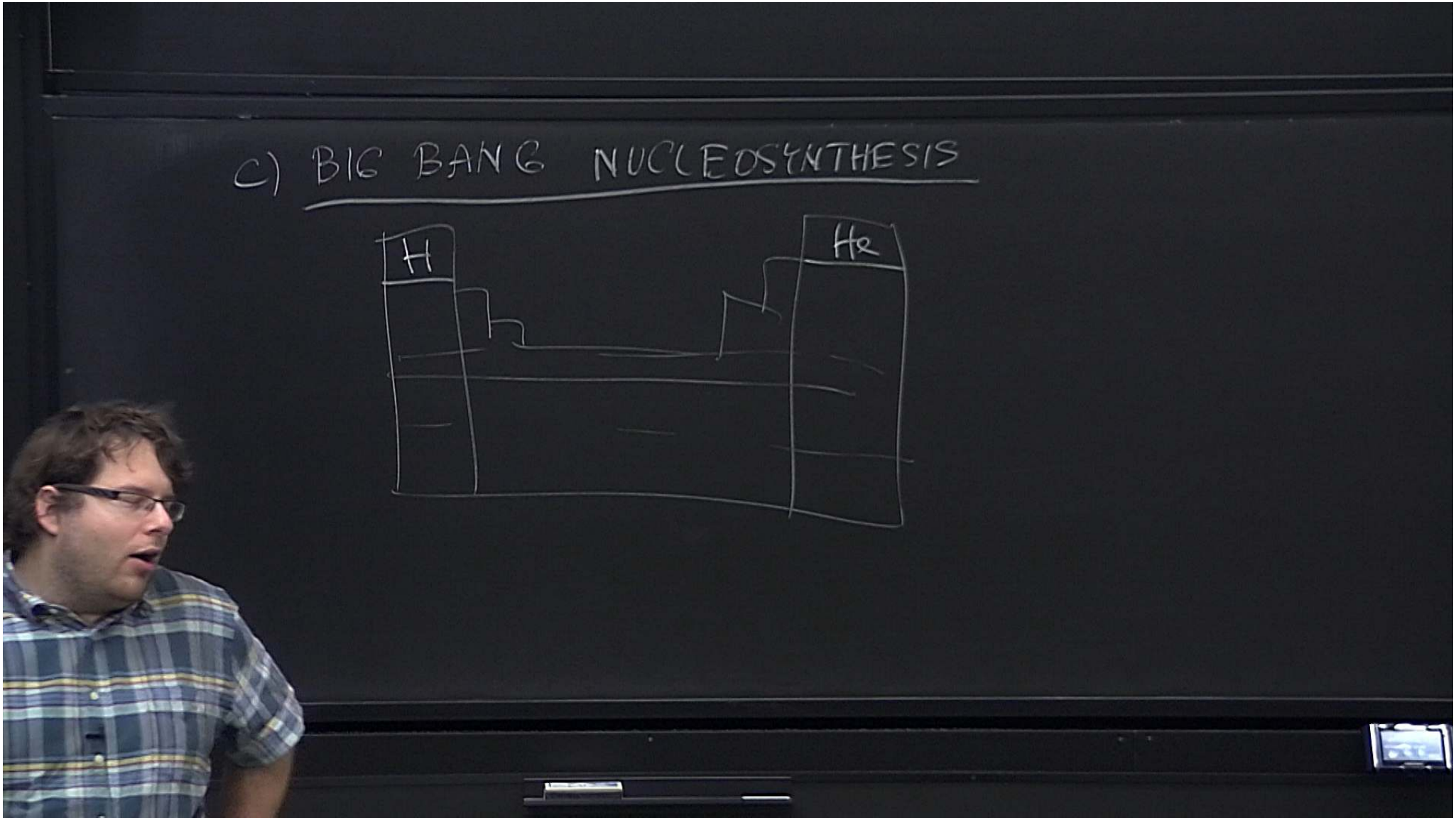
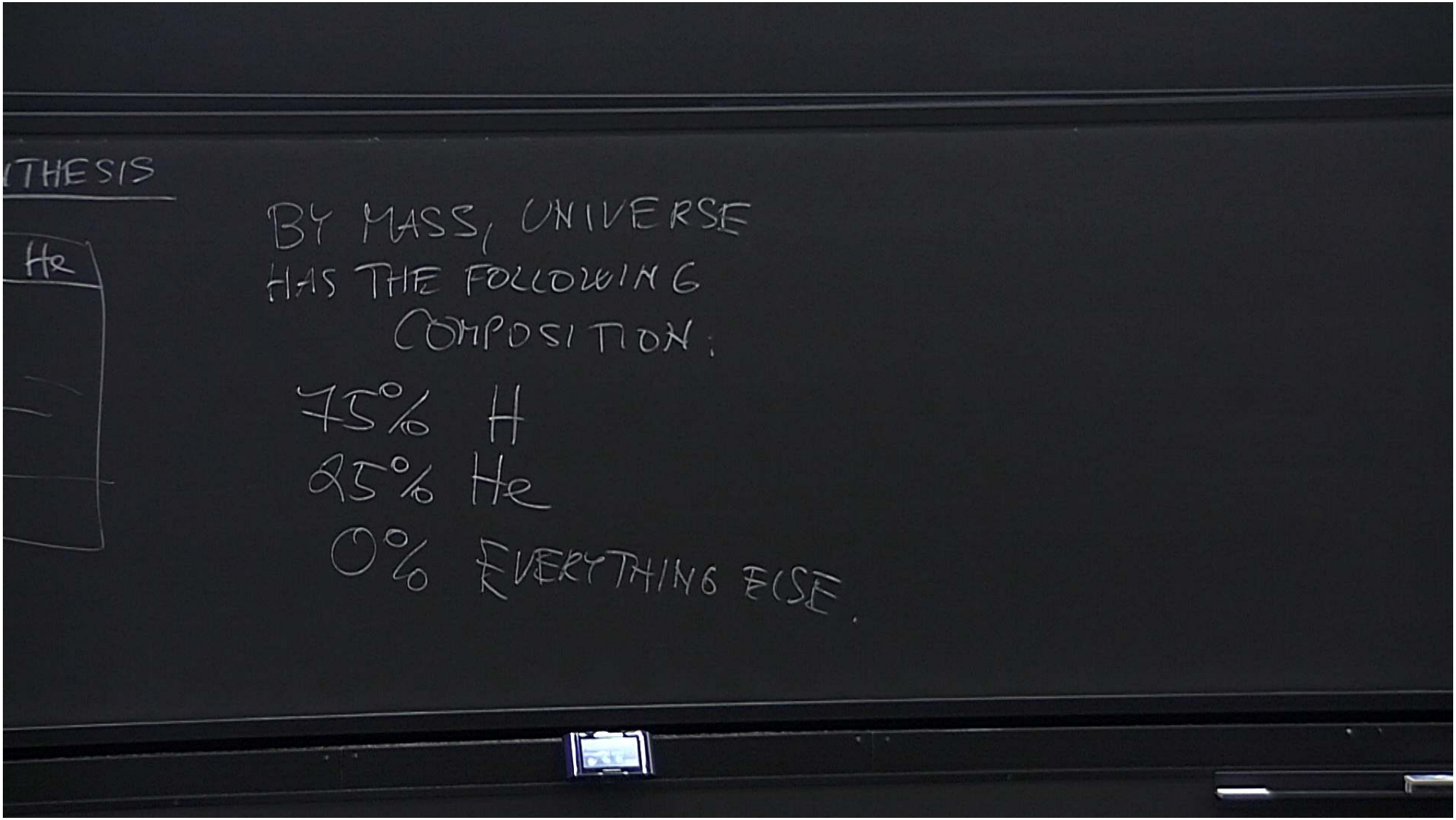
Title: PSI 2016/2017 Cosmology (Review) - Lecture 6

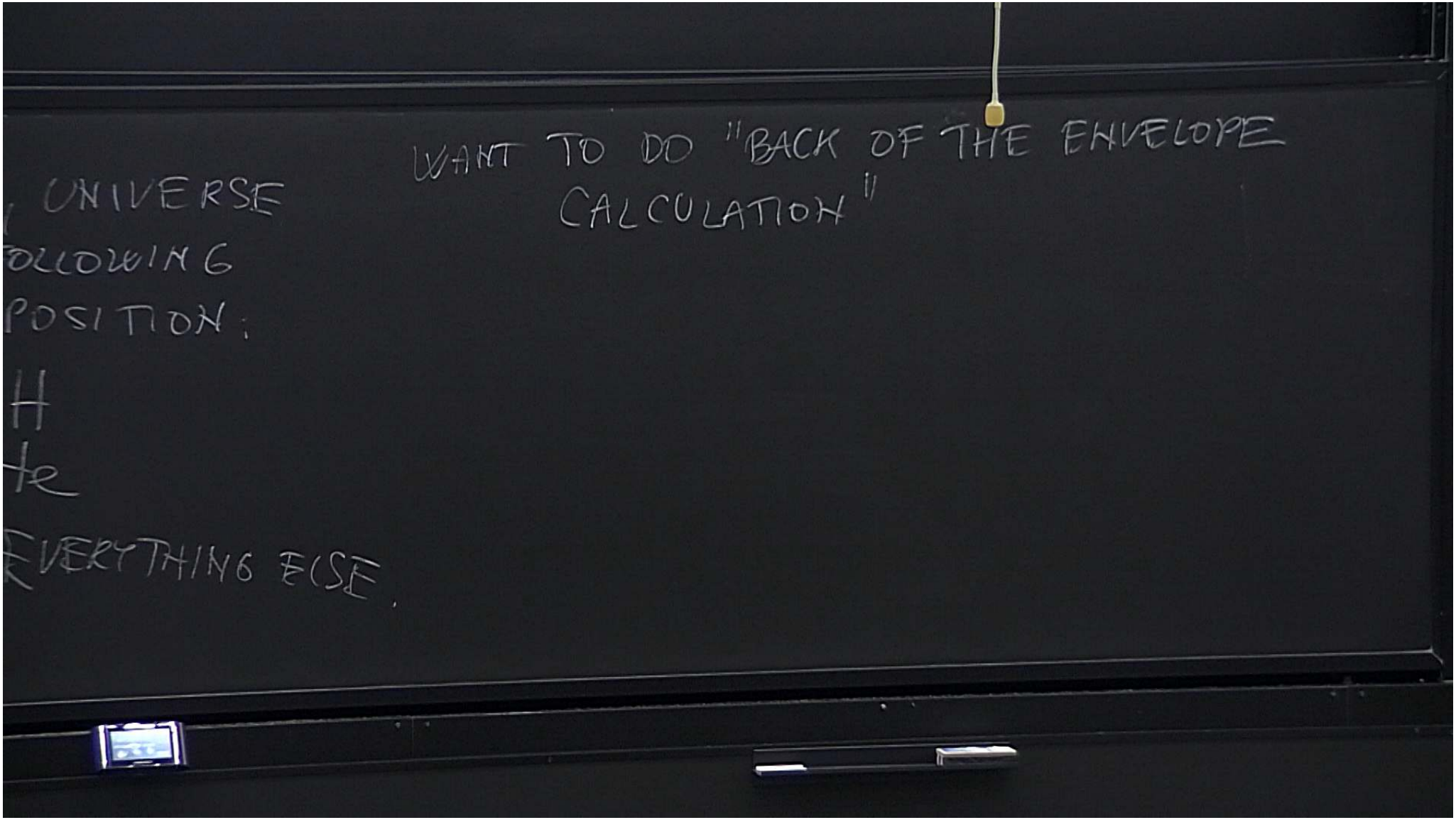
Date: Feb 07, 2017 10:15 AM

URL: http://pirsa.org/17020054

Abstract:


c) BIG BANG NUCLEOSYNTHESIS
H
He


THESIS
He
BY MASS, UNIVERSE HAS THE FOLLOWING COMPOSITION:
75% H
25% He
0% EVERYTHING ELSE.


UNIVERSE
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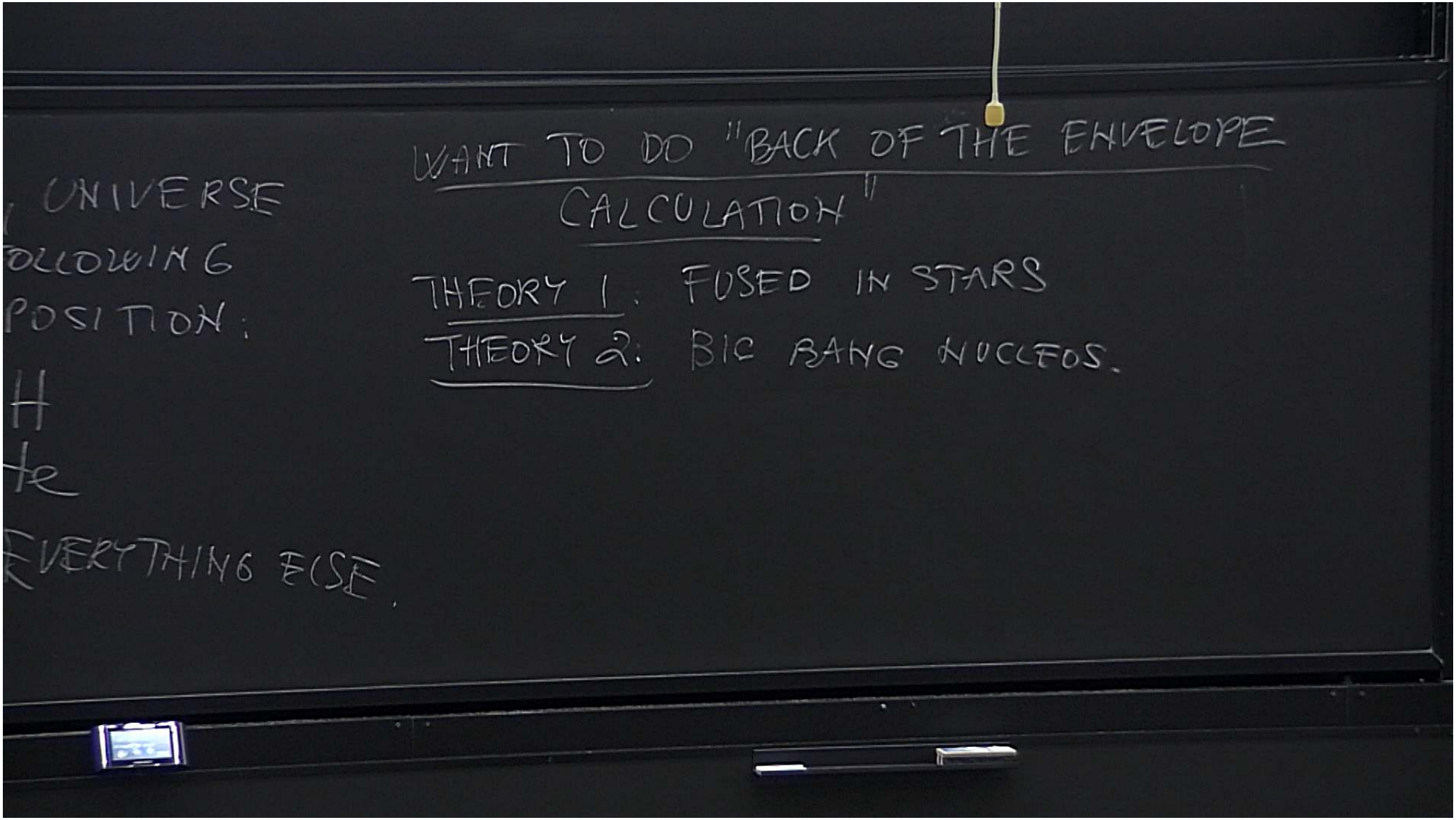
VERYTHING ELSE.
WANT TO DO "BACK OF THE ENVELOPE
CALCULATION"


UNIVERSE
OLLOWING
POSITION:
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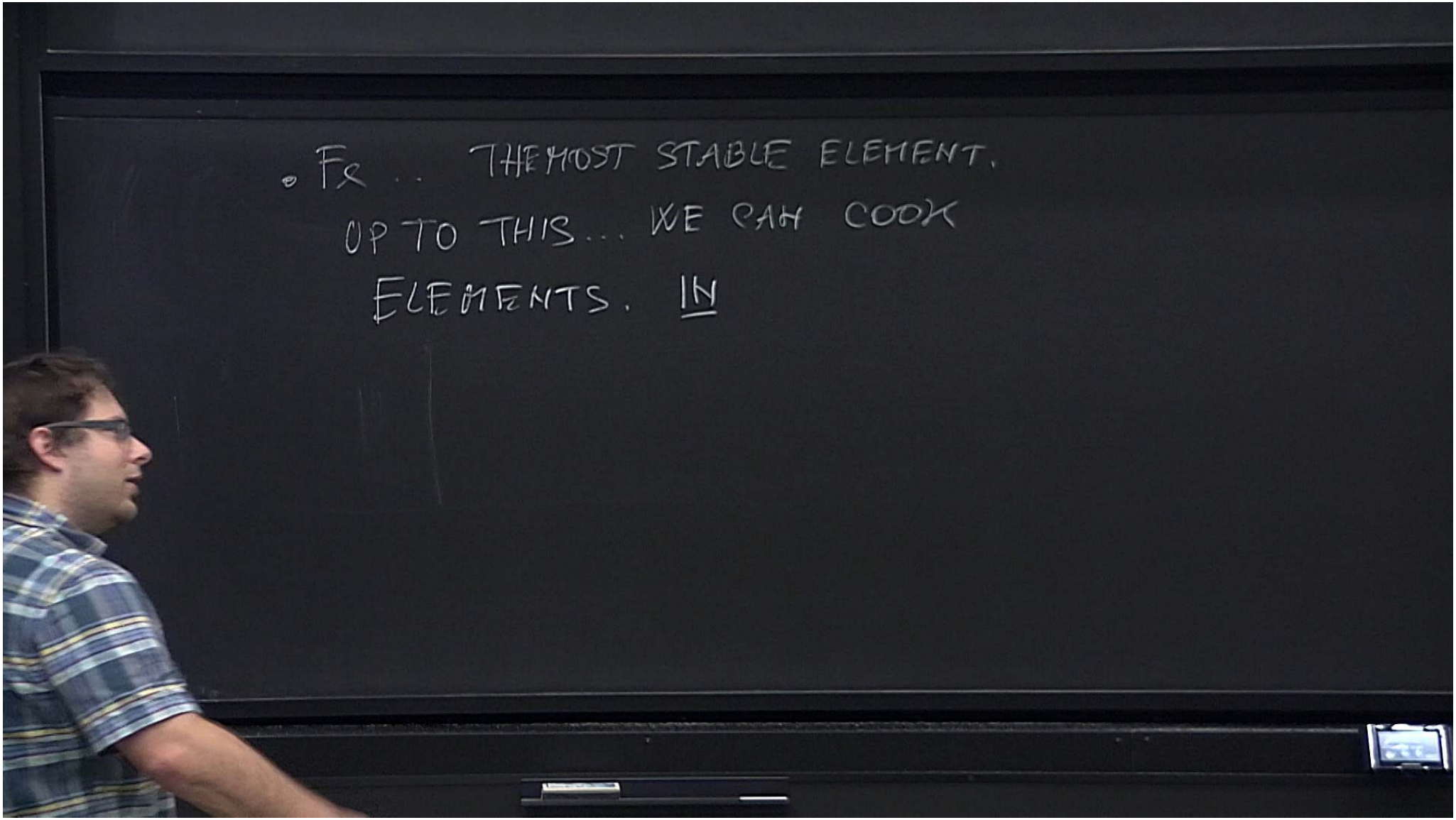
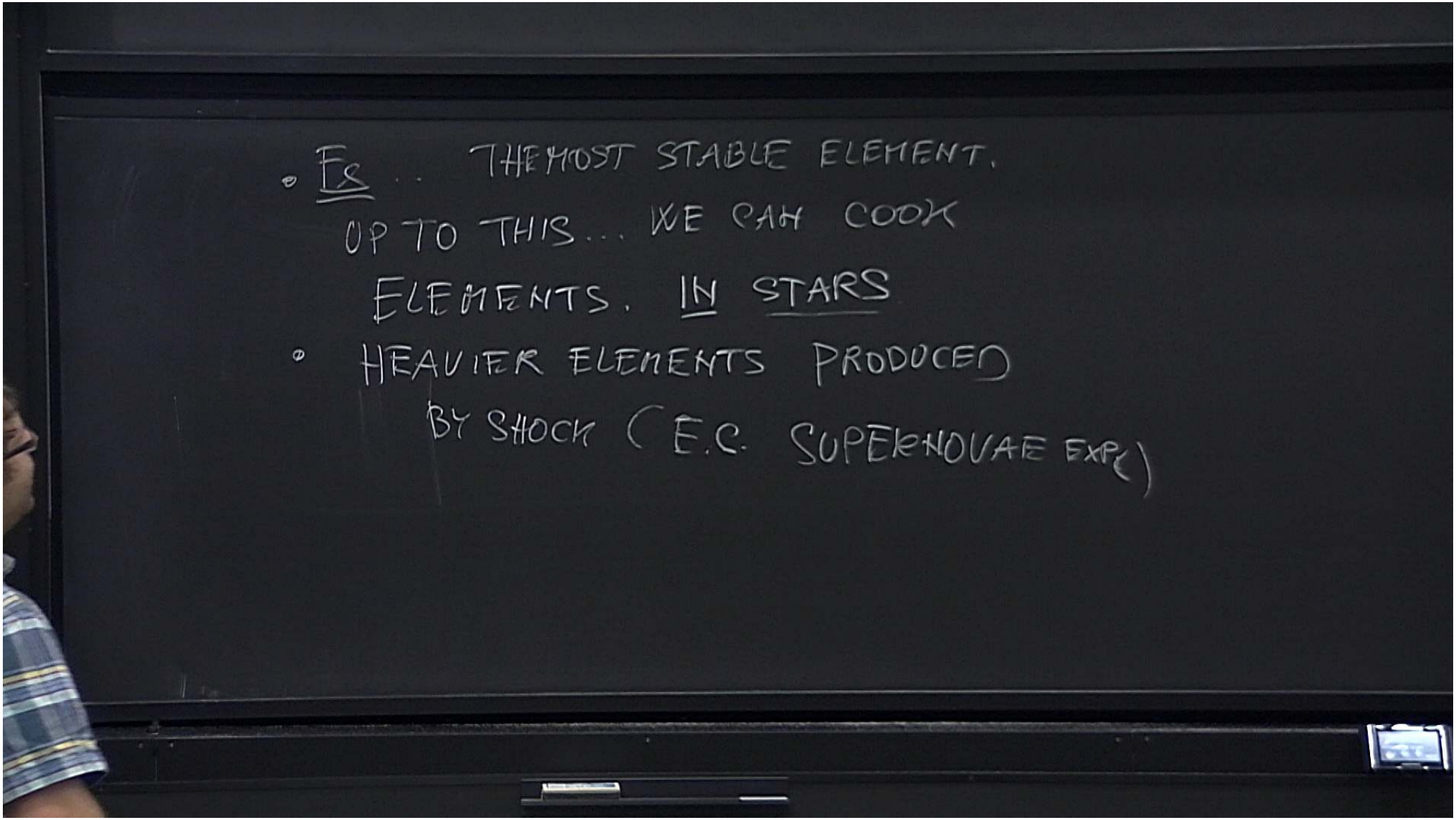
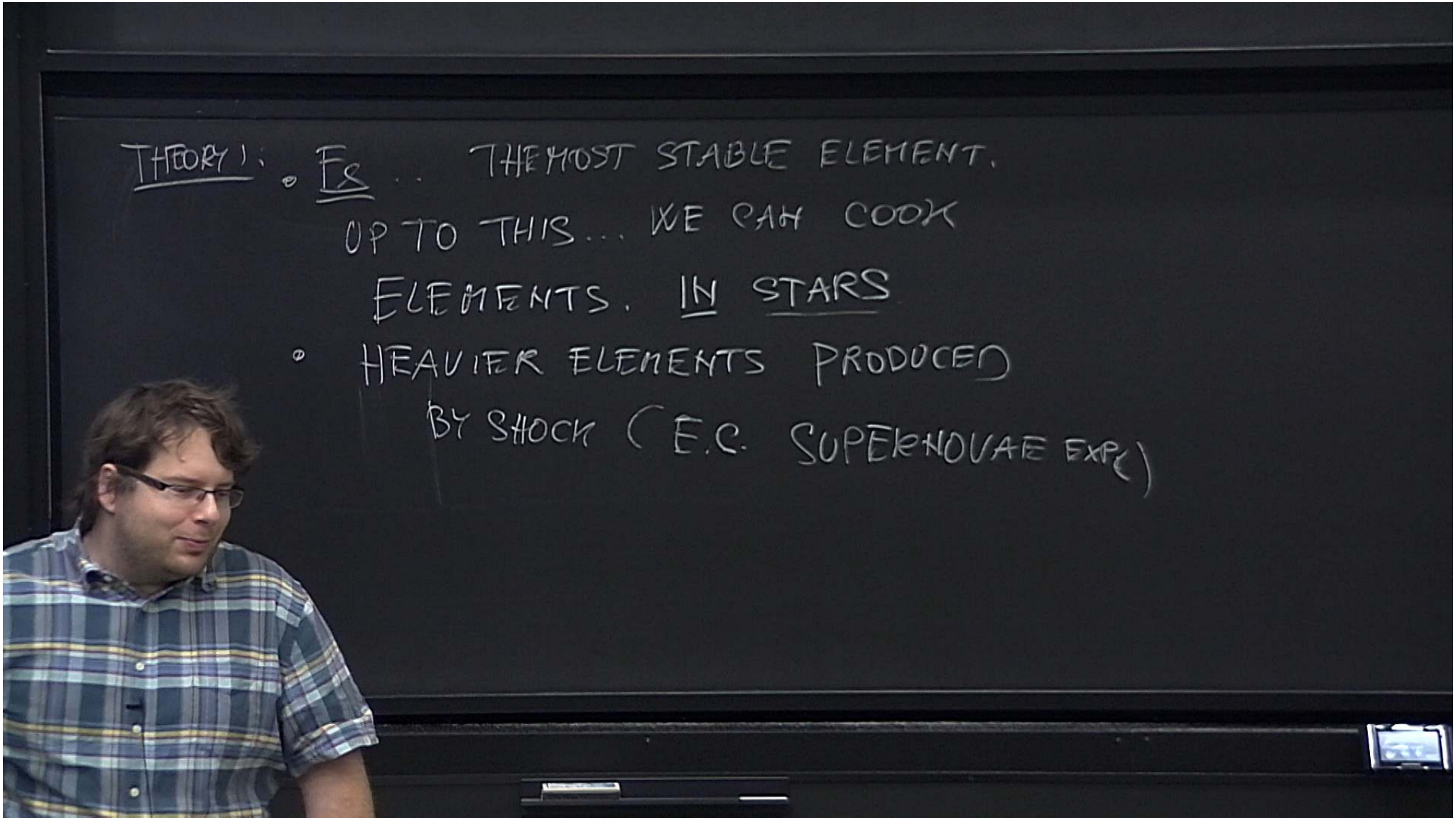
VERYTHING ELSE.
WANT TO DO "BACK OF THE ENVELOPE CALCULATION"
THEORY 1: FUSED IN STARS
THEORY 2: BIG BANG NUCLEOS.


• Fe .. THE MOST STABLE ELEMENT.
UP TO THIS... WE CAN COOK
ELEMENTS. IN


• Fe .. THE MOST STABLE ELEMENT.
UP TO THIS ... WE CAN COOK
ELEMENTS. IN STARS
• HEAVIER ELEMENTS PRODUCED
BY SHOCK (E.G. SUPERNOVAE EXP.)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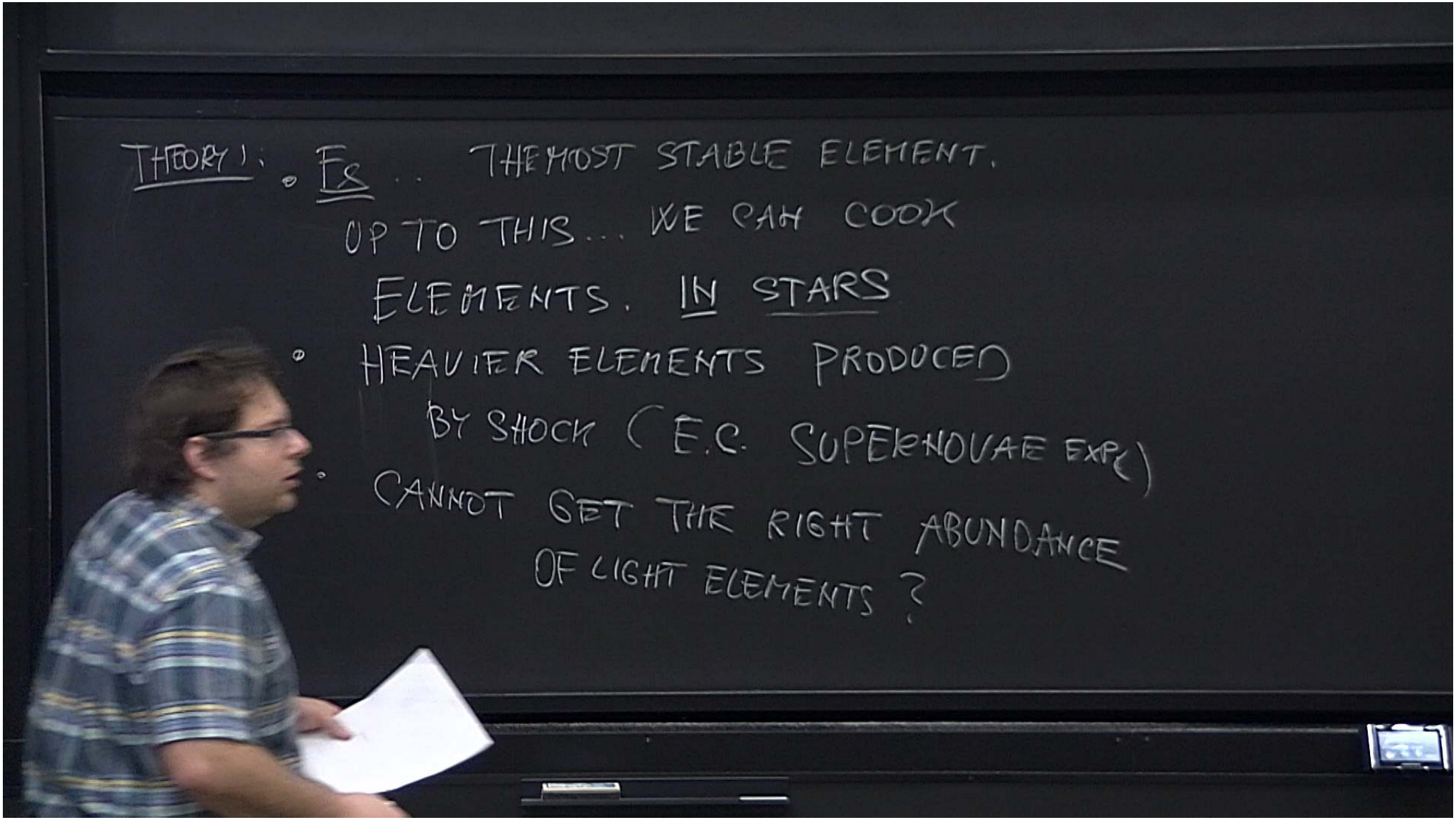
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UP TO THIS... WE CAN COOK
ELEMENTS. IN STARS
HEAVIER ELEMENTS PRODUCED
BY SHOCK (E.G. SUPERNOVAE EXP.)
CANNOT GET THE RIGHT ABUNDANCE
OF LIGHT ELEMENTS ?

FOR EXAMPLE: He^4 .. 28 MeV ... 7 MeV $\simeq 10^{-5}$ ERG / BARYON

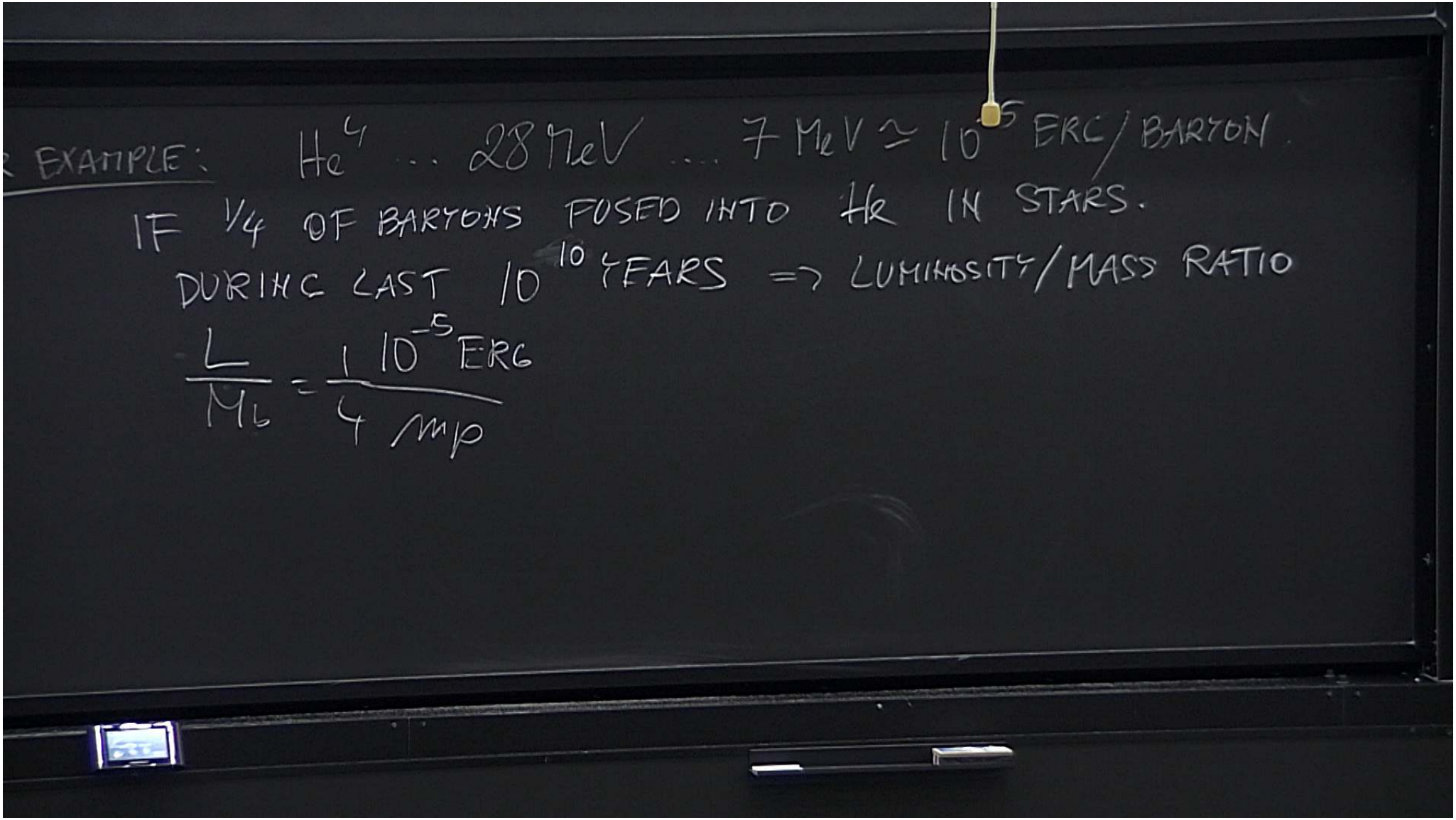
EXP( )

ANCE

EXAMPLE: He^4 .. 28 MeV .... 7 MeV $\simeq 10^{-5}$ ERG/BARYON

IF 1/4 OF BARYONS FUSED INTO He IN STARS.

DURING LAST 10^{10} YEARS

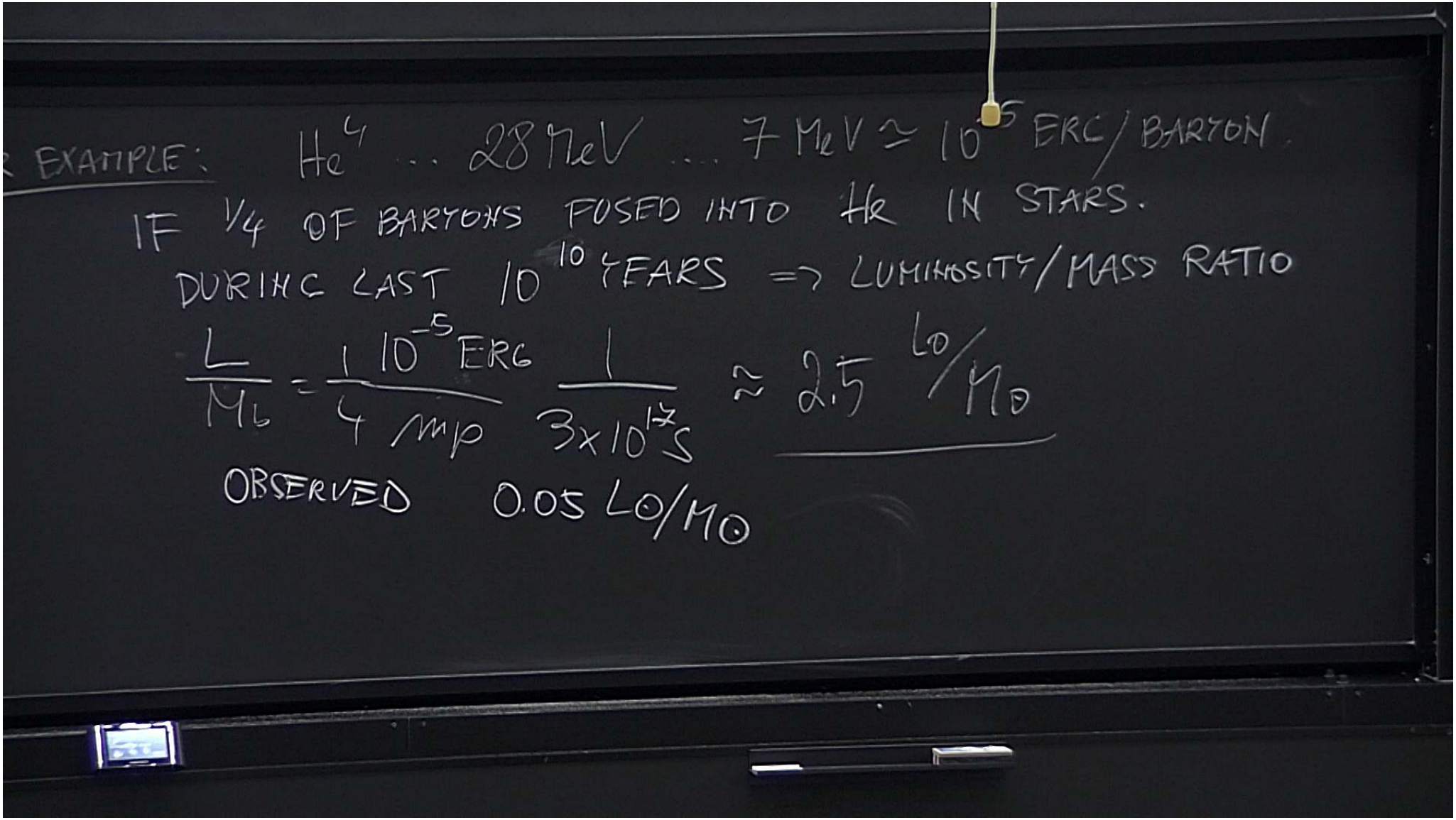

EXAMPLE: He^4 ... 28 MeV ... 7 MeV $\simeq 10^{-5}$ ERG/BARYON
IF 1/4 OF BARYONS FUSED INTO He IN STARS.
DURING LAST 10^{10} YEARS => LUMINOSITY/MASS RATIO
$\frac{L}{M_b} = \frac{1}{4} 10^{-5}$ ERG
m_p

EXAMPLE: He^4 .. 28 MeV ... 7 MeV $\simeq 10^{-5}$ ERG/BARYON

IF 1/4 OF BARYONS FUSED INTO He IN STARS.

DURING LAST 10^{10} YEARS $\Rightarrow$ LUMINOSITY/MASS RATIO

$$\frac{L}{M_b} = \frac{1}{4}\frac{10^{-5}\,\text{ERG}}{m_p}\,\frac{1}{3\times10^{17}\,\text{s}} \simeq 2.5\ L_\odot/M_\odot$$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OBSERVED $0.05\ L_\odot/M_\odot$

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OBSERVED $0.05\ L_\odot/M_\odot \Rightarrow$ 0.5% OF He FUSED IN STARS.

EXAMPLE: He^4 ... 28 MeV ... 7 MeV $\simeq 10^{-5}$ ERG/BARYON.

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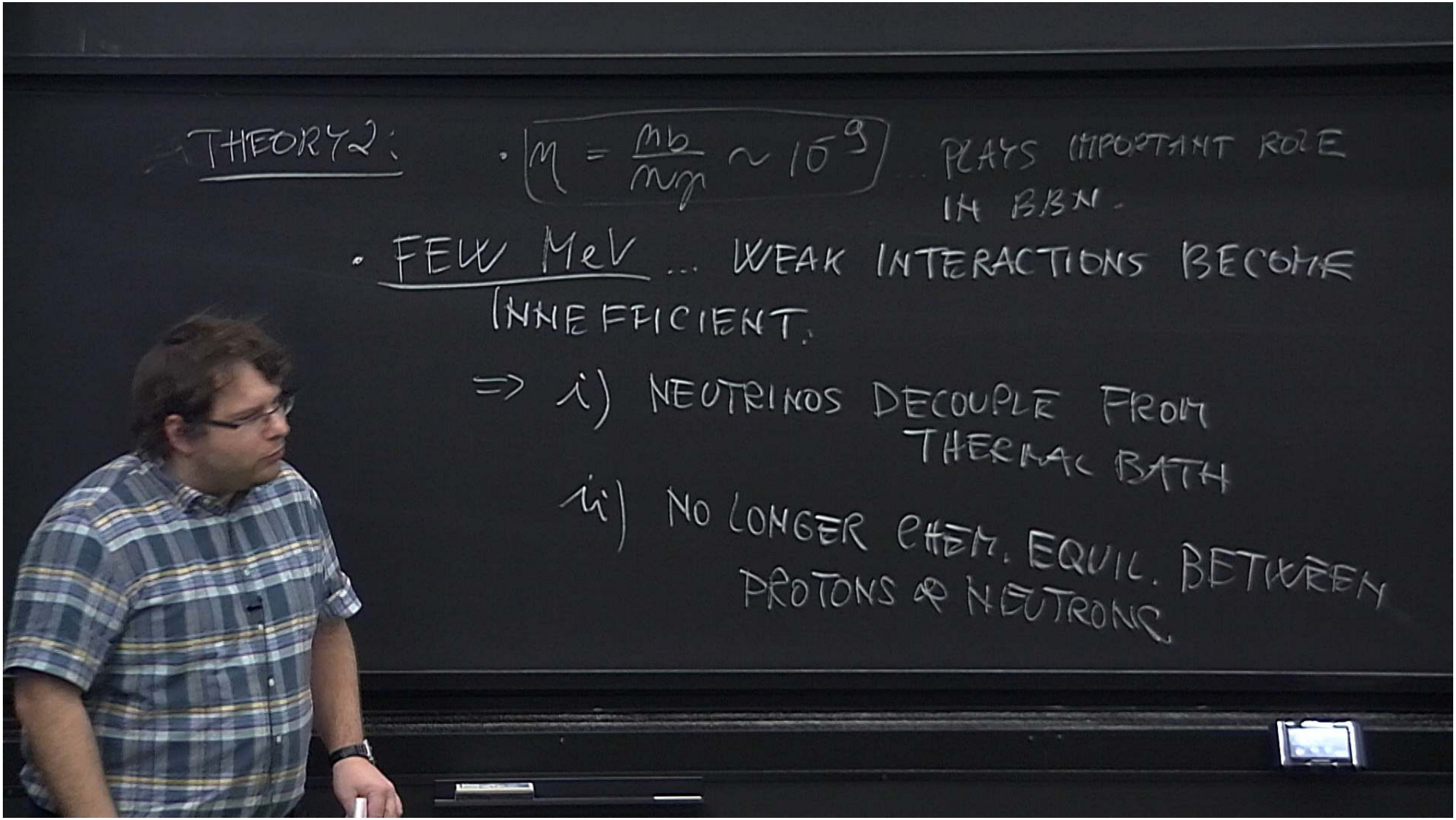
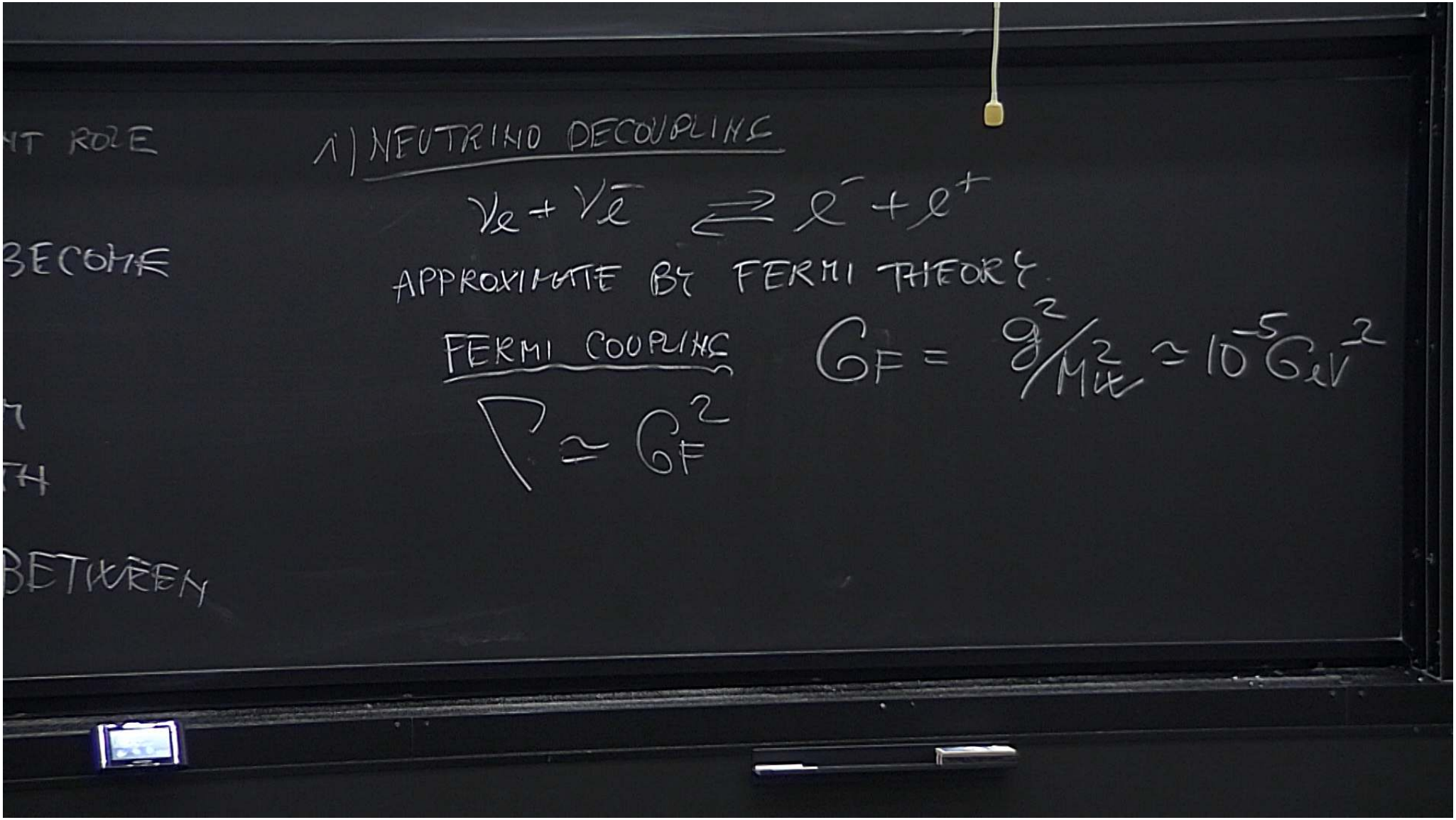
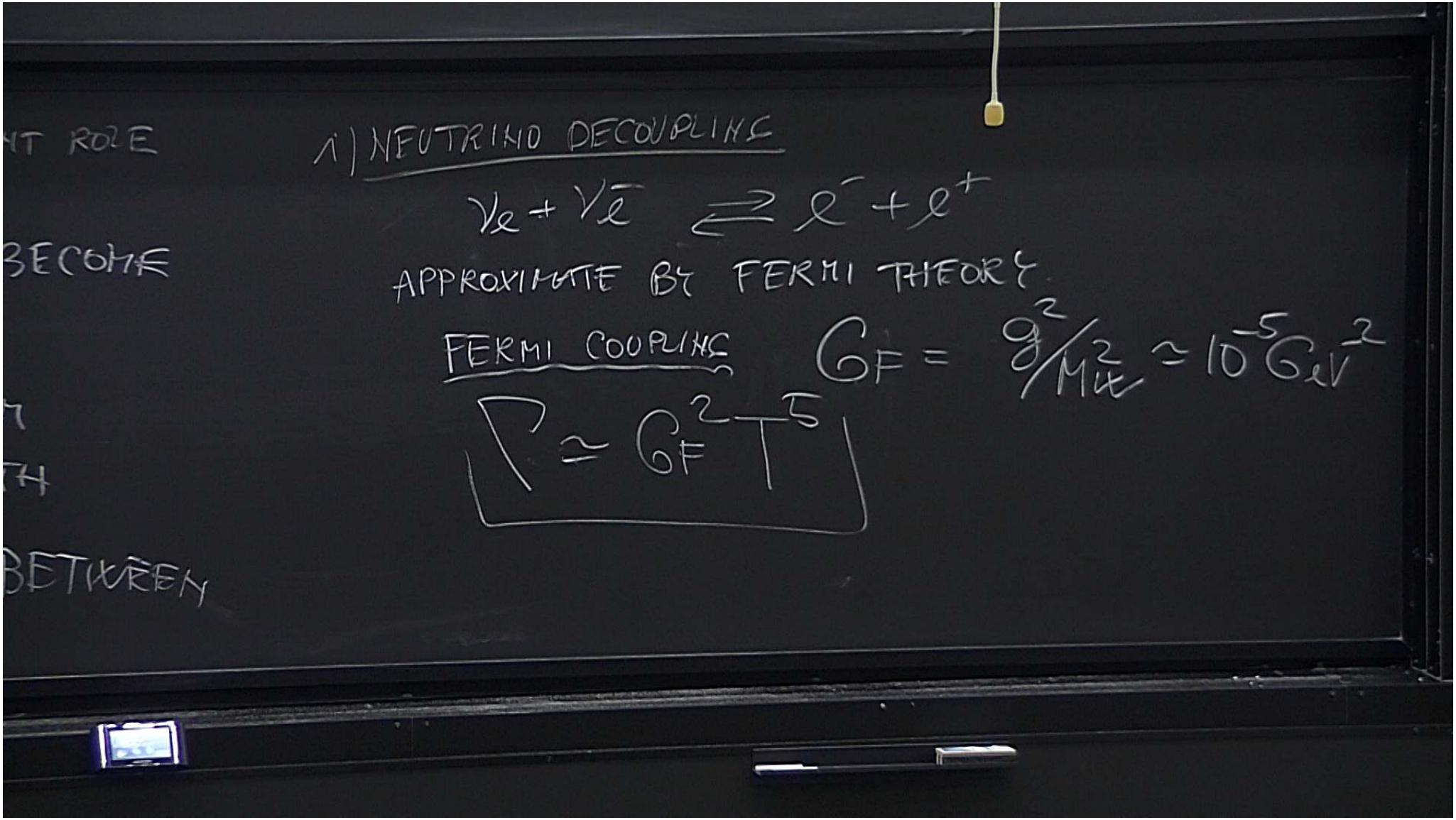

THEORY2:
$\eta = \frac{n_b}{n_\gamma} \sim 10^{-9}$
PLAYS IMPORTANT ROLE IN BBN.
FEW MeV ... WEAK INTERACTIONS BECOME INNEFFICIENT.
=> i) NEUTRINOS DECOUPLE FROM THERMAL BATH
ii) NO LONGER CHEM. EQUIL. BETWEEN PROTONS & NEUTRONS


NT ROLE
BECOME
TH
BETWEEN
1) NEUTRINO DECOUPLING
$\nu_e + \bar{\nu}_e \rightleftarrows e^- + e^+$
APPROXIMATE BY FERMI THEORY
FERMI COUPLING
$G_F = g^2/M_W^2 \simeq 10^{-5}\,GeV^{-2}$
$\Gamma \simeq G_F^2$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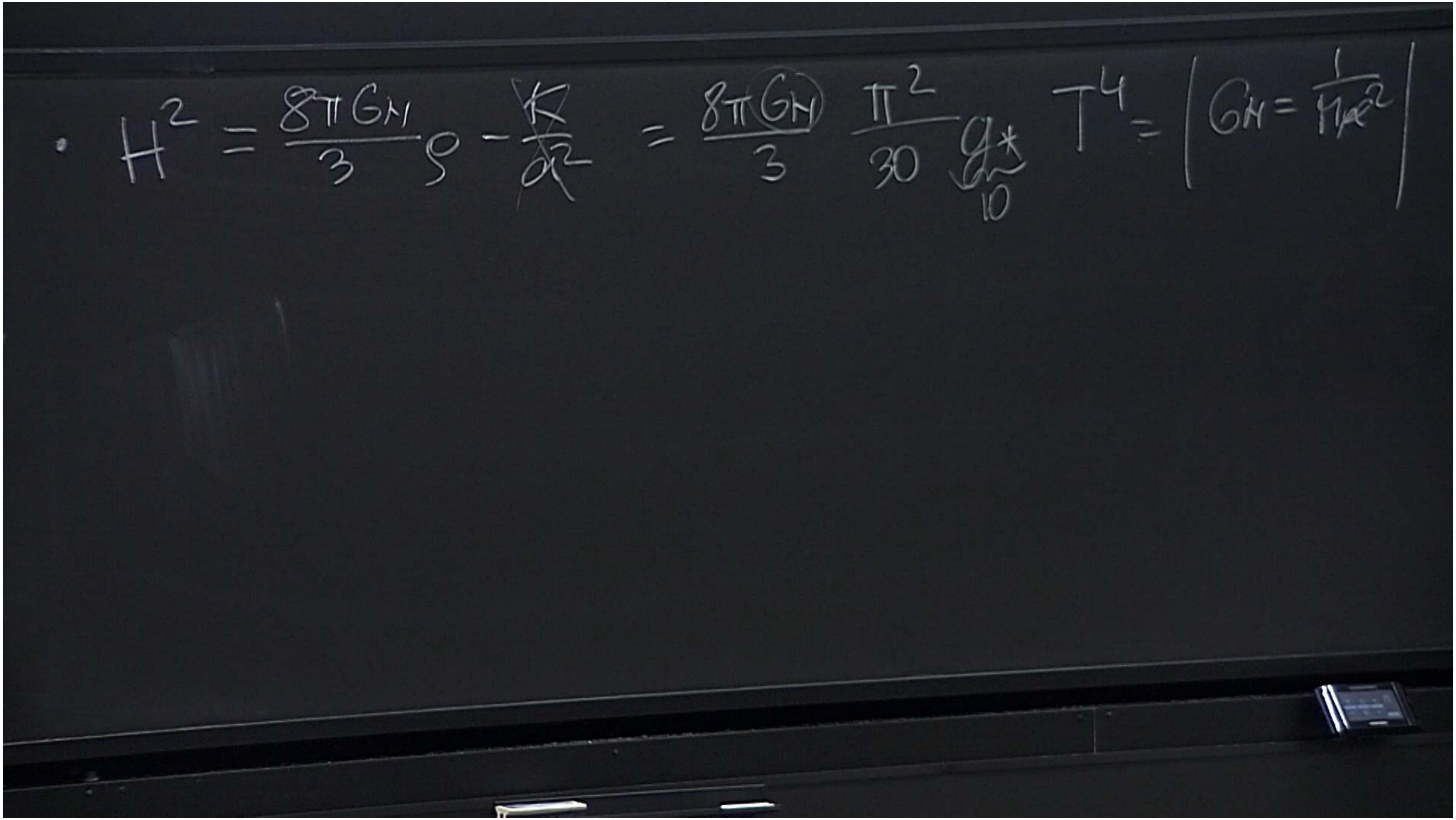
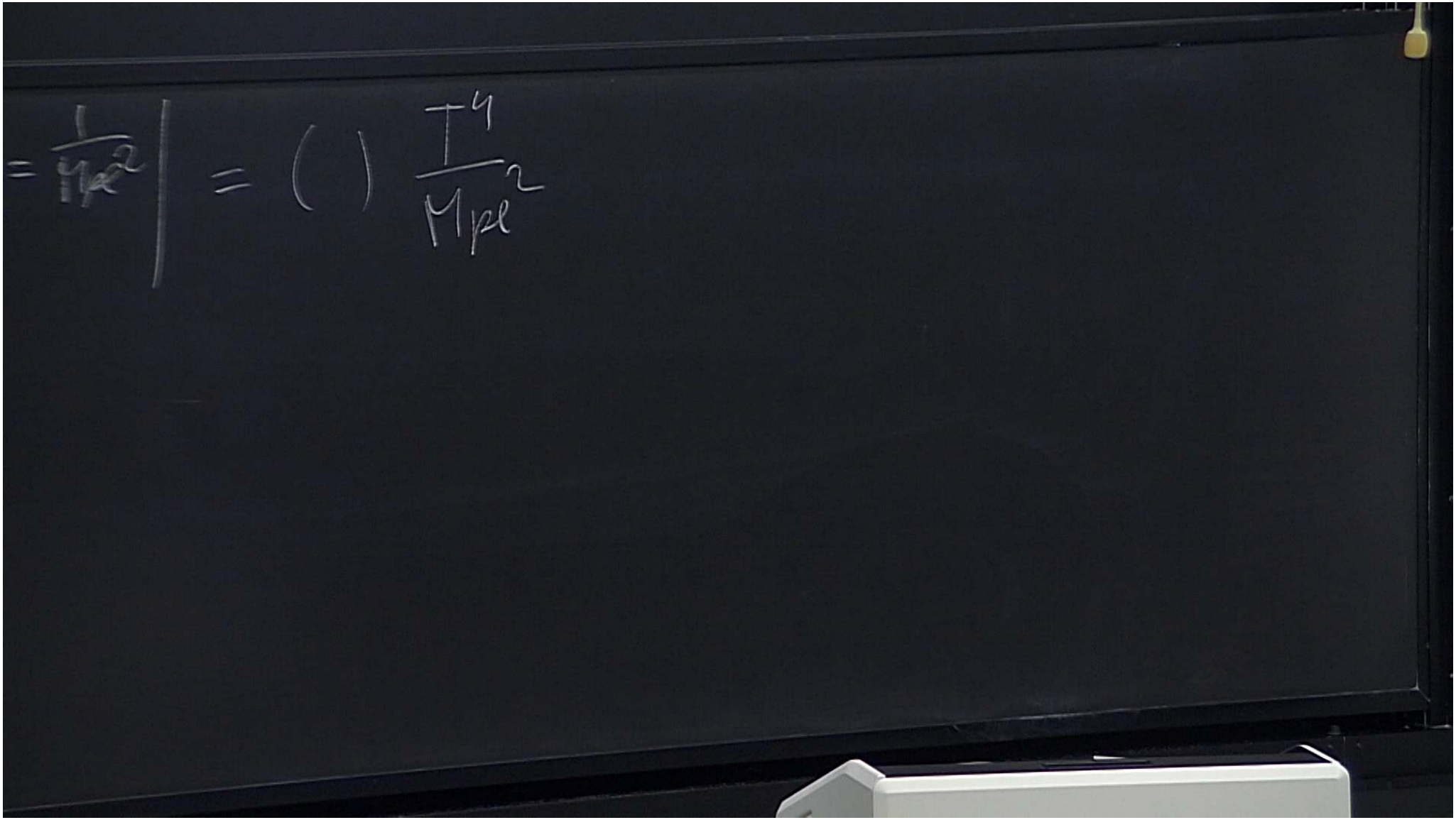
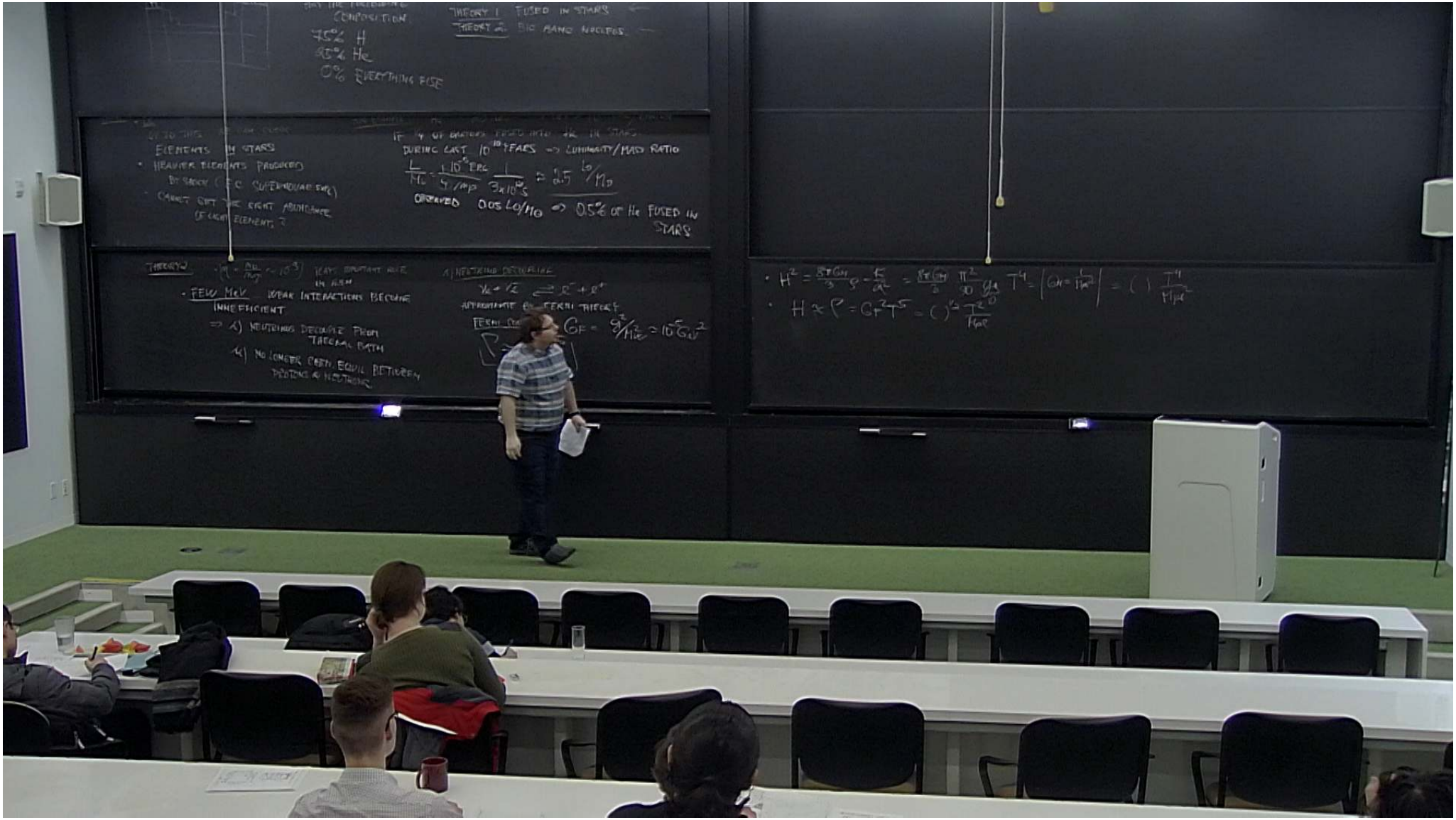
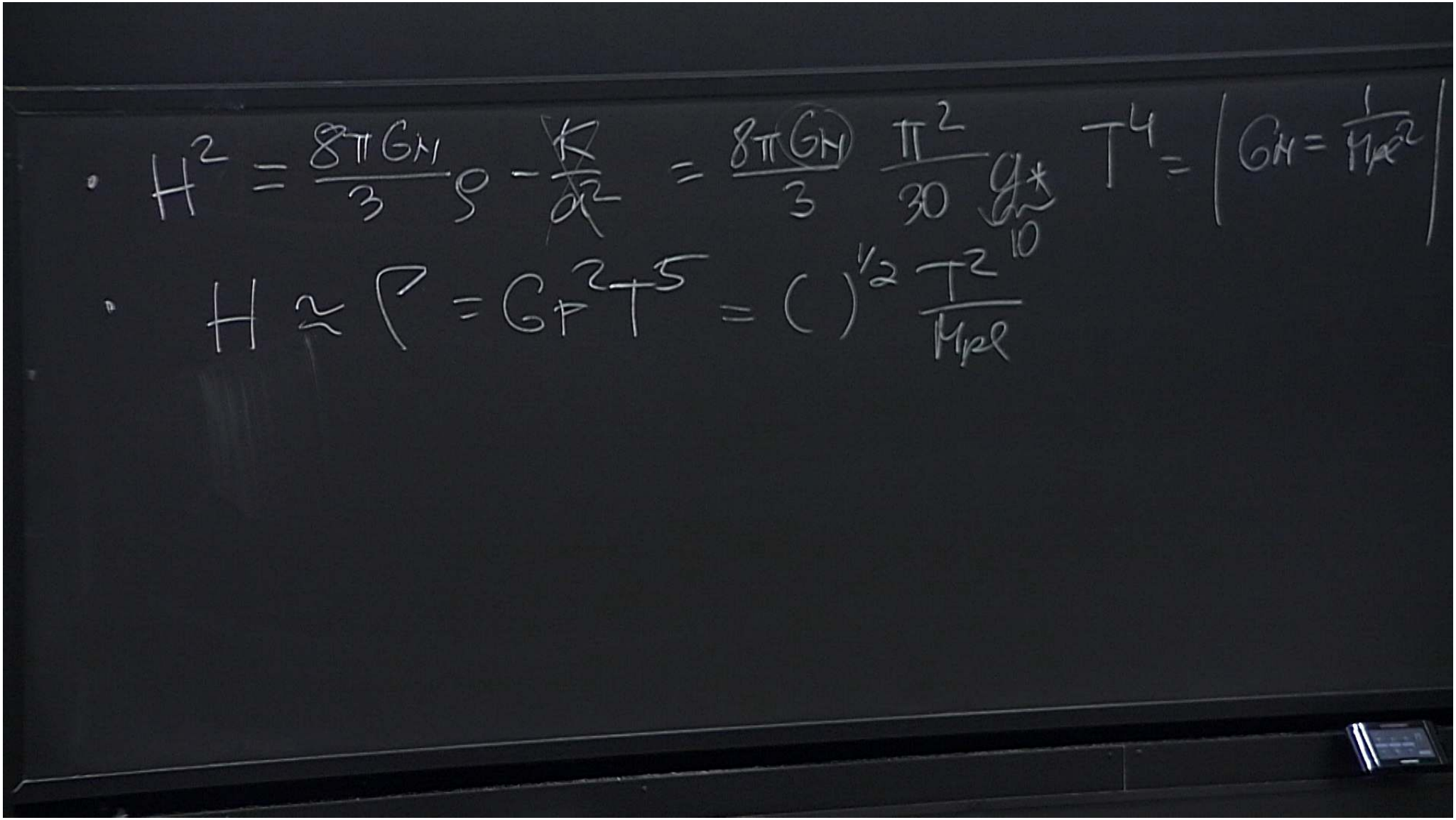
FERMI COUPLING $G_F = g^2/M_W^2 \simeq 10^{-5}\,GeV^{-2}$
$\Gamma \simeq G_F^2 T^5$


$H^2 = \frac{8\pi G_N}{3}\rho - \frac{K}{a^2} = \frac{8\pi G_N}{3}\frac{\pi^2}{30}g_{10}^{*}T^4 = \left| G_N = \frac{1}{M_{Pl}^2} \right|$


$= \frac{1}{4\pi r^2} \Big| = ( ) \frac{T^4}{M_{Pl}^2}$


COMPOSITION
75% H
25% He
0% EVERYTHING ELSE
THEORY I FUSED IN STARS
THEORY II BIG BANG NUCLEOS
ELEMENTS IN STARS
HEAVIER ELEMENTS PRODUCED
DURING CAST 10^{10} YEARS => LUMINOSITY/MASS RATIO
OBSERVED 0.05 $L_\odot/M_\odot$ => 05% OF He FUSED IN STARS
FEW MeV WEAK INTERACTIONS BECOME INEFFICIENT
=> A) NEUTRINOS DECOUPLE FROM THERMAL PATH
B) NO LONGER ENOUGH EQUIL BETWEEN PROTONS & NEUTRONS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$H \simeq \Gamma = G_F^2 T^5 = ()^{1/2} \frac{T^2}{M_{PL}}$

- $H^2 = \frac{8\pi G_N}{3}\rho - \frac{K}{a^2} = \frac{8\pi G_N}{3}\frac{\pi^2}{30} g_* T^4 = \left| G_N = \frac{1}{M_{Pl}^2} \right|$

- $H \simeq \Gamma = G_F^2 T^5 = (\,)^{1/2} \frac{T^2}{M_{Pl}}$

$\Rightarrow T \simeq 1\,\text{MeV}$

$$H \simeq \Gamma = G_F^2 T^5 = (\quad)^{1/2} \frac{T^2}{M_{Pl}} \qquad \frac{1}{10}$$

$$\Rightarrow T \simeq 1\,\text{MeV}$$

iii) CHEMICAL EQUIL BETWEEN p & n:

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

$$H \simeq \Gamma = G_F^2 T^5 = (\quad)^{1/2} \frac{T^2}{M_{Pl}}$$

$$\Rightarrow T \simeq 1\,\text{MeV}$$

iii) CHEMICAL EQUIL BETWEEN p & n:

STOP... T

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

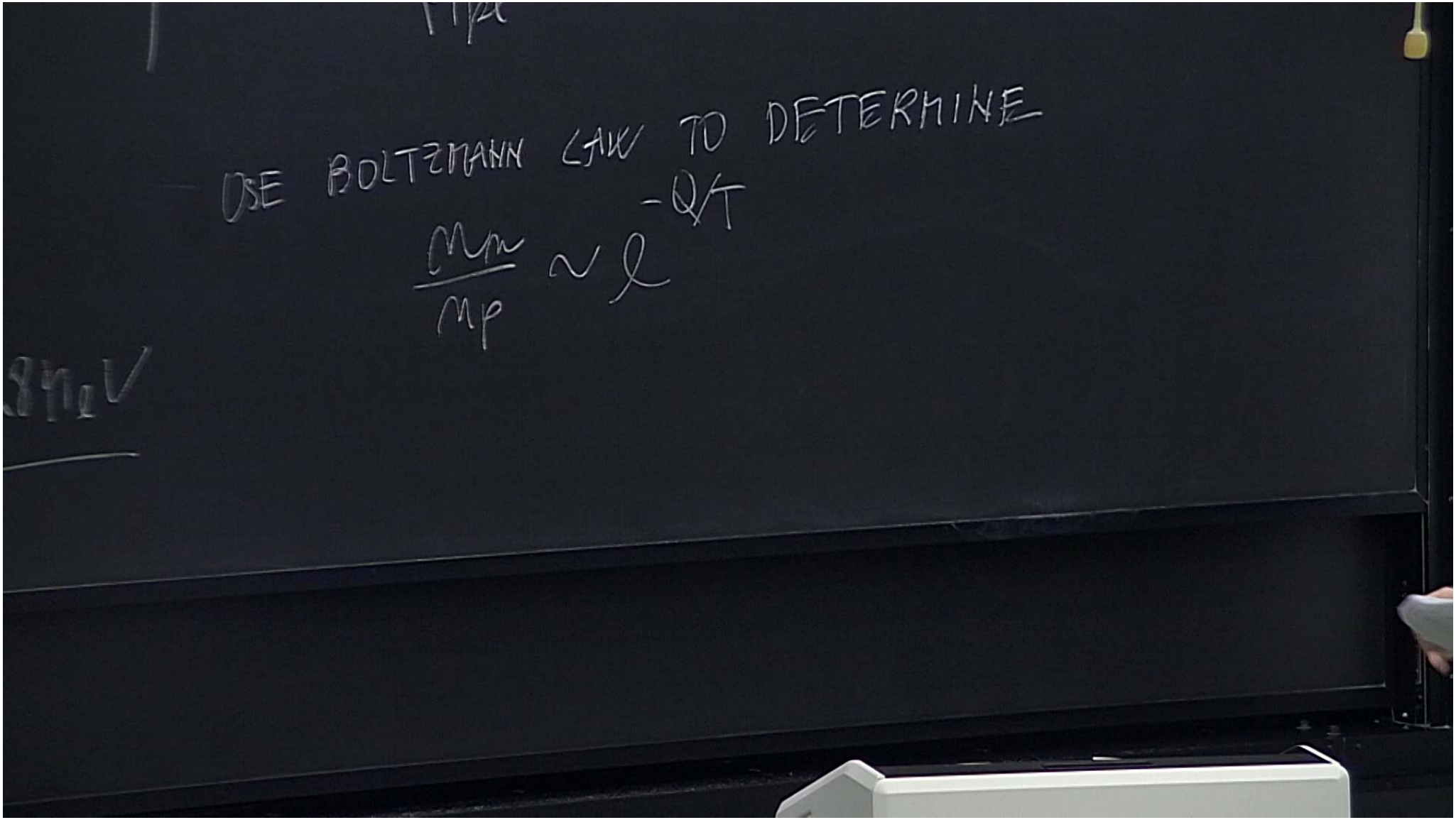
$H \simeq \Gamma = G_F^2 T^5 = ()^{1/2} \frac{T^2}{M_{Pl}}$

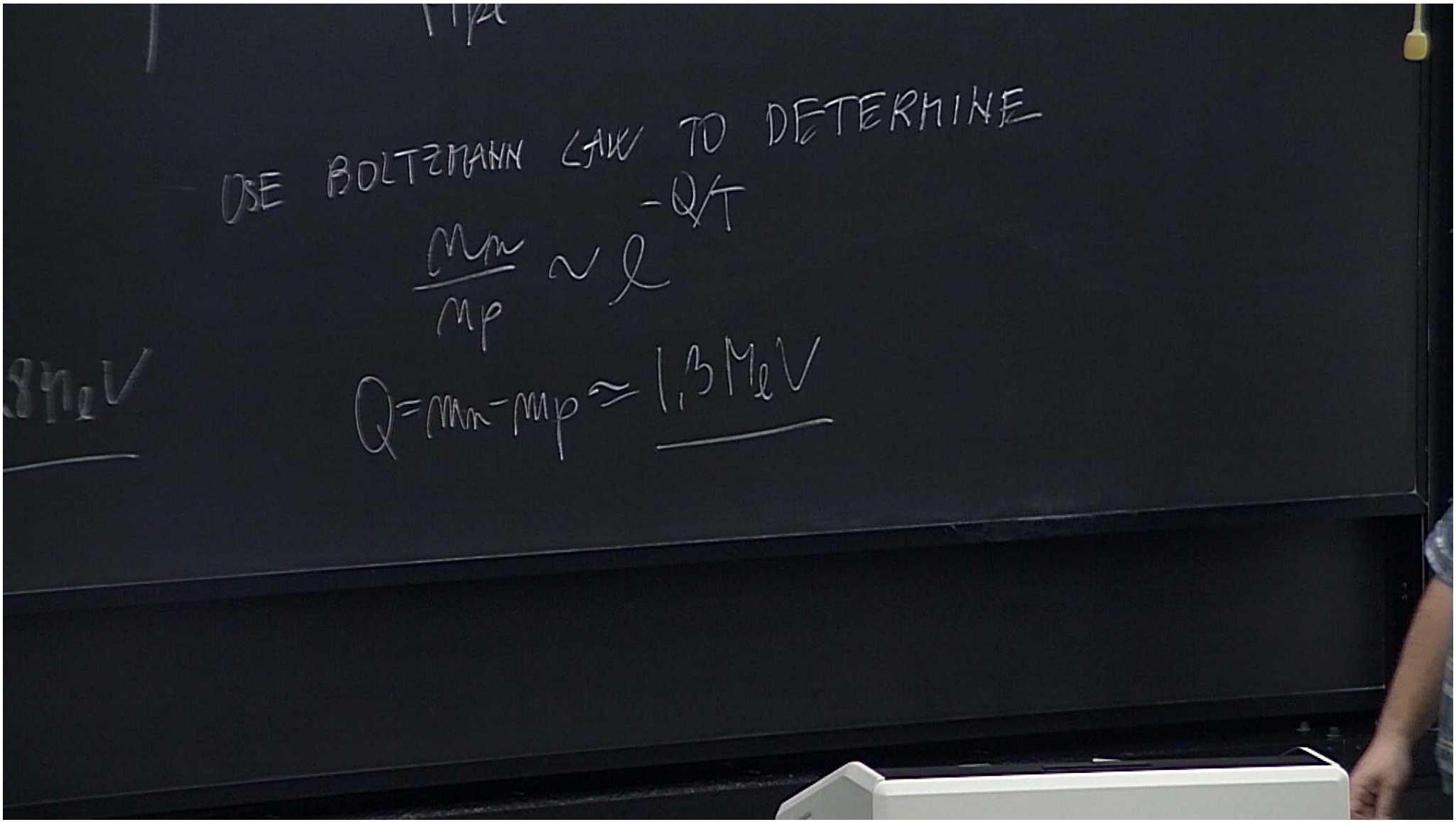
$\Rightarrow T \simeq 1\,MeV$

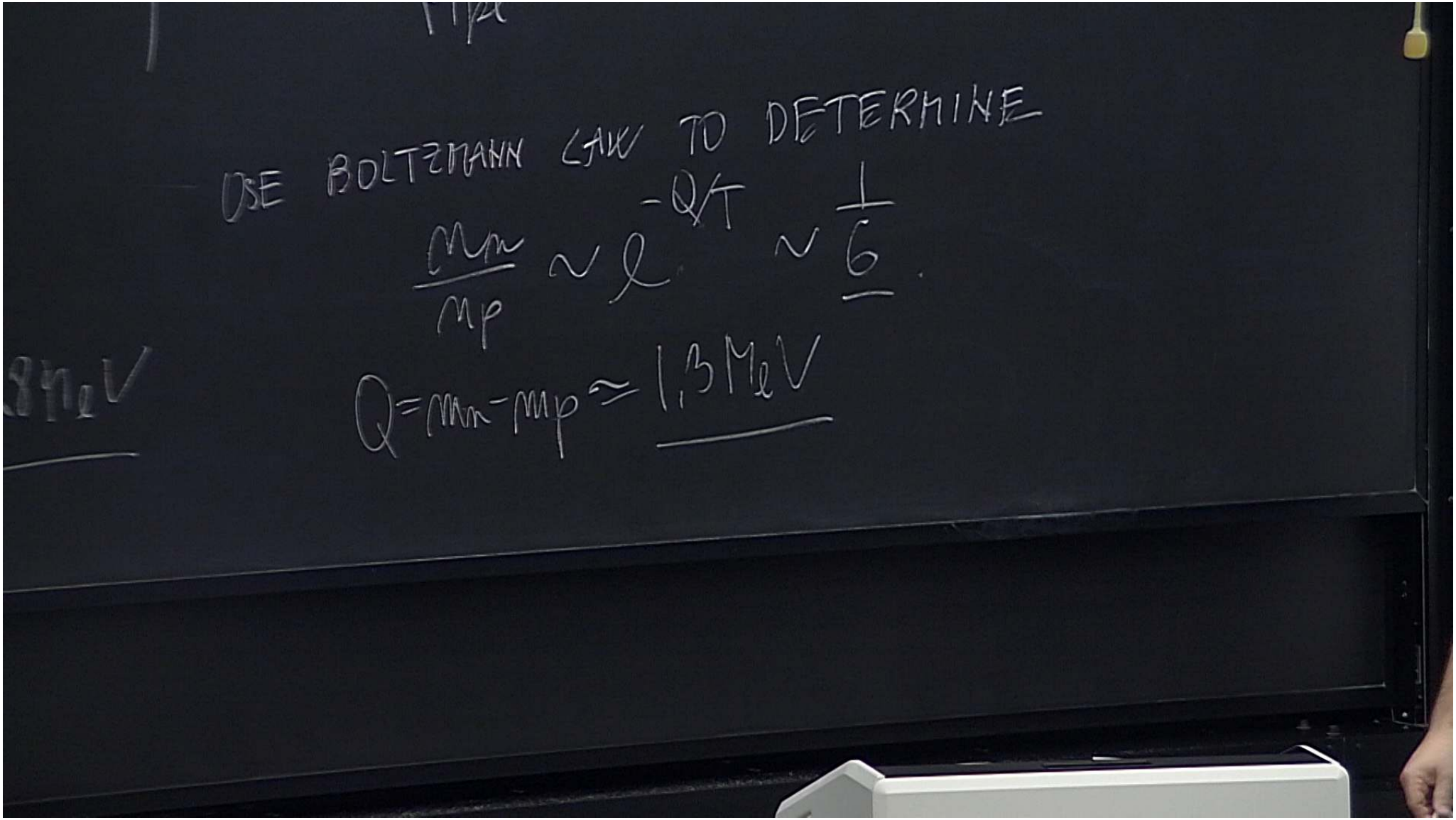
iii) CHEMICAL EQUIL BETWEEN p & n:

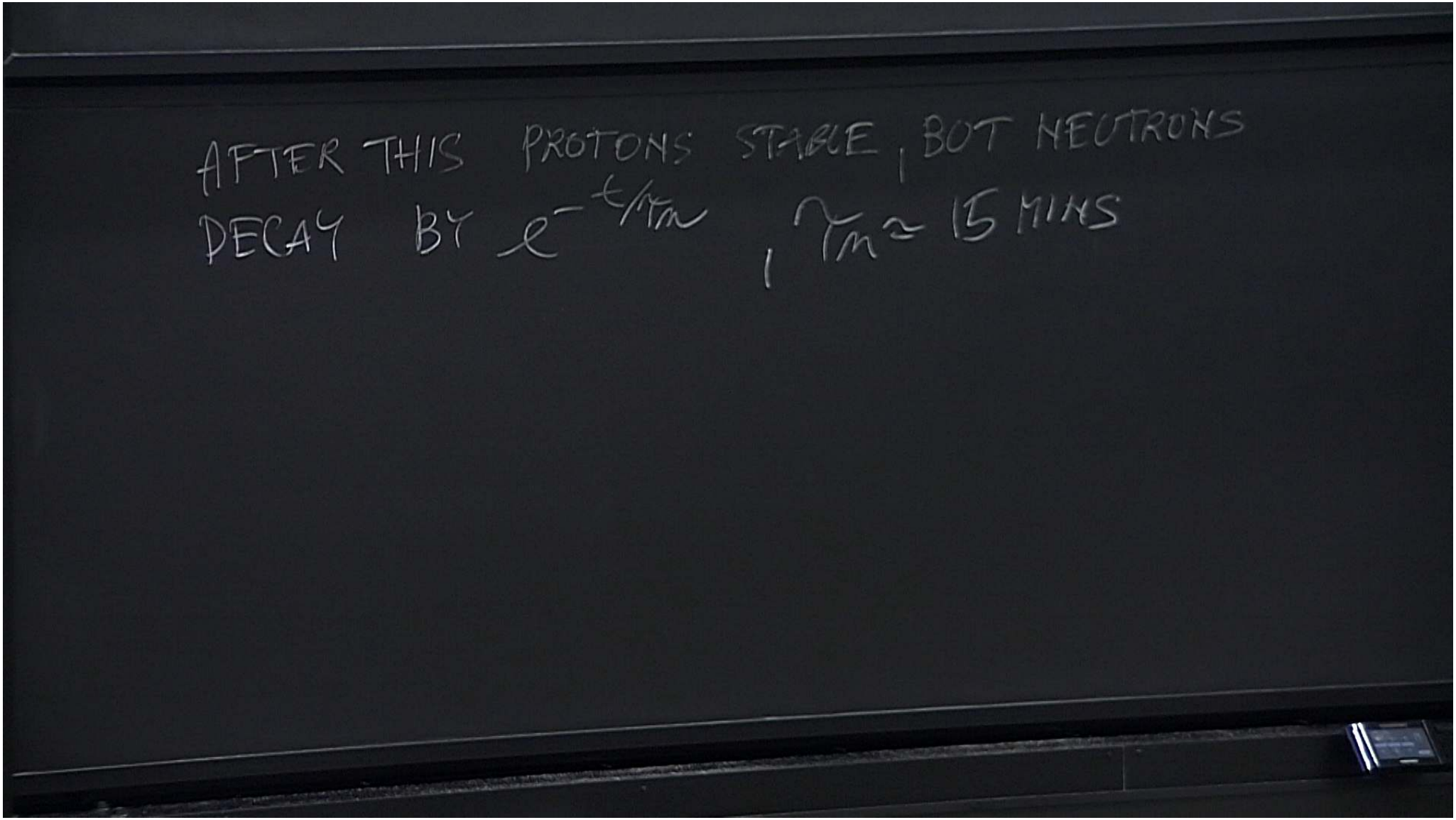
$p^+ + e^- \rightleftarrows n + \nu_e$

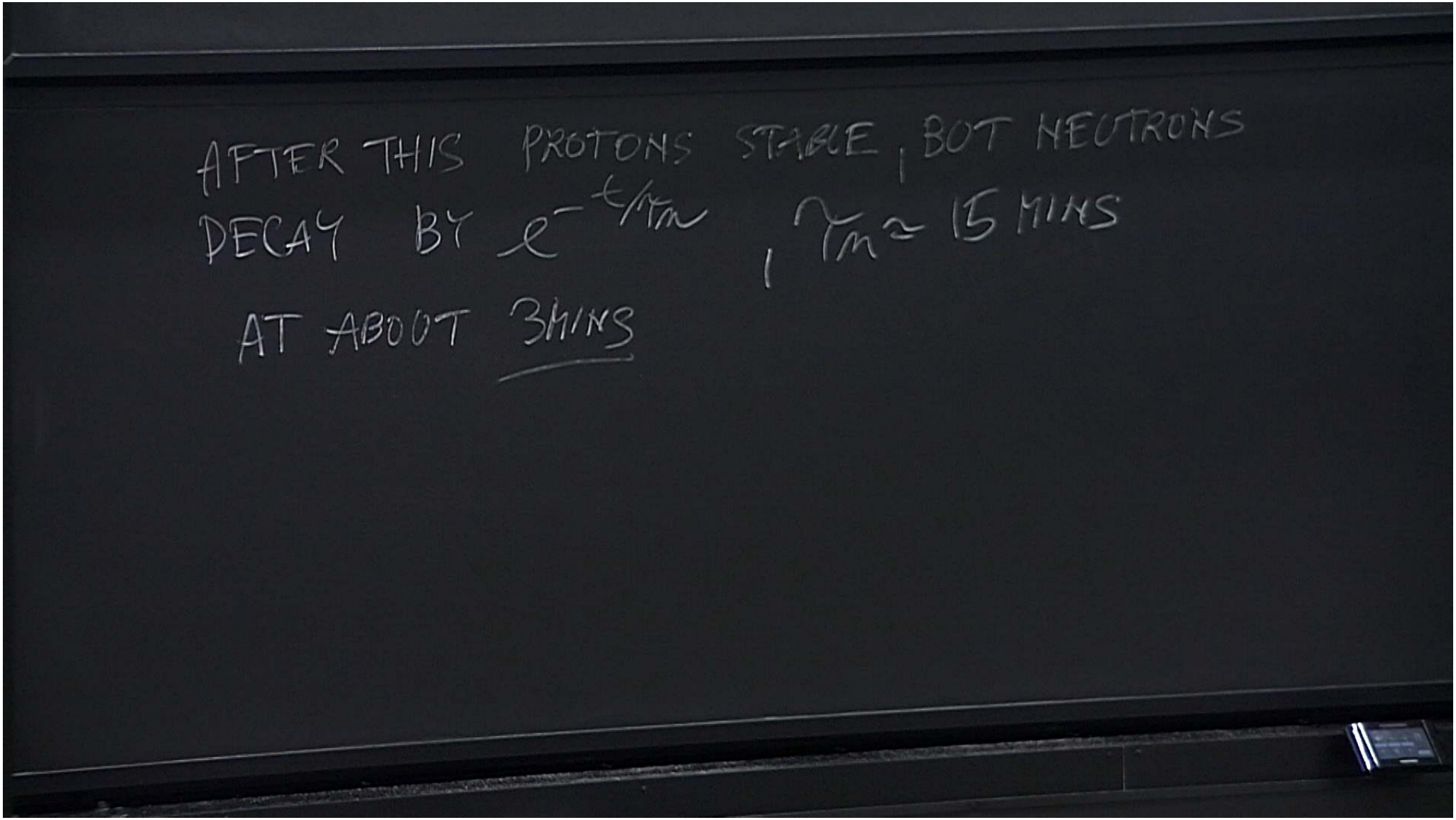
STOP... $T \simeq 0.8\,MeV$


USE BOLTZMANN GAS TO DETERMINE
$\frac{n_m}{n_p} \sim e^{-Q/T}$


USE BOLTZMANN LAW TO DETERMINE
$\frac{n_n}{n_p} \sim e^{-Q/T}$
$Q = m_n - m_p \simeq 1{,}3\,\mathrm{MeV}$

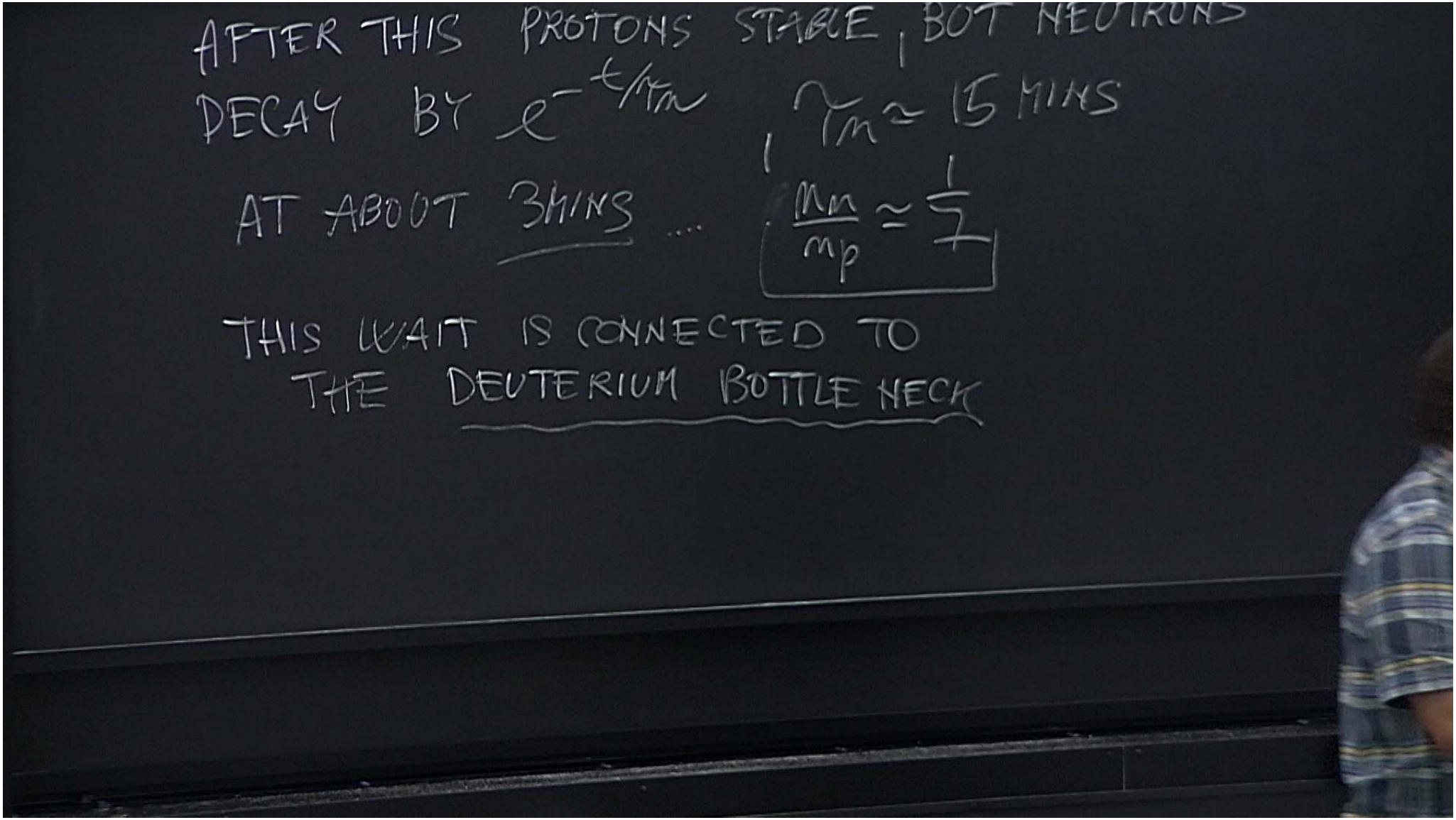

USE BOLTZMANN LAW TO DETERMINE
$\frac{n_n}{n_p} \sim e^{-Q/T} \sim \frac{1}{6}$
$Q = m_n - m_p \simeq 1{,}3\,\mathrm{MeV}$

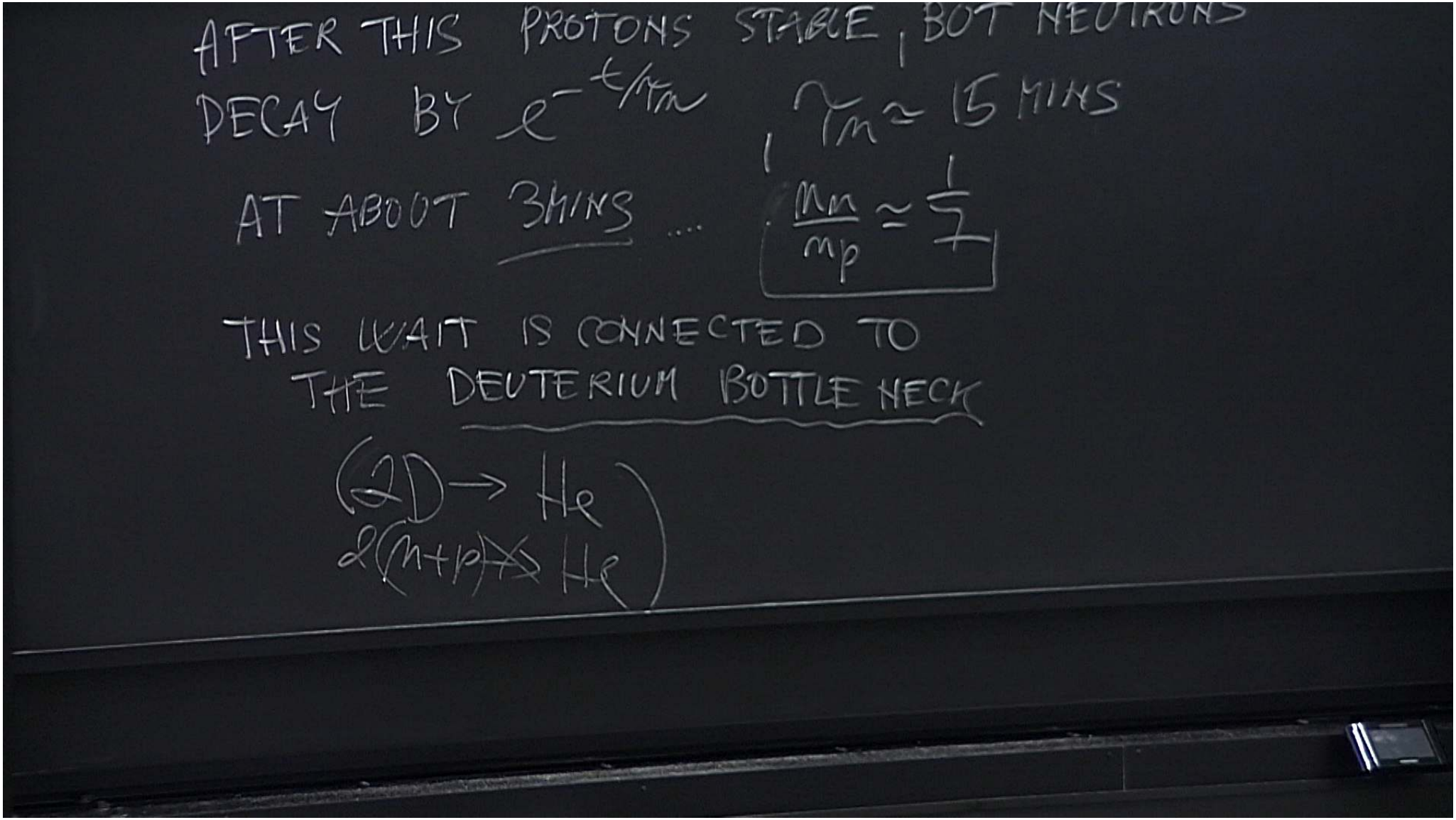

AFTER THIS PROTONS STABLE, BOT NEUTRONS
DECAY BY e^{-t/τ_n}, $\tau_n \simeq 15$ MINS


AFTER THIS PROTONS STABLE, BOT NEUTRONS
DECAY BY e^{-t/τ_n}, $\tau_n \simeq 15$ MINS
AT ABOUT 3MINS

AFTER THIS PROTONS STABLE, BUT NEUTRONS DECAY BY e^{-t/τ_n}, $\tau_n \simeq 15$ MINS

AT ABOUT 3MINS ... $\frac{n_n}{n_p} \simeq \frac{1}{7}$


AFTER THIS PROTONS STABLE, BOT NEUTRONS
DECAY BY e^{-t/τ_n} , $\tau_n \simeq 15$ MINS
AT ABOUT 3MINS ... $\frac{n_n}{n_p} \simeq \frac{1}{7}$
THIS WAIT IS CONNECTED TO
THE DEUTERIUM BOTTLE NECK


AFTER THIS PROTONS STABLE, BOT NEUTRONS
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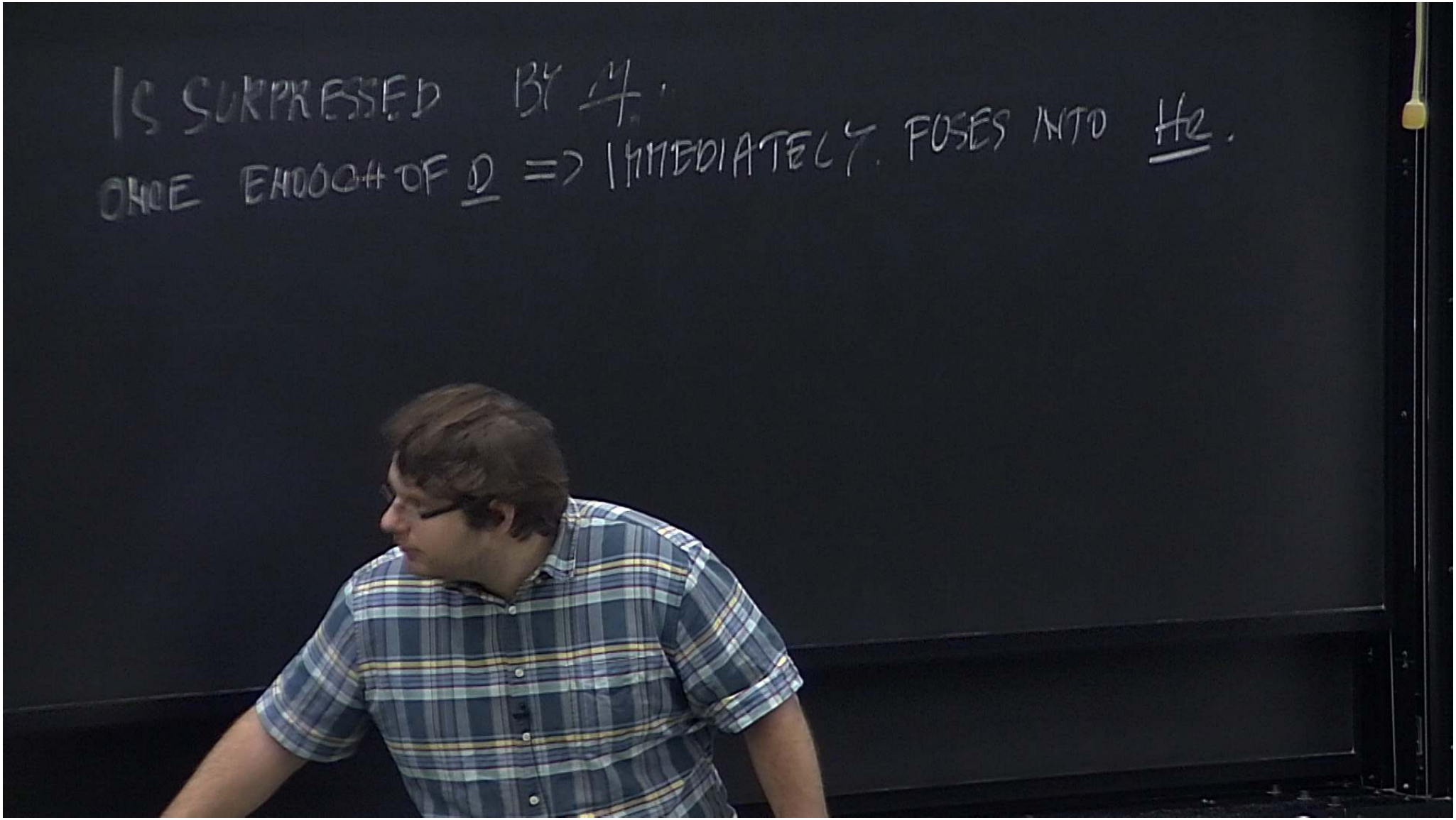
THIS WAIT IS CONNECTED TO
THE DEUTERIUM BOTTLE NECK
$(^2D \rightarrow {}^4He$
$2(n+p) \not\rightarrow {}^4He)$

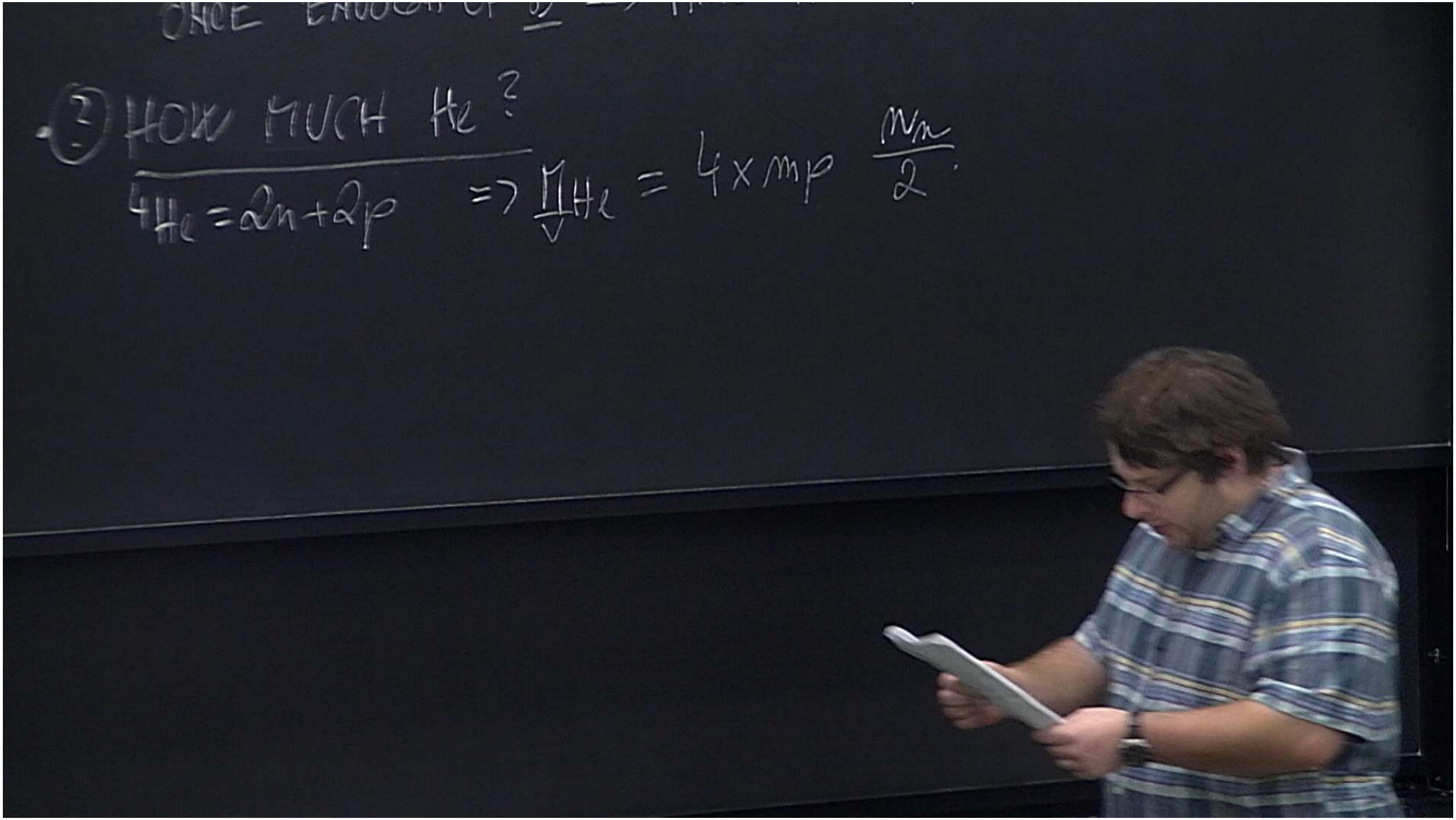
AFTER THIS PROTONS STABLE, BOT NEUTRONS IS
DECAY BY e^{-t/τ_n} , $\tau_n \approx 15$ MINS
AT ABOUT 3MINS ... $\frac{n_n}{n_p} \approx \frac{1}{7}$

THIS WAIT IS CONNECTED TO
THE DEUTERIUM BOTTLE NECK

$(2D \rightarrow He$
$2(n+p) \not\rightarrow He)$

NEED ENOUGH D.
BUT ITS CREATION

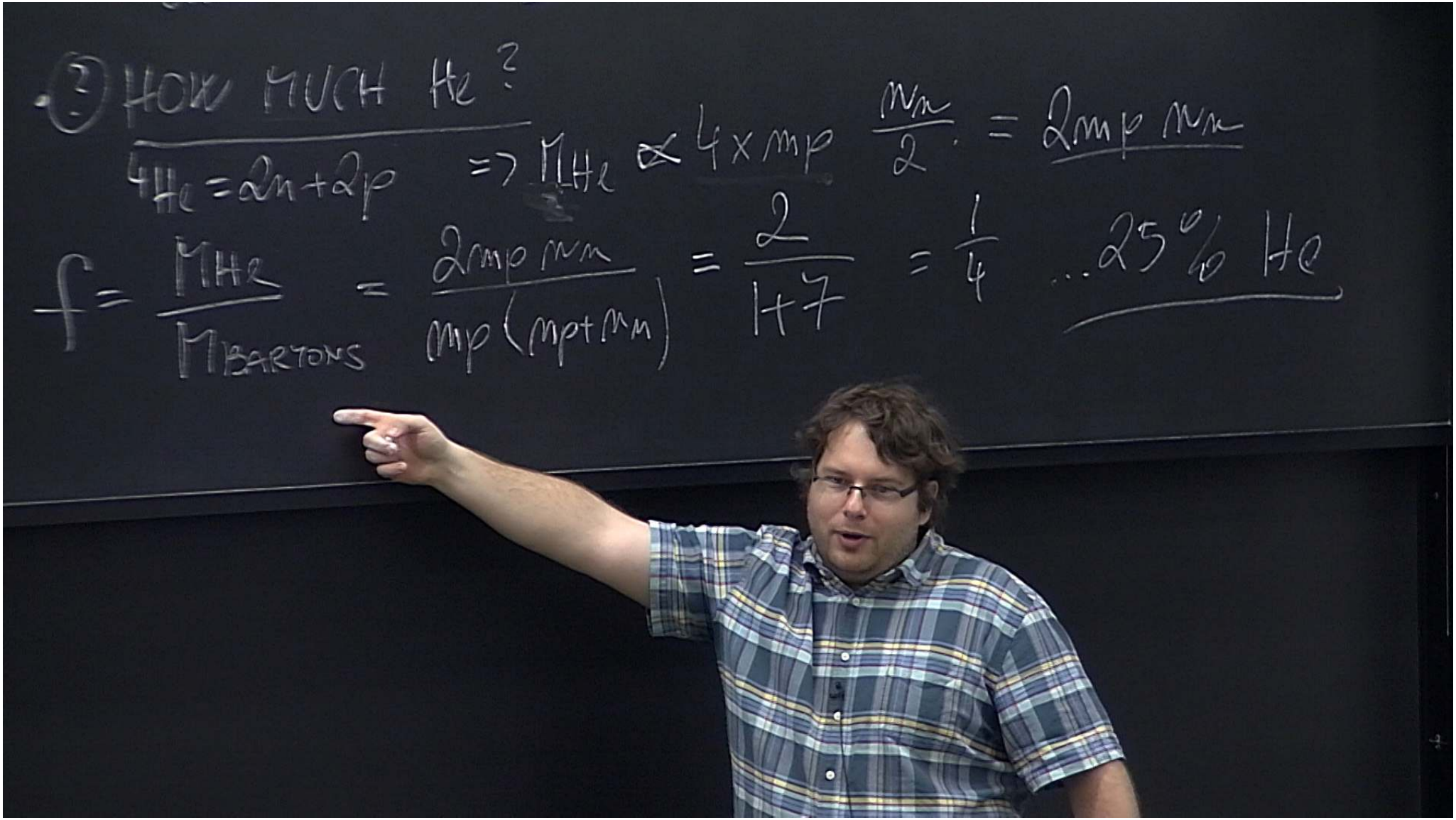

IS SUPPRESSED BY 4.
ONCE ENOUGH OF D => IMMEDIATELY FUSES INTO He.

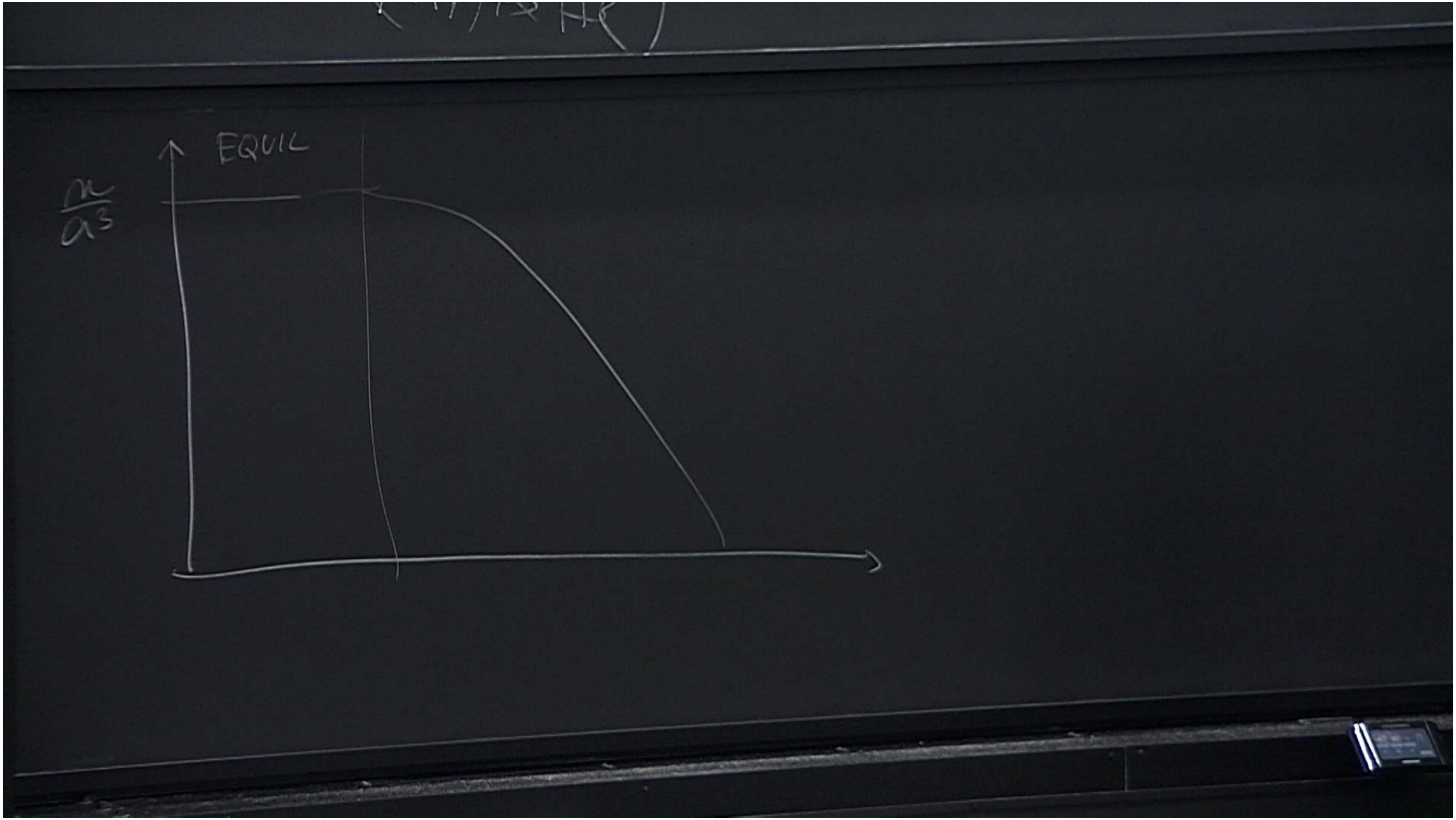

ONCE
(3) HOW MUCH He?
$^4He = 2n + 2p \Rightarrow \prod_{\downarrow} He = 4 \times mp \frac{m_n}{2}$.

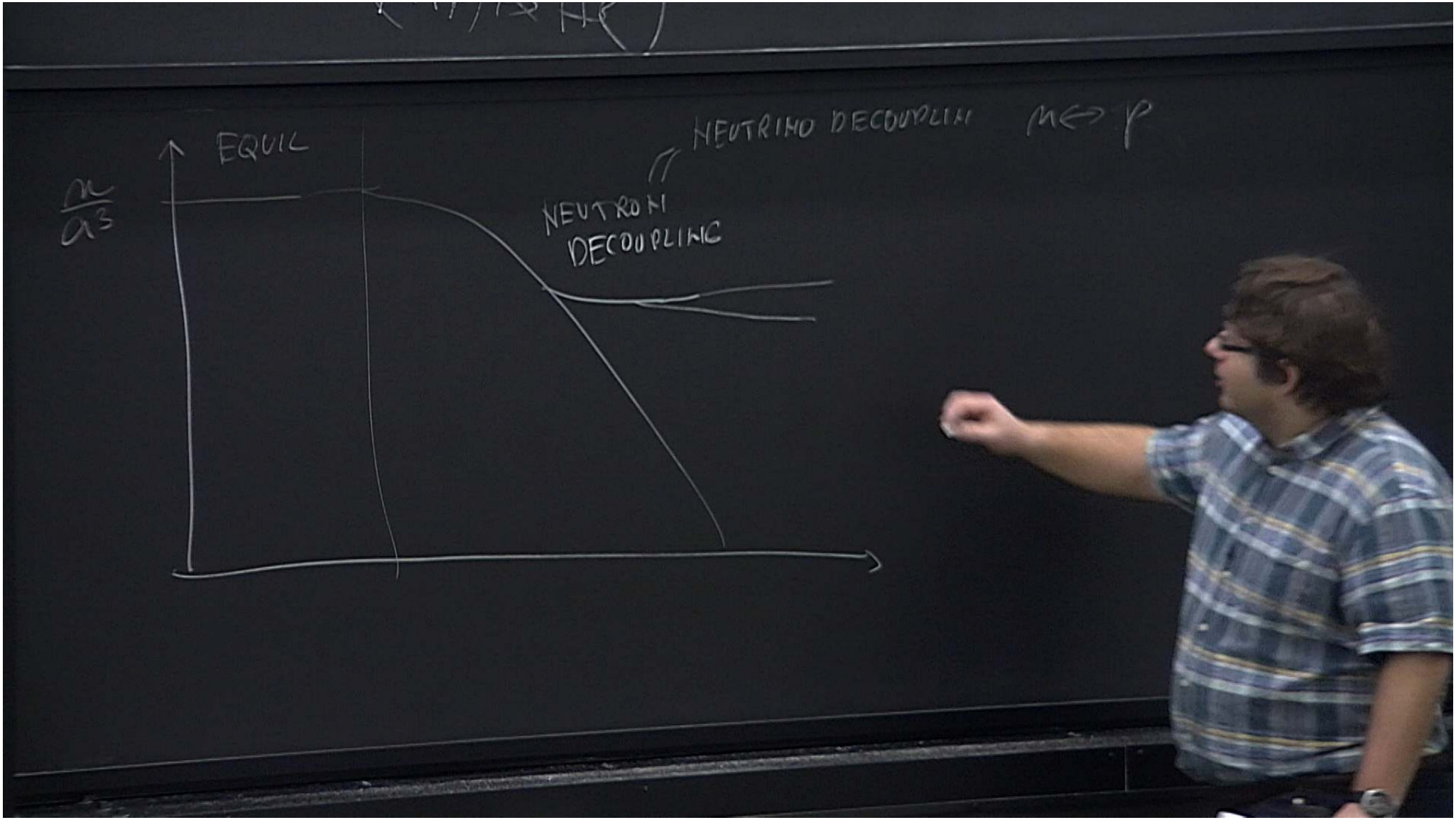
③ HOW MUCH ^4He?

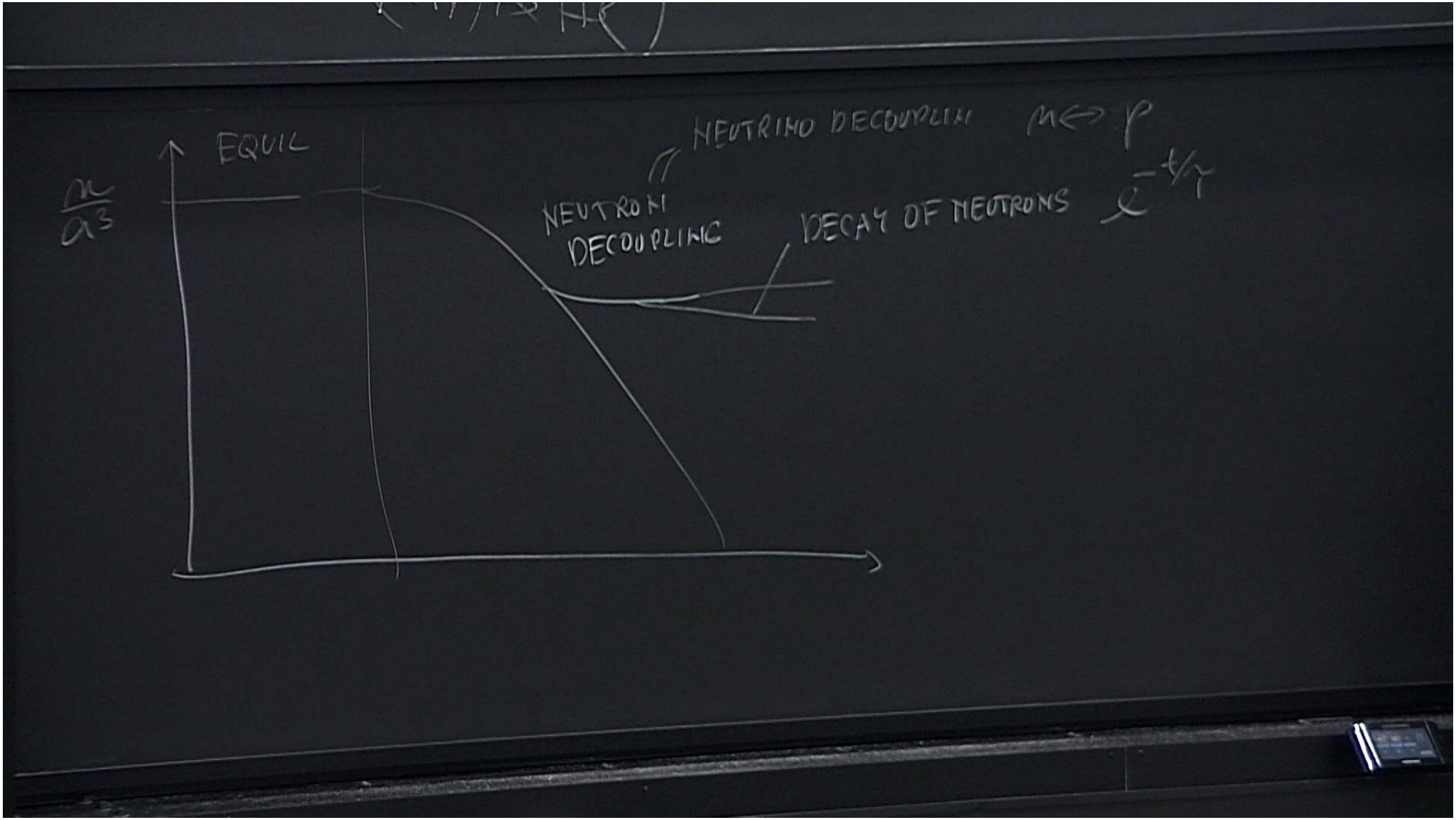
$^4He = 2n + 2p \Rightarrow M_{^4He} = 4 \times m_p \frac{n_n}{2} = 2 m_p n_n$

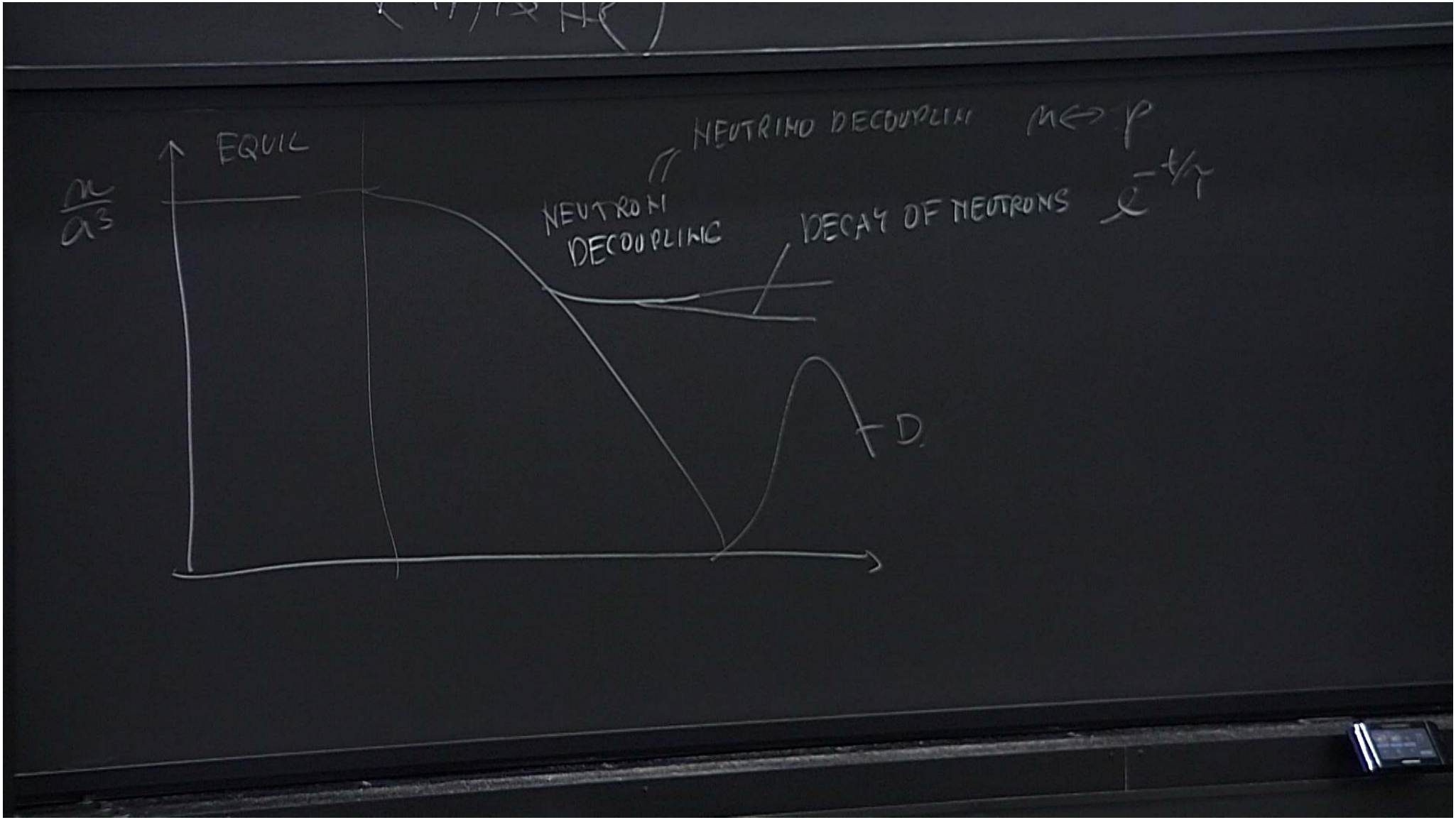
$f = \frac{M_{^4He}}{M_{BARYONS}} = \frac{2 m_p n_n}{m_p (n_p + n_n)} = \frac{2}{1+7} = \frac{1}{4}$ ...25% He

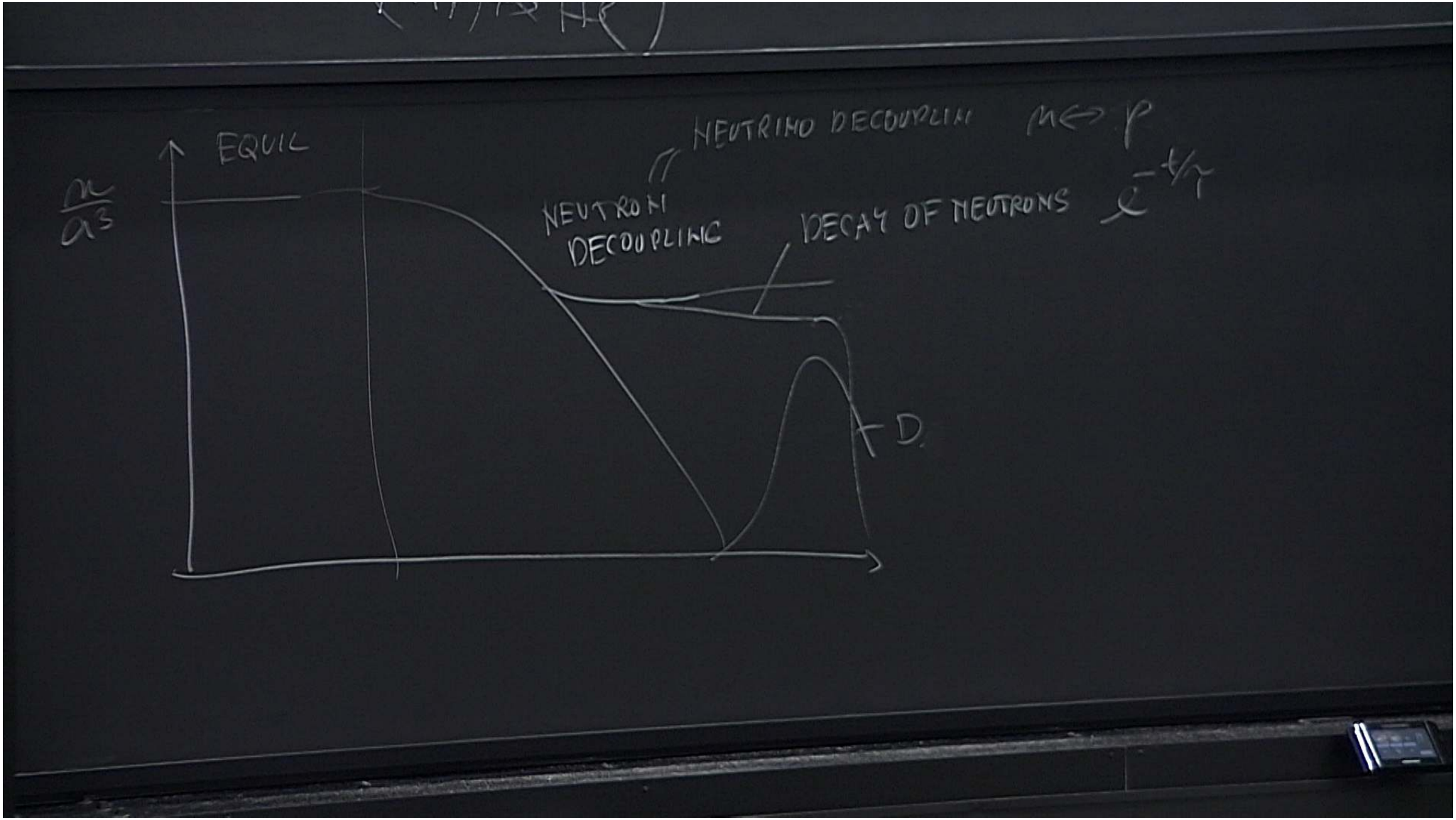

3 HOW MUCH He?
4He = 2n + 2p
=> MHe ≈ 4 x mp nn/2 = 2 mp nn
f = MHe / MBARYONS = 2 mp nn / mp (mp + nn) = 2/17 = 1/4 ...25% He

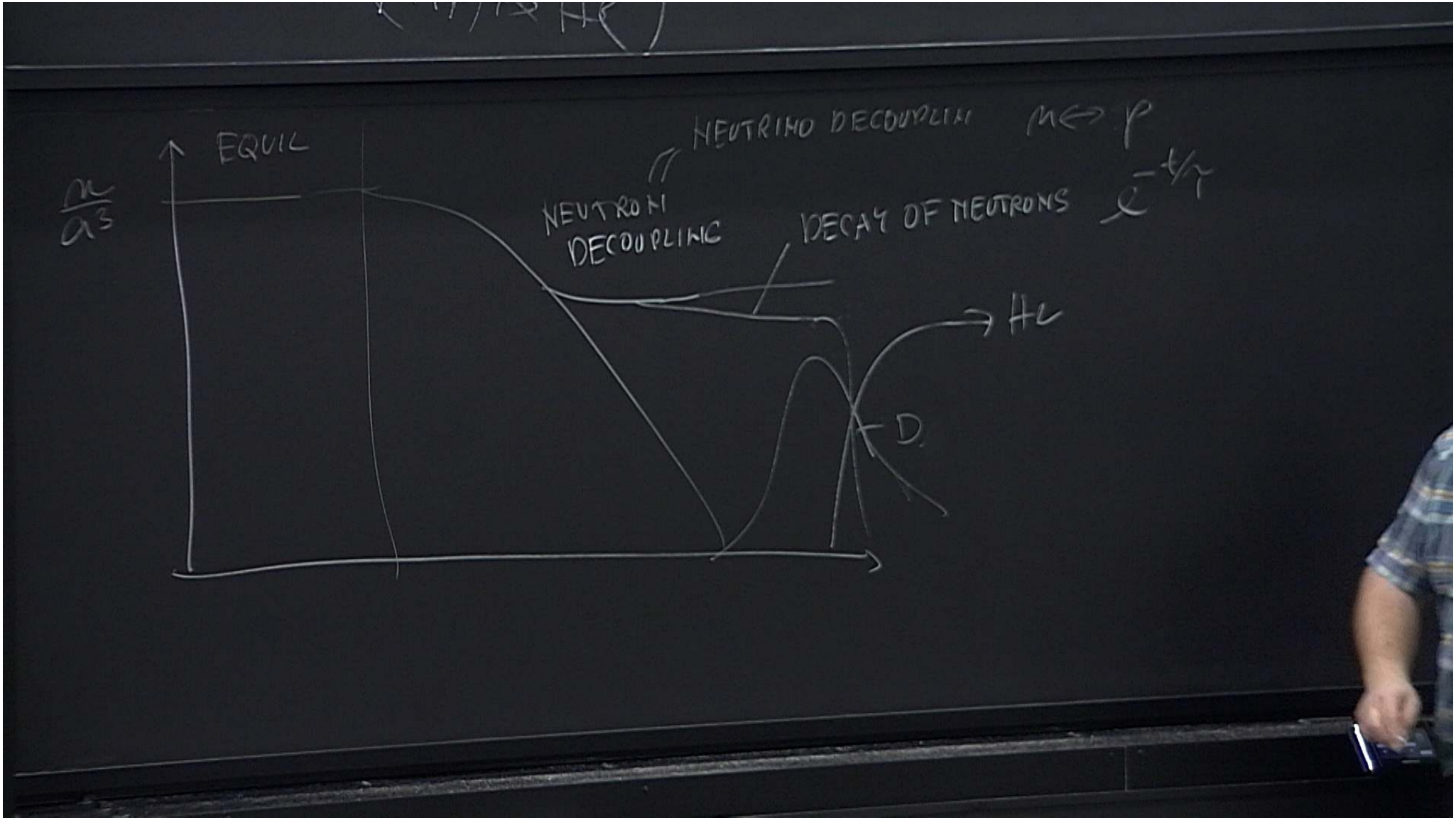

EQUIL

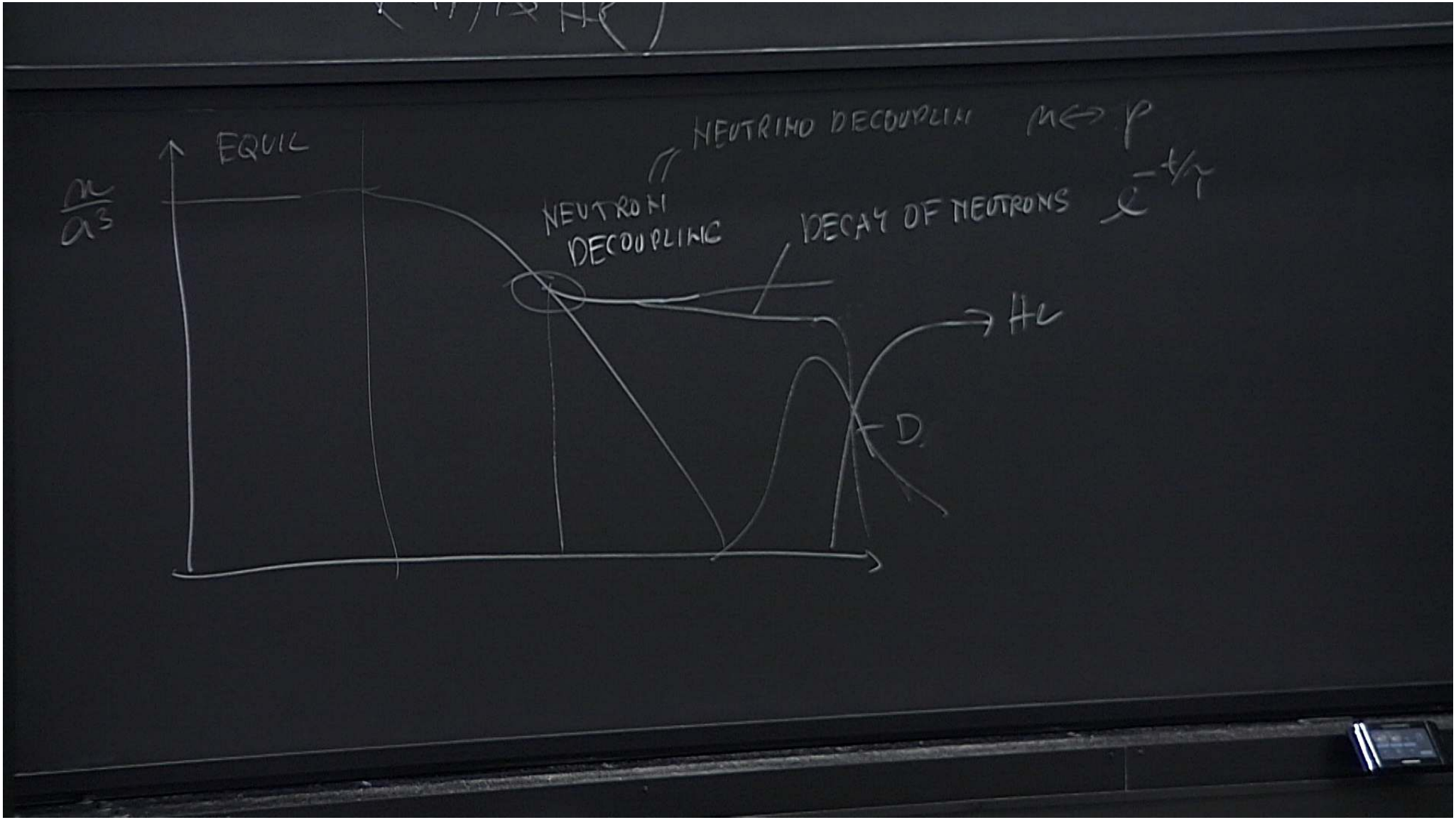

EQUIL
NEUTRINO DECOUPLING
NEUTRON
DECOUPLING


EQUIL
NEUTRINO DECOUPLING
NEUTRON DECOUPLING
DECAY OF NEUTRONS


EQUIL
NEUTRINO DECOUPLING
NEUTRON DECOUPLING
DECAY OF NEUTRONS
+D


EQUIL
NEUTRINO DECOUPLING
NEUTRON DECOUPLING
DECAY OF NEUTRONS
D


EQUIL
NEUTRINO DECOUPLING
NEUTRON DECOUPLING
DECAY OF NEUTRONS
D


EQUIL
NEUTRINO DECOUPLING
NEUTRON DECOUPLING
DECAY OF NEUTRONS
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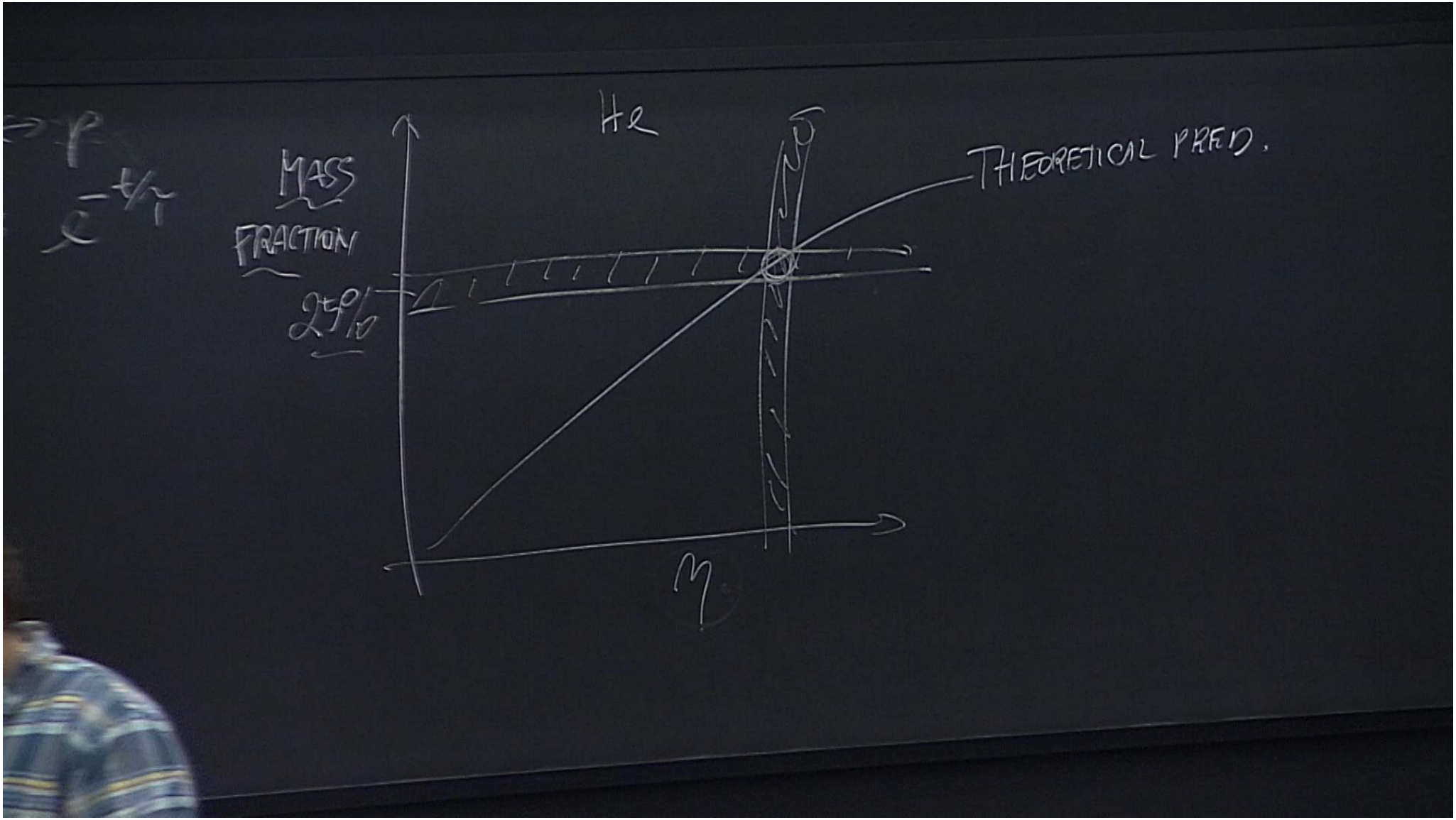
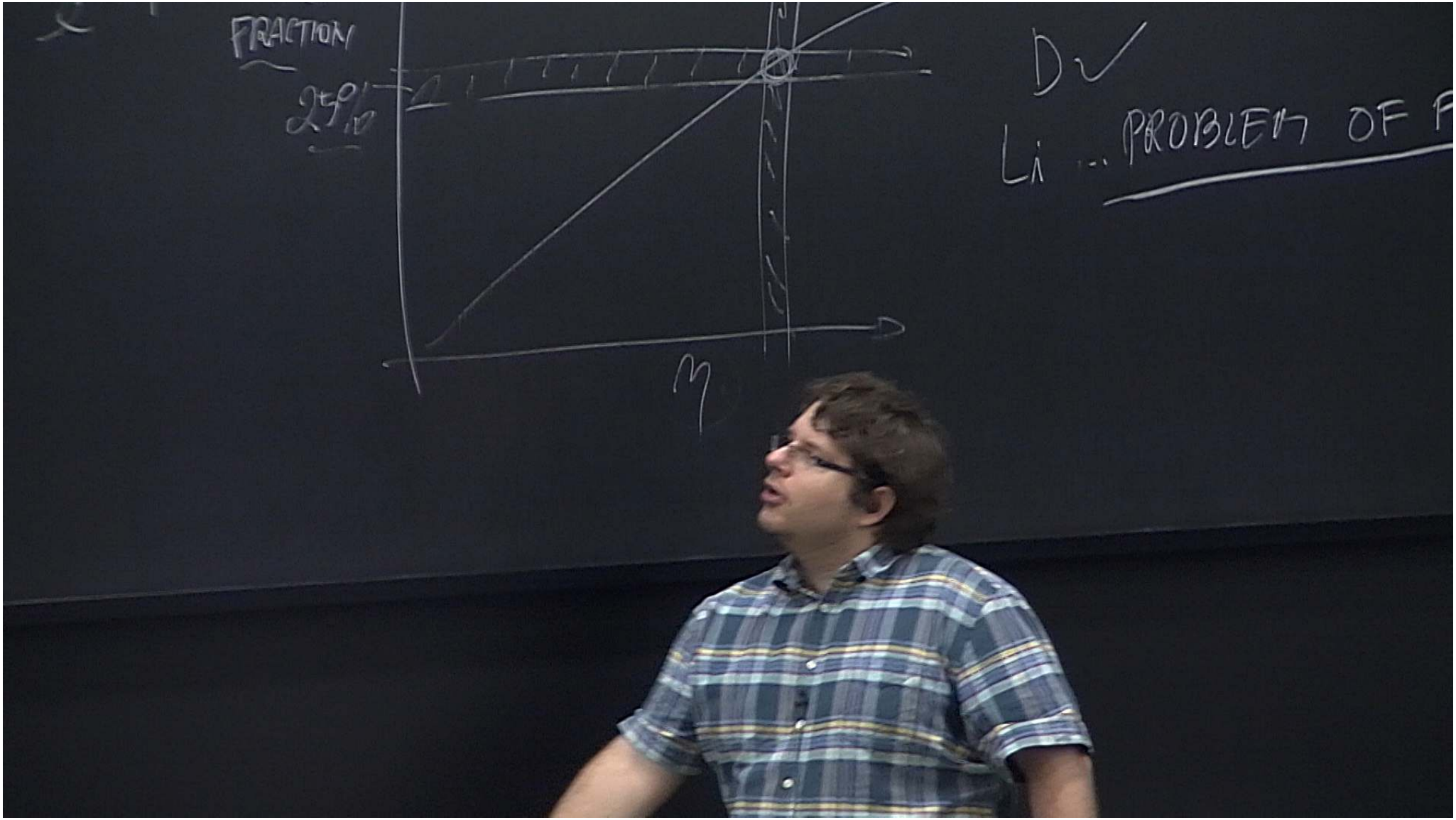
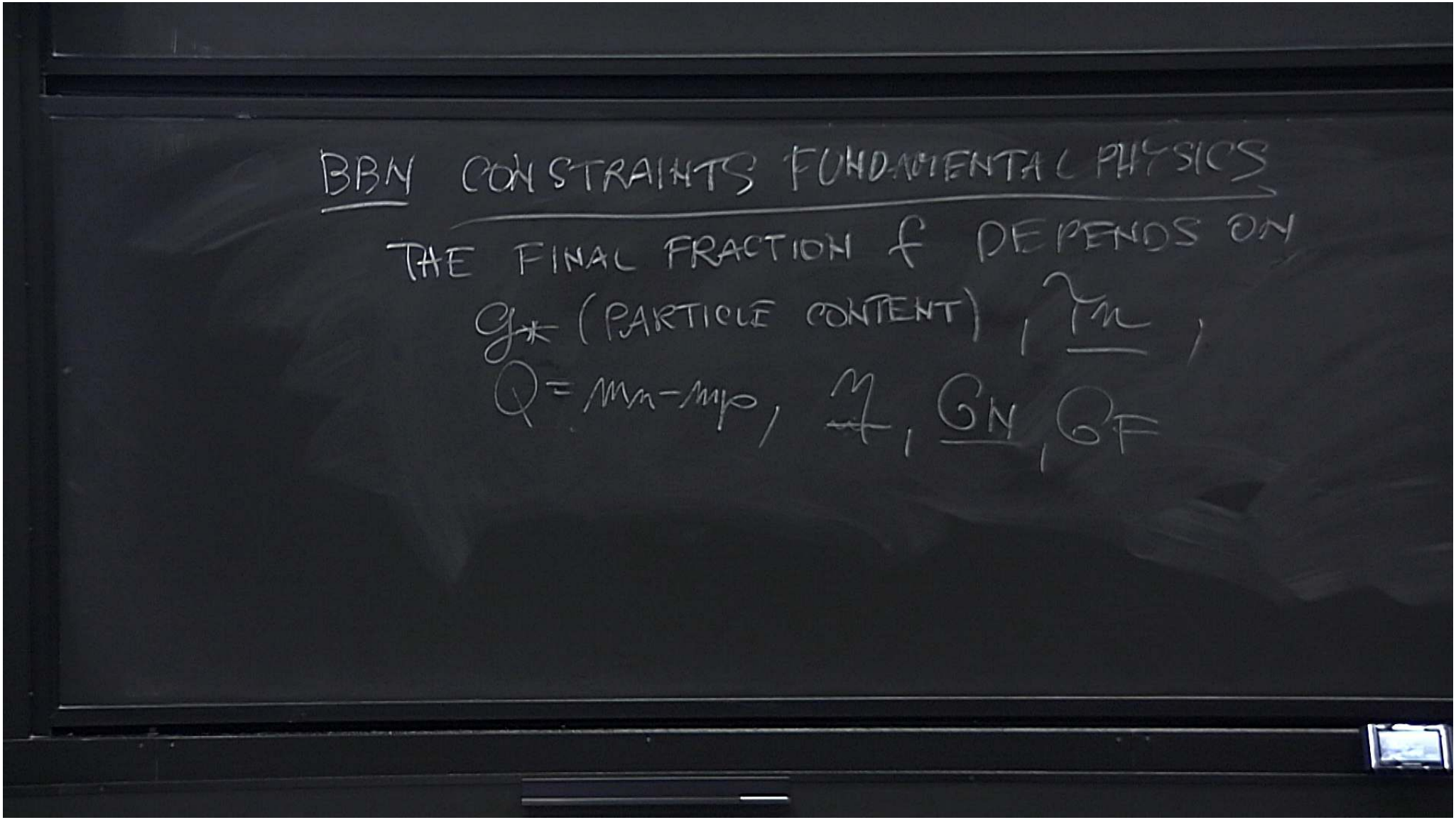

MASS
FRACTION
25%
He
THEORETICAL PRED.
M


FRACTION
25%
M
DV
Li ... PROBLEM OF F


BBN CONSTRAINTS FUNDAMENTAL PHYSICS
THE FINAL FRACTION f DEPENDS ON
g_* (PARTICLE CONTENT), τ_n,
$Q = m_n - m_p$, τ, G_N, G_F