$\Omega_r \simeq 10^{-4}$
$T \sim 3k$
$\sim 3.10^{-4}$ eV
$z \simeq 3000$

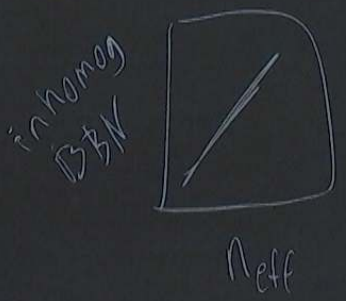
$\Omega_m \simeq 0.3$

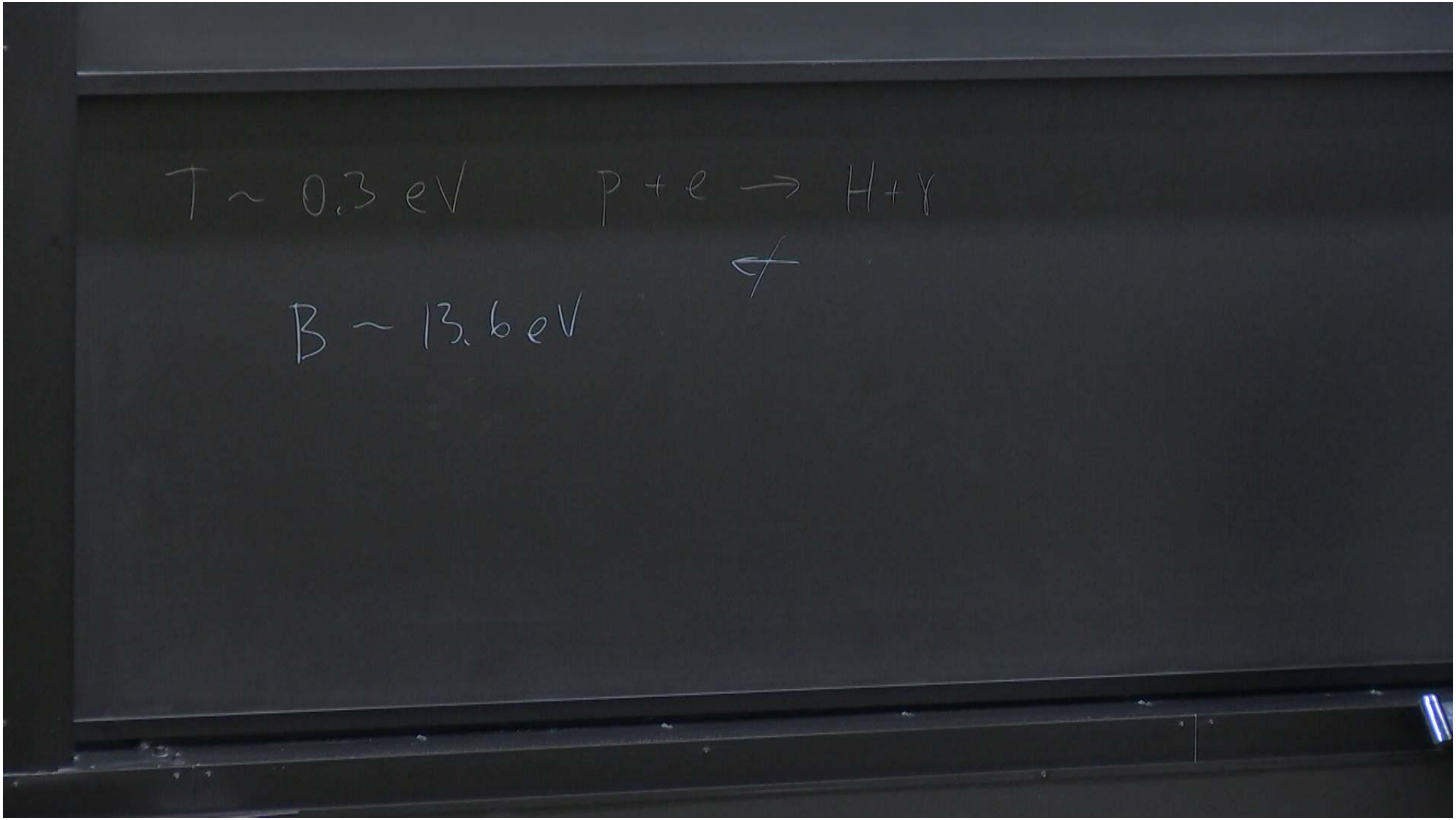
$\Omega_r \simeq 10^{-4}$

$T \sim 3k$

$\sim 3 \cdot 10^{-4}$ eV

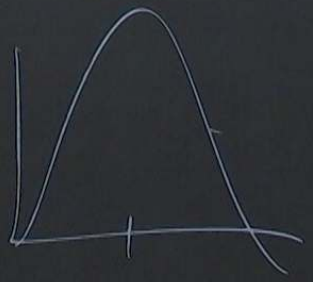
$z \simeq 3000$

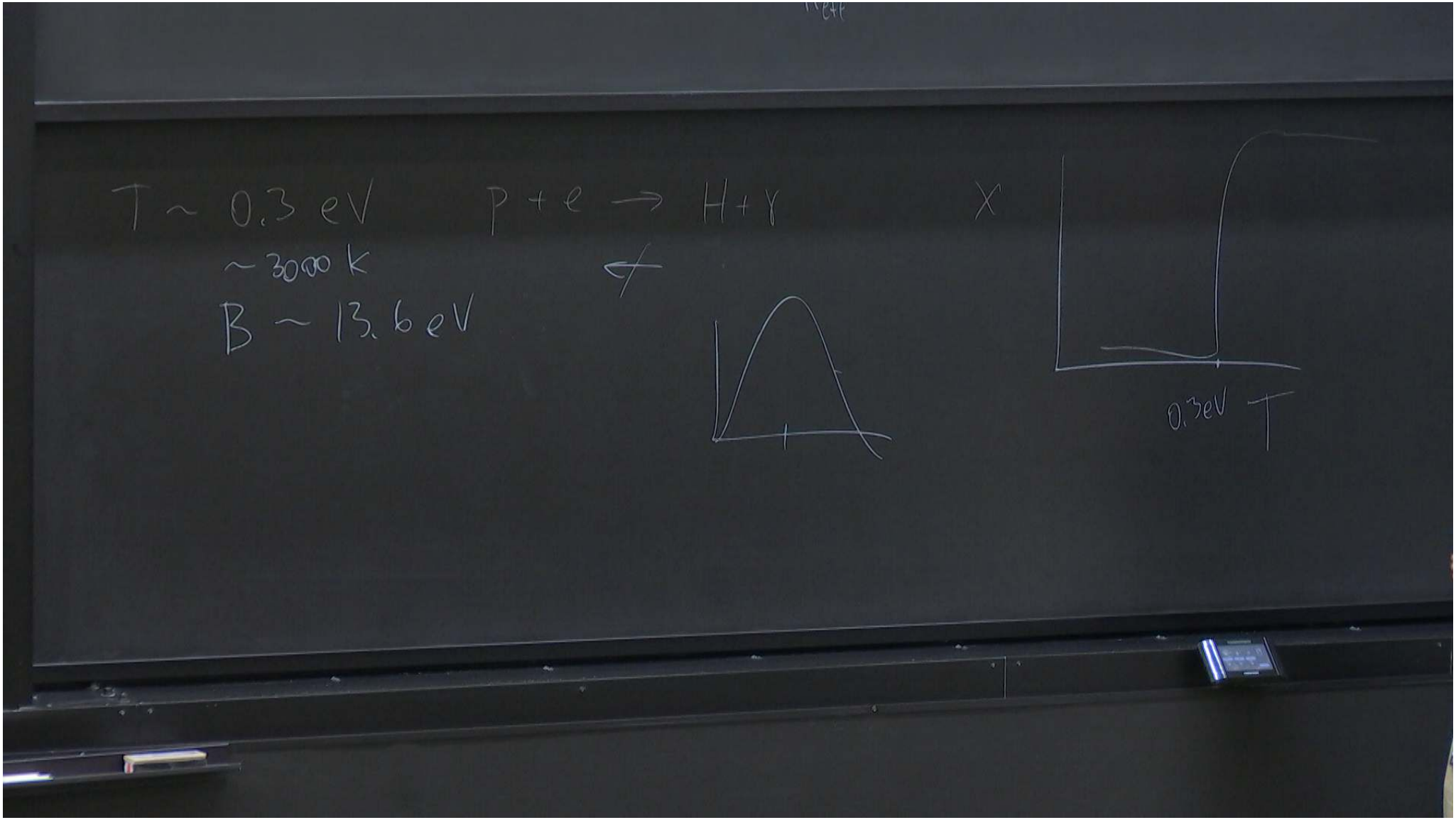



T ~ 0.3 eV
p + e → H + γ
B ~ 13.6 eV

$T \sim 0.3\ eV$ $\quad p + e \rightarrow H + \gamma$

$B \sim 13.6\ eV$




T ~ 0.3 eV
~ 3000 k
B ~ 13.6 eV
p + e → H + γ
0.3eV
T