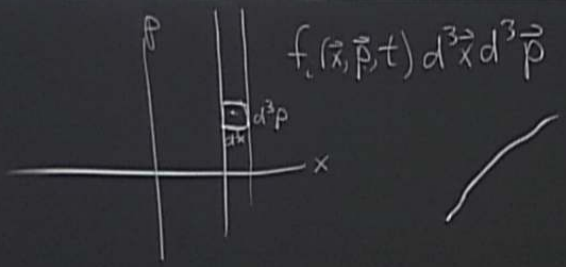
Title: 12/13 PSI - Cosmology Review Lecture 8

Date: Feb 28, 2013 11:30 AM

URL: http://pirsa.org/13020108

Abstract:



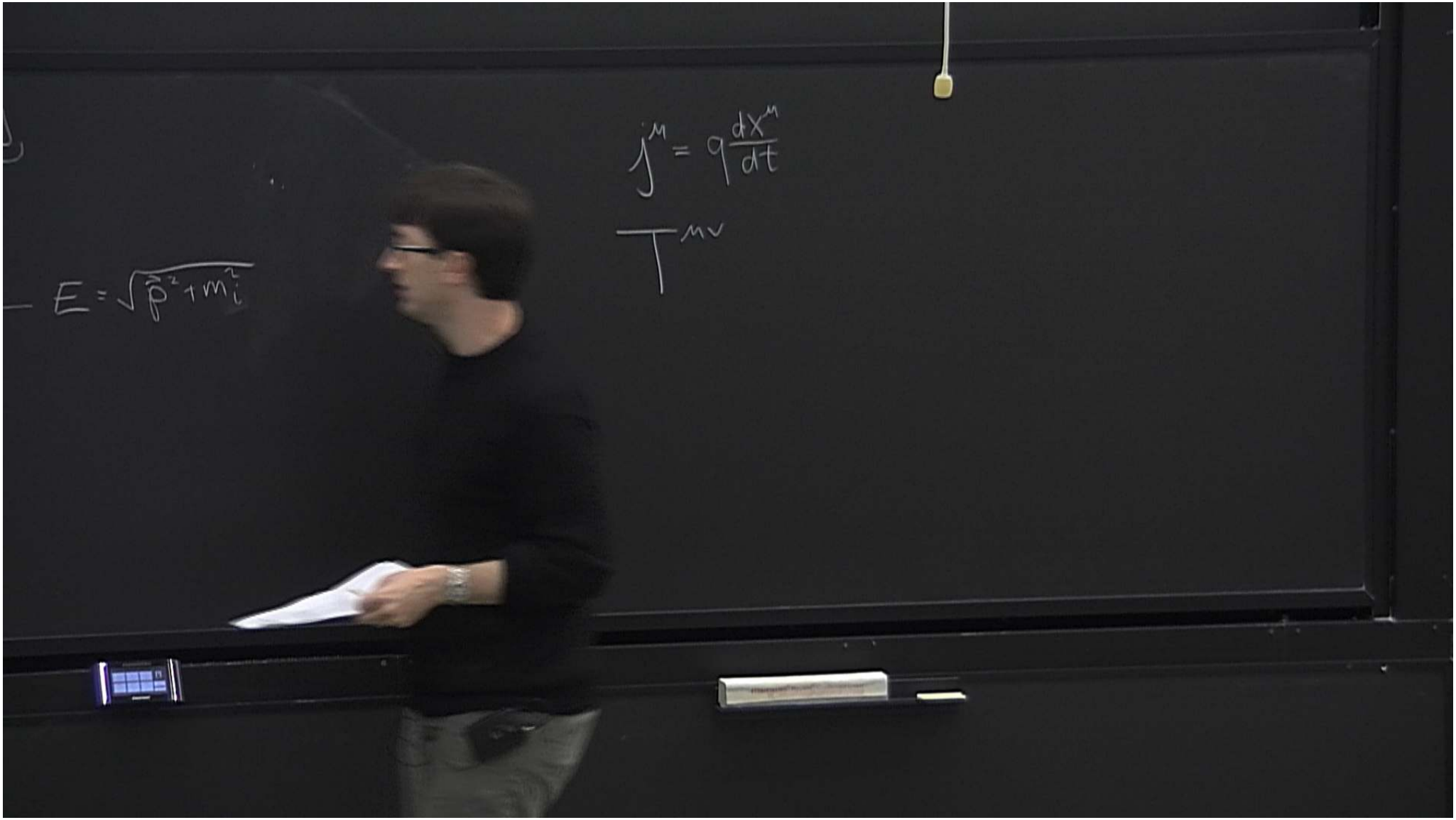

$f_i(\vec{x},\vec{p},t)\, d^3\vec{x}\, d^3\vec{p}$

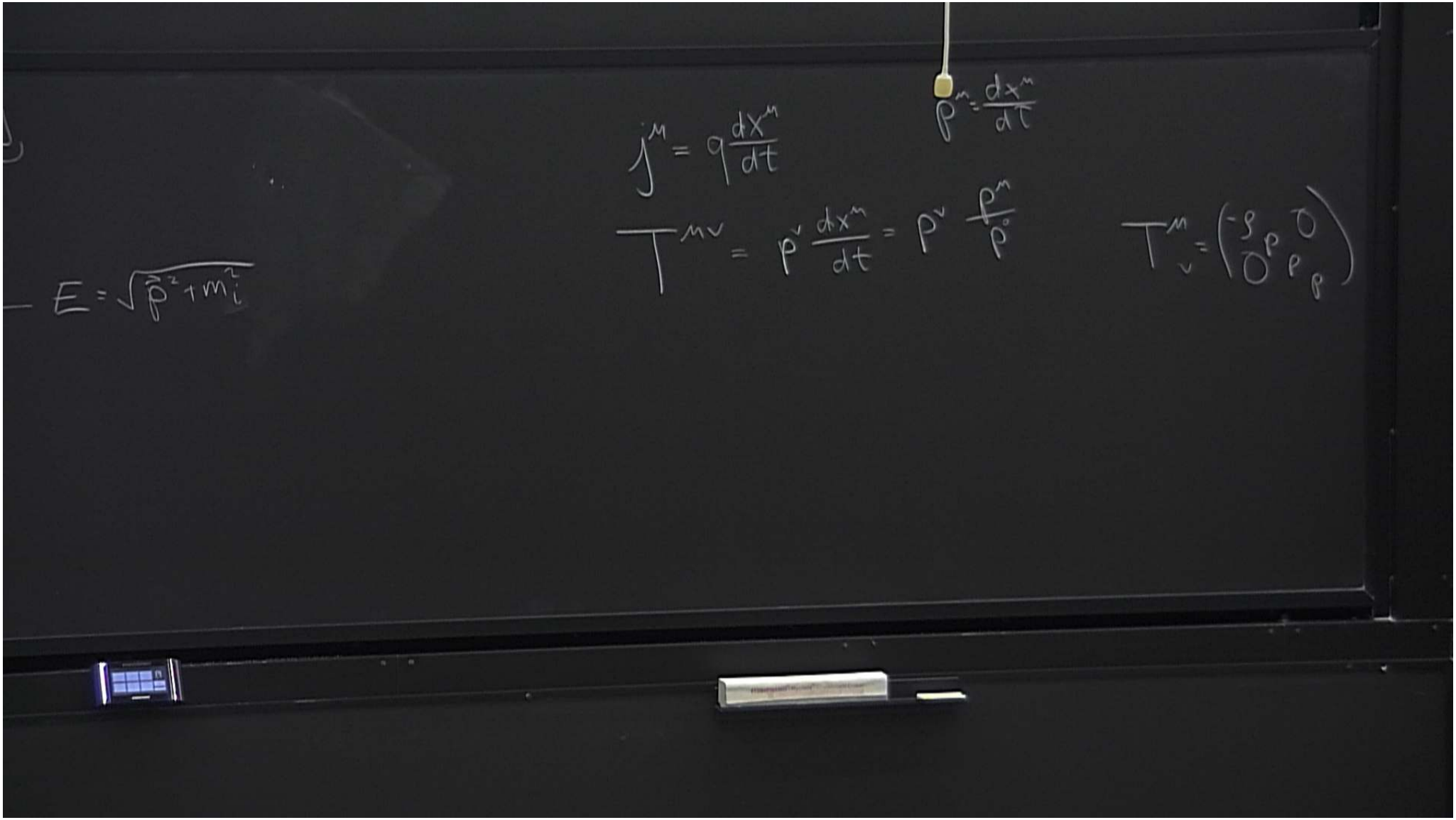
Boltzmann $\underline{(\quad) f_i} = \underline{C[f]}$

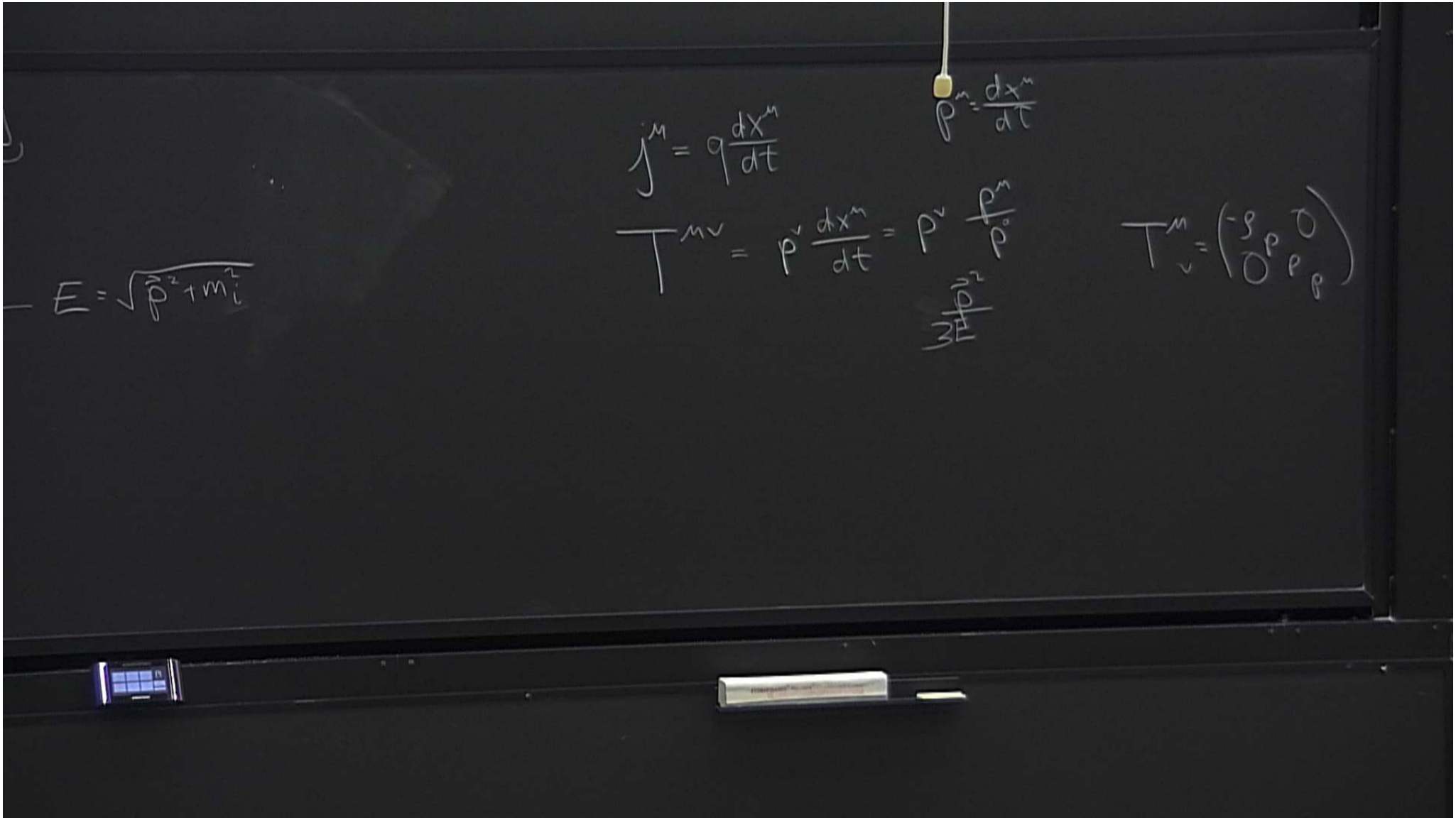
$$n_i = \int d^3\vec{p}\, f_i(\vec{x},\vec{p},t)$$

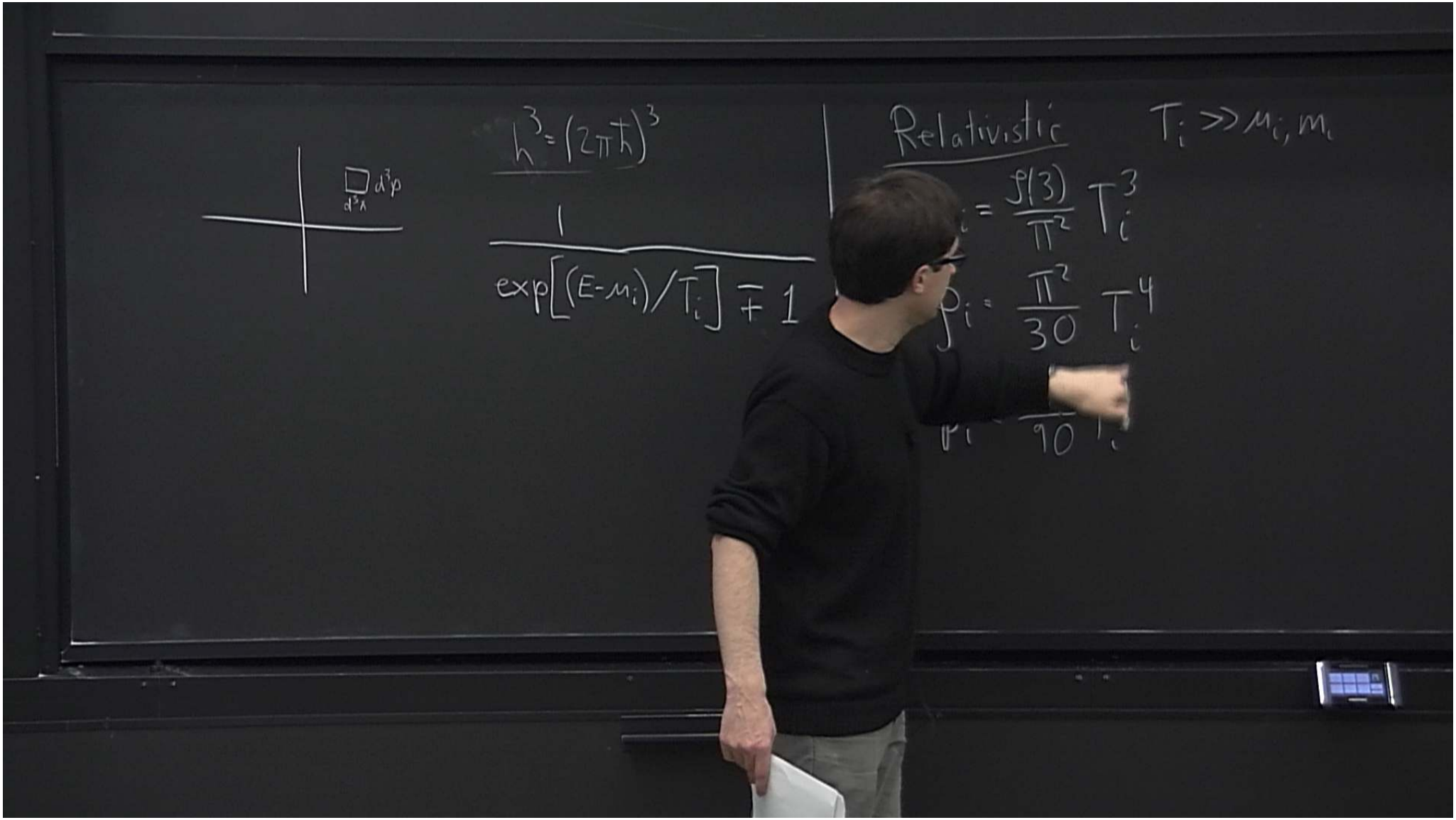
$$\rho_i = \int d^3\vec{p}\, f_i(\vec{x},\vec{p},t)\, E \longleftarrow E = \sqrt{\vec{p}^2 + m_i^2}$$

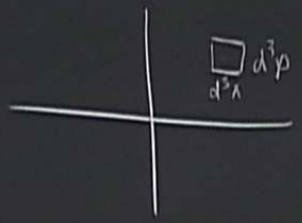
$$P_i = \int d^3\vec{p}\, f_i(\vec{x},\vec{p},t)\, \frac{\vec{p}^2}{3E}$$


$j^\mu = q\frac{dx^\mu}{dt}$
$T^{\mu\nu}$
$E = \sqrt{\vec{p}^2 + m_i^2}$


$E = \sqrt{\vec{p}^2 + m_i^2}$
$j^\mu = q\frac{dx^\mu}{dt}$
$p^\mu = \frac{dx^\mu}{d\tau}$
$T^{\mu\nu} = p^\nu \frac{dx^\mu}{dt} = p^\nu \frac{p^\mu}{p^0}$
$T^\mu_{\ \nu} = \begin{pmatrix} -\rho & 0 \\ 0 & p \end{pmatrix}$


$E = \sqrt{\vec{p}^2 + m_i^2}$
$j^\mu = q\frac{dx^\mu}{dt}$
$p^\mu = \frac{dx^\mu}{dt}$
$T^{\mu\nu} = \rho^\nu \frac{dx^\mu}{dt} = \rho^\nu \frac{p^\mu}{p^0}$
$\frac{1}{3}\frac{\vec{p}^2}{E}$
$T^\mu_\nu = \begin{pmatrix} -\rho & 0 \\ 0 & p \end{pmatrix}$


$d^3p$
$d^3x$
$h^3 = (2\pi\hbar)^3$
$\frac{1}{\exp[(E-\mu_i)/T_i] \mp 1}$
Relativistic $T_i \gg \mu_i, m_i$
$= \frac{\zeta(3)}{\pi^2} T_i^3$
$\rho_i = \frac{\pi^2}{30} T_i^4$
$\frac{}{90}$




$$h^3 = (2\pi\hbar)^3$$

$$\frac{1}{\exp\left[(E-\mu_i)/T_i\right] \mp 1}$$

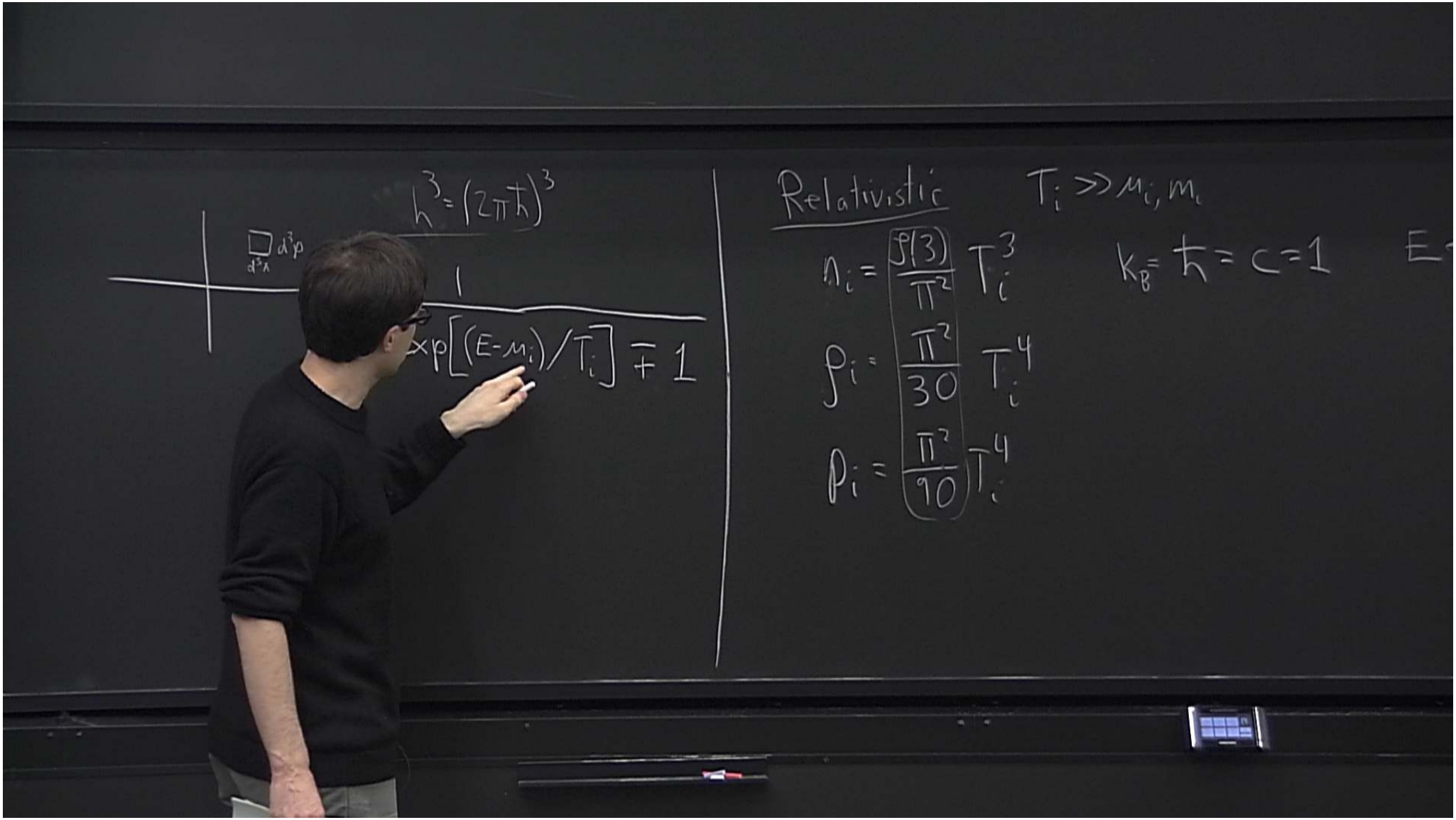
Relativistic $T_i \gg \mu_i, m_i$

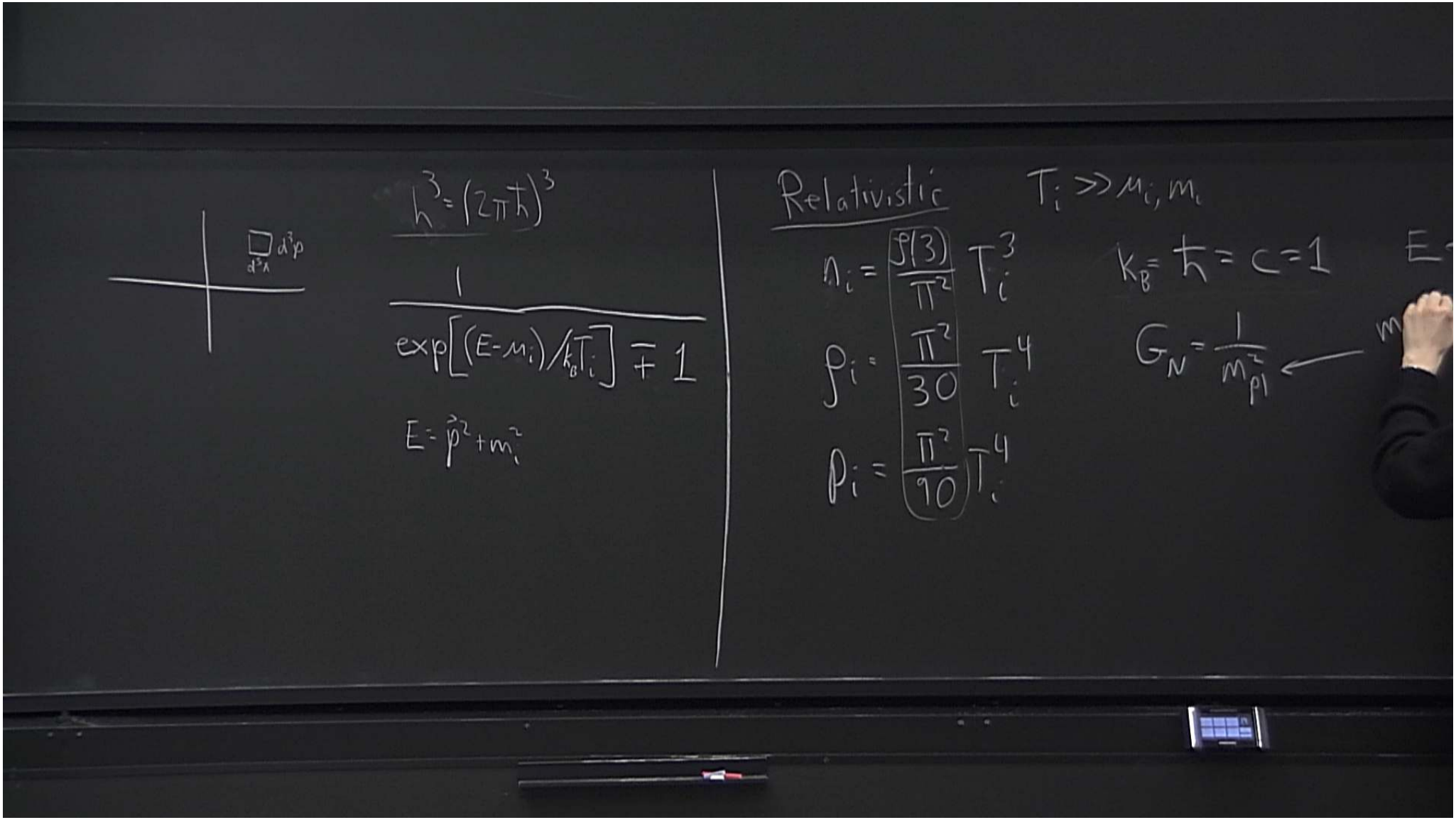
$\hbar = c = 1$

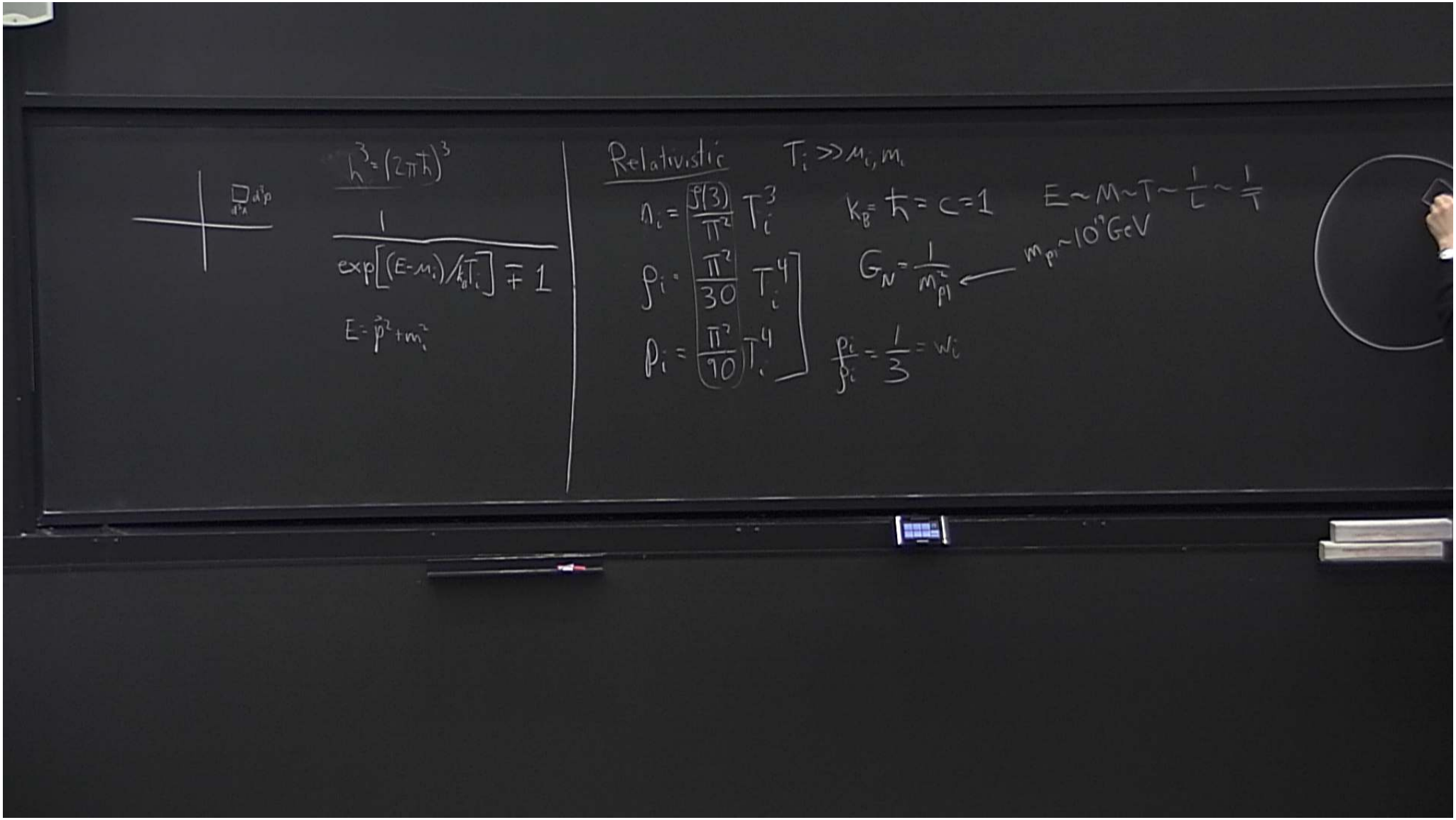
$$n_i = \frac{\zeta(3)}{\pi^2} T_i^3$$

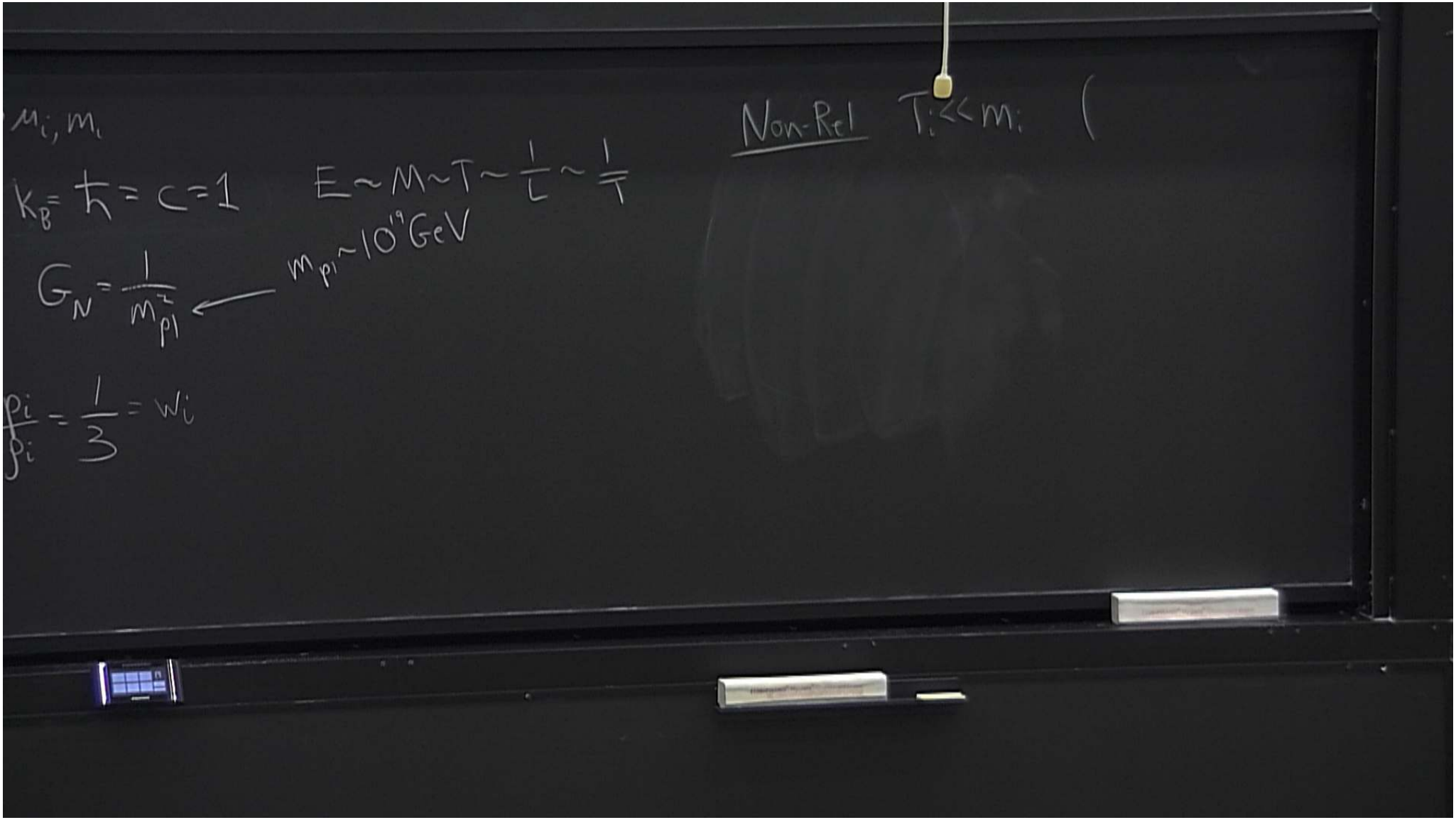
$$\rho_i = \frac{\pi^2}{30} T_i^4$$

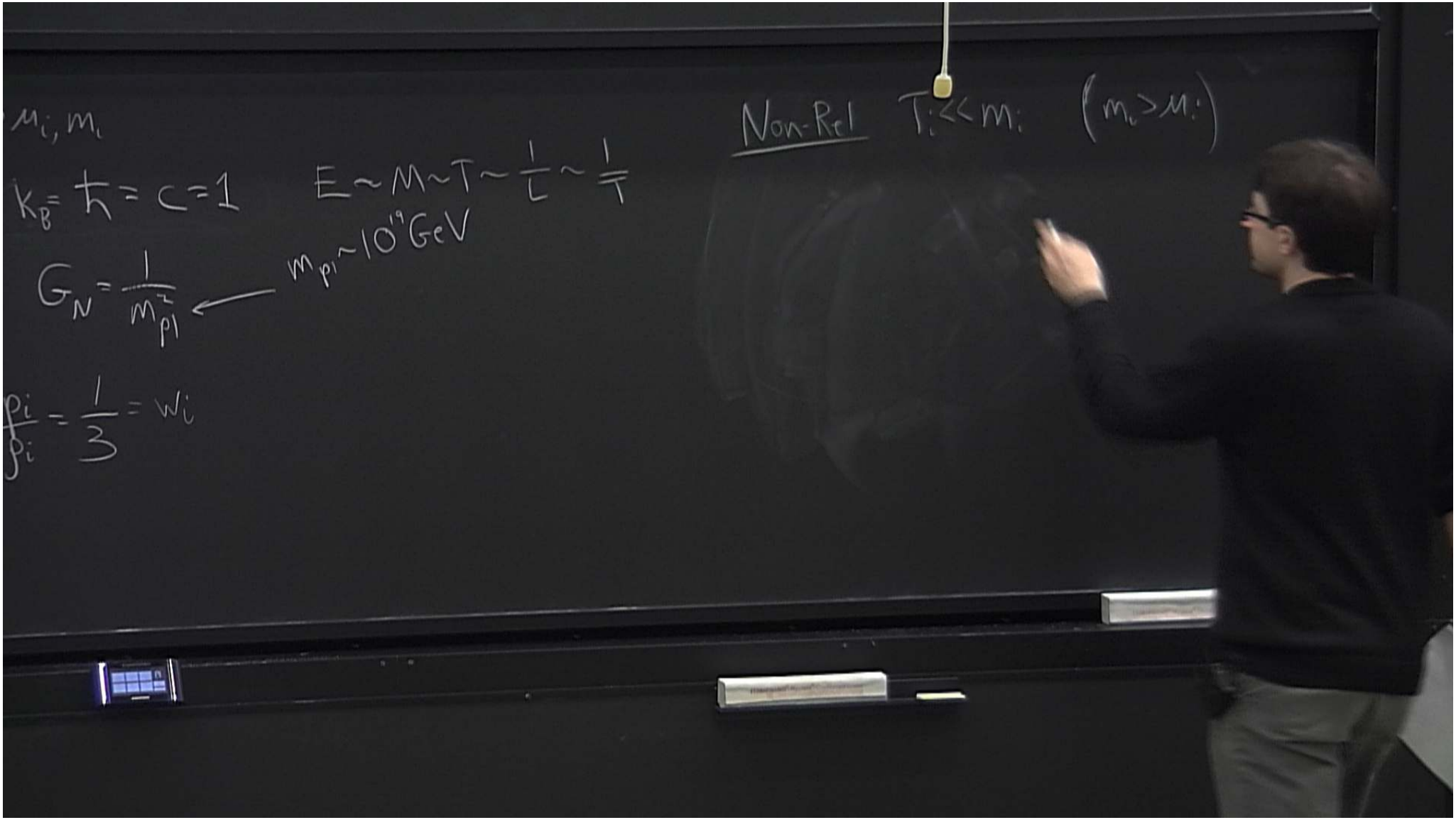
$$p_i = \frac{\pi^2}{90} T_i^4$$


$h^3 = (2\pi\hbar)^3$
$d^3x\, d^3p$
$\frac{1}{\exp[(E-\mu_i)/T_i] \mp 1}$
Relativistic $T_i \gg \mu_i, m_i$
$n_i = \frac{\zeta(3)}{\pi^2} T_i^3$
$\rho_i = \frac{\pi^2}{30} T_i^4$
$p_i = \frac{\pi^2}{90} T_i^4$
$k_B = \hbar = c = 1$


$d^3p$
$d^3x$
$h^3 = (2\pi\hbar)^3$
$\frac{1}{\exp\left[(E-\mu_i)/k_B T_i\right] \mp 1}$
$E = \vec{p}^2 + m_i^2$
Relativistic $T_i \gg \mu_i, m_i$
$n_i = \frac{\zeta(3)}{\pi^2} T_i^3$
$\rho_i = \frac{\pi^2}{30} T_i^4$
$p_i = \frac{\pi^2}{90} T_i^4$
$k_B = \hbar = c = 1$
$G_N = \frac{1}{m_{Pl}^2}$


$d^3x$ $d^3p$
$h^3 = (2\pi\hbar)^3$
$\frac{1}{\exp[(E-\mu_i)/k_B T_i] \mp 1}$
$E = \vec{p}^2 + m_i^2$
Relativistic $T_i \gg \mu_i, m_i$
$n_i = \frac{\zeta(3)}{\pi^2} T_i^3$
$\rho_i = \frac{\pi^2}{30} T_i^4$
$p_i = \frac{\pi^2}{90} T_i^4$
$k_B = \hbar = c = 1$
$E \sim M \sim T \sim \frac{1}{L} \sim \frac{1}{\tau}$
$G_N = \frac{1}{m_{pl}^2}$
$m_{pl} \sim 10^{19}$ GeV
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$


$m_i, m_i$
$k_B = \hbar = c = 1$
$E \sim M \sim T \sim \frac{1}{L} \sim \frac{1}{T}$
$G_N = \frac{1}{m_{pl}^2}$
$m_{pl} \sim 10^{19}$ GeV
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$
Non-Rel $T_i << m_i$ (


$m_i, m_i$
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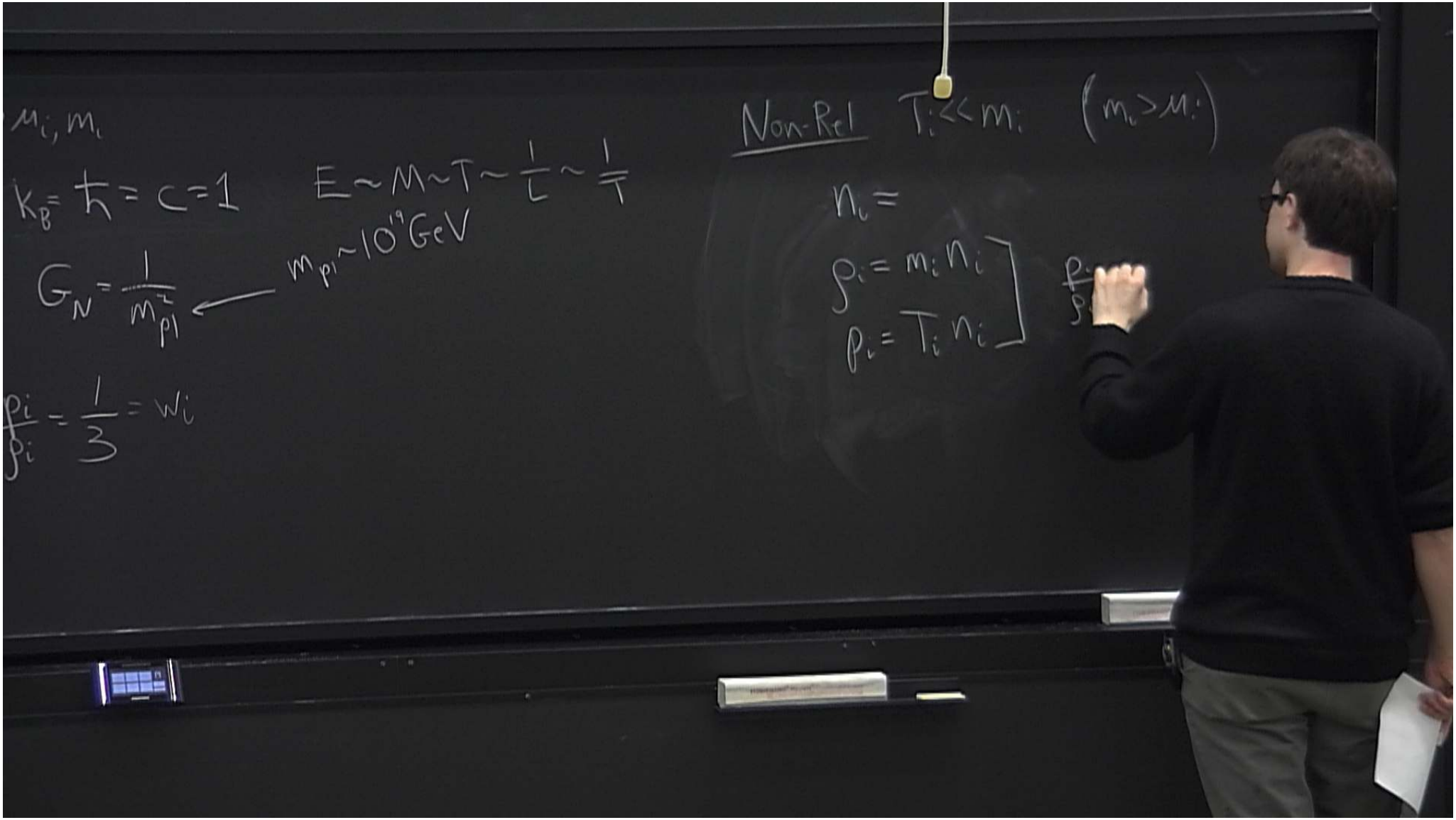
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$
Non-Rel $T_i \ll m_i$ $(m_i > M_i)$


$m_i, m_i$
$k_B = \hbar = c = 1$
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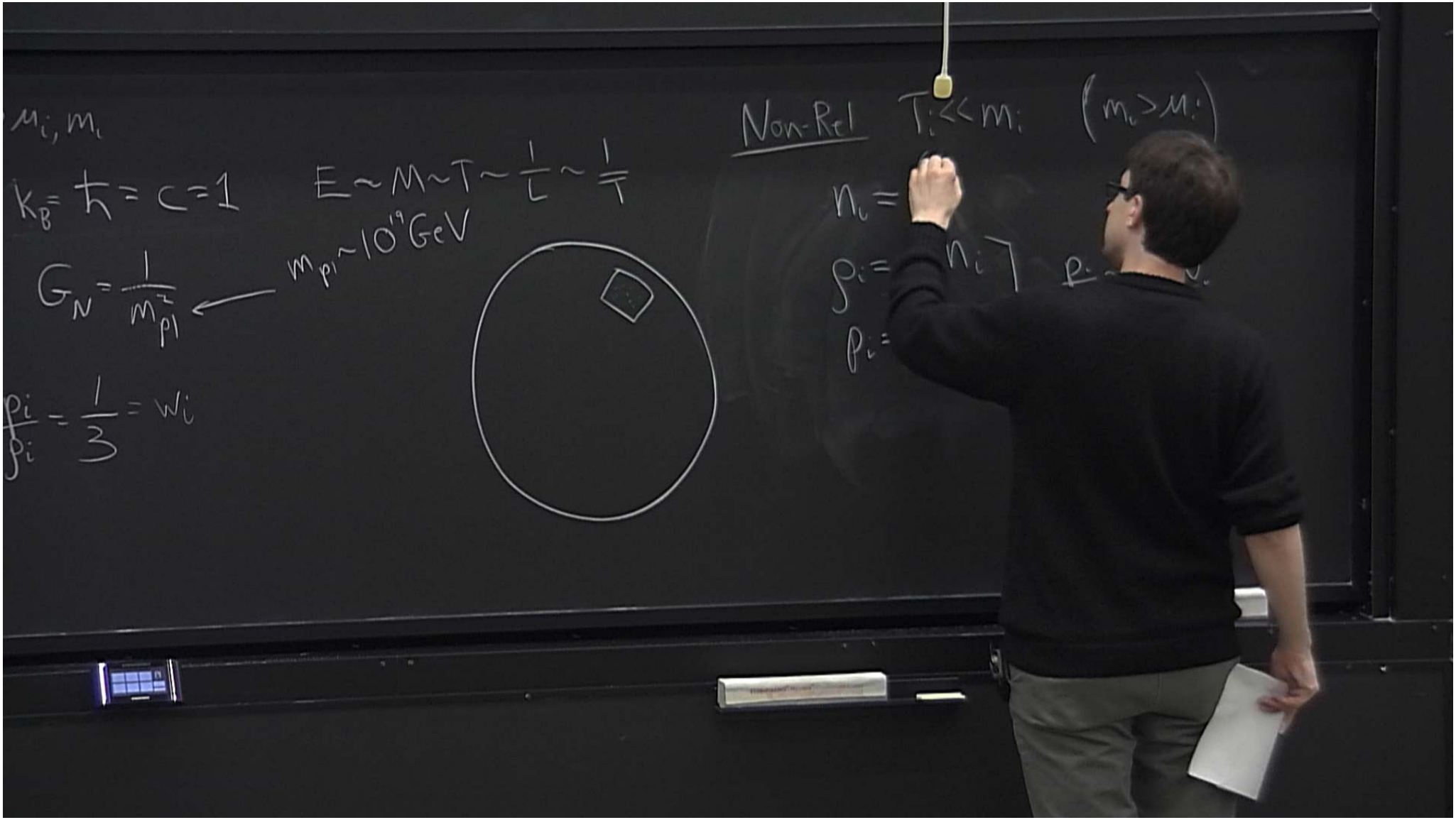
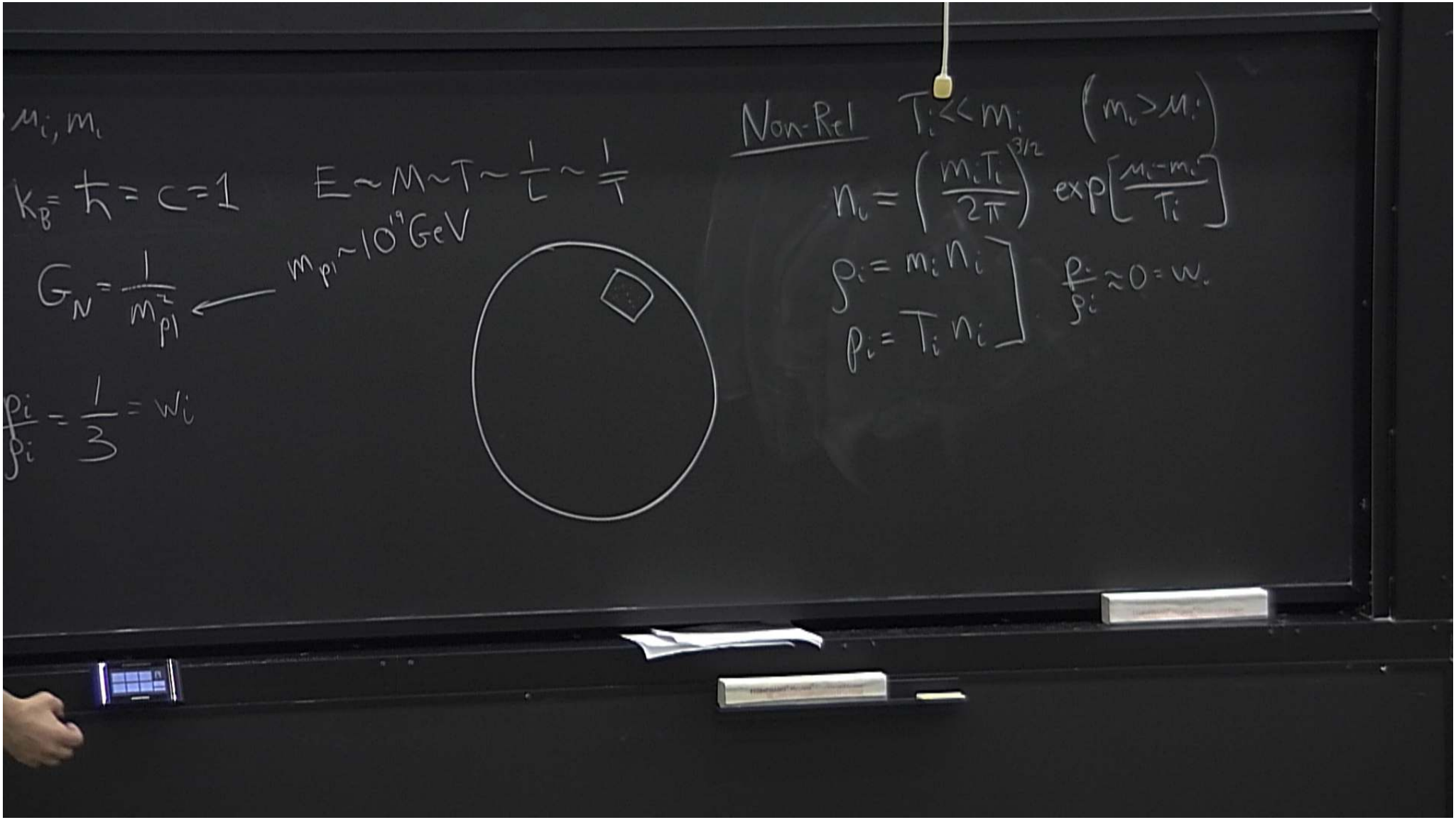
$m_{pl} \sim 10^{19}\,GeV$
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$
Non-Rel $T_i << m_i$ $(m_i > M_i)$
$n_i =$
$\rho_i = m_i n_i$
$\rho_i = T_i n_i$


$m_i, m_i$
$k_B = \hbar = c = 1$
$E \sim M \sim T \sim \frac{1}{L} \sim \frac{1}{T}$
$G_N = \frac{1}{m_{pl}^2}$
$m_{pl} \sim 10^{19}\,GeV$
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$
Non-Rel $T_i << m_i$ $(m_i > M_i)$
$n_i =$
$\rho_i =$ $n_i$
$p_i =$


$m_i, m_i$
$k_B = \hbar = c = 1$
$E \sim M \sim T \sim \frac{1}{L} \sim \frac{1}{T}$
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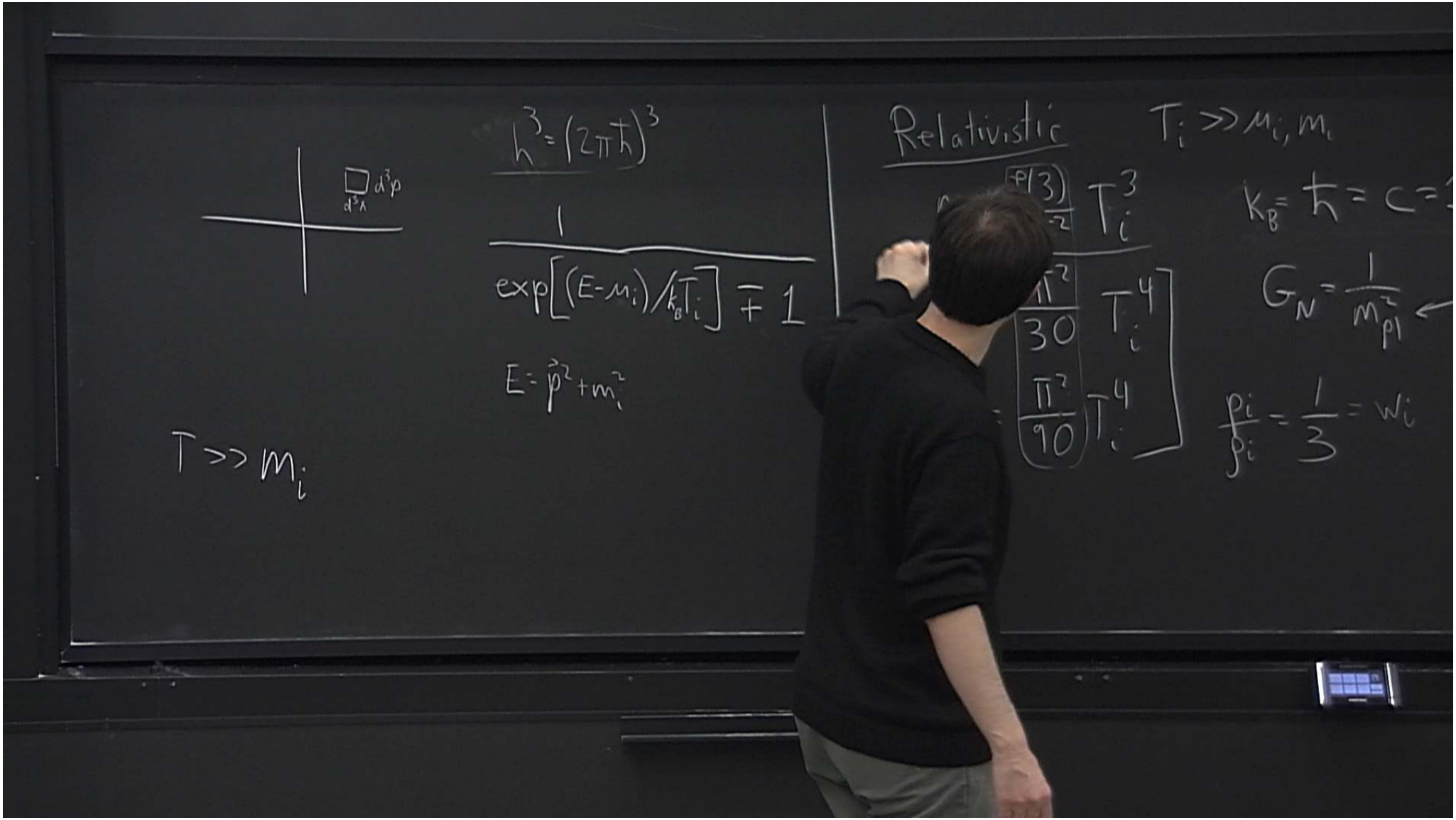
$m_{Pl} \sim 10^{19}\,GeV$
$\frac{p_i}{\rho_i} = \frac{1}{3} = w_i$
Non-Rel $T_i << m_i$ $(m_i > m_i)$
$n_i = \left(\frac{m_i T_i}{2\pi}\right)^{3/2} \exp\left[\frac{m_i - m_i}{T_i}\right]$
$\rho_i = m_i n_i$
$p_i = T_i n_i$
$\frac{p_i}{\rho_i} \approx 0 = w_i$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$E = \vec{p}^2 + m_i^2$
$T \gg m_i$
Relativistic
$T_i \gg \mu_i, m_i$
$T_i^3$
$\frac{\pi^2}{30} T_i^4$
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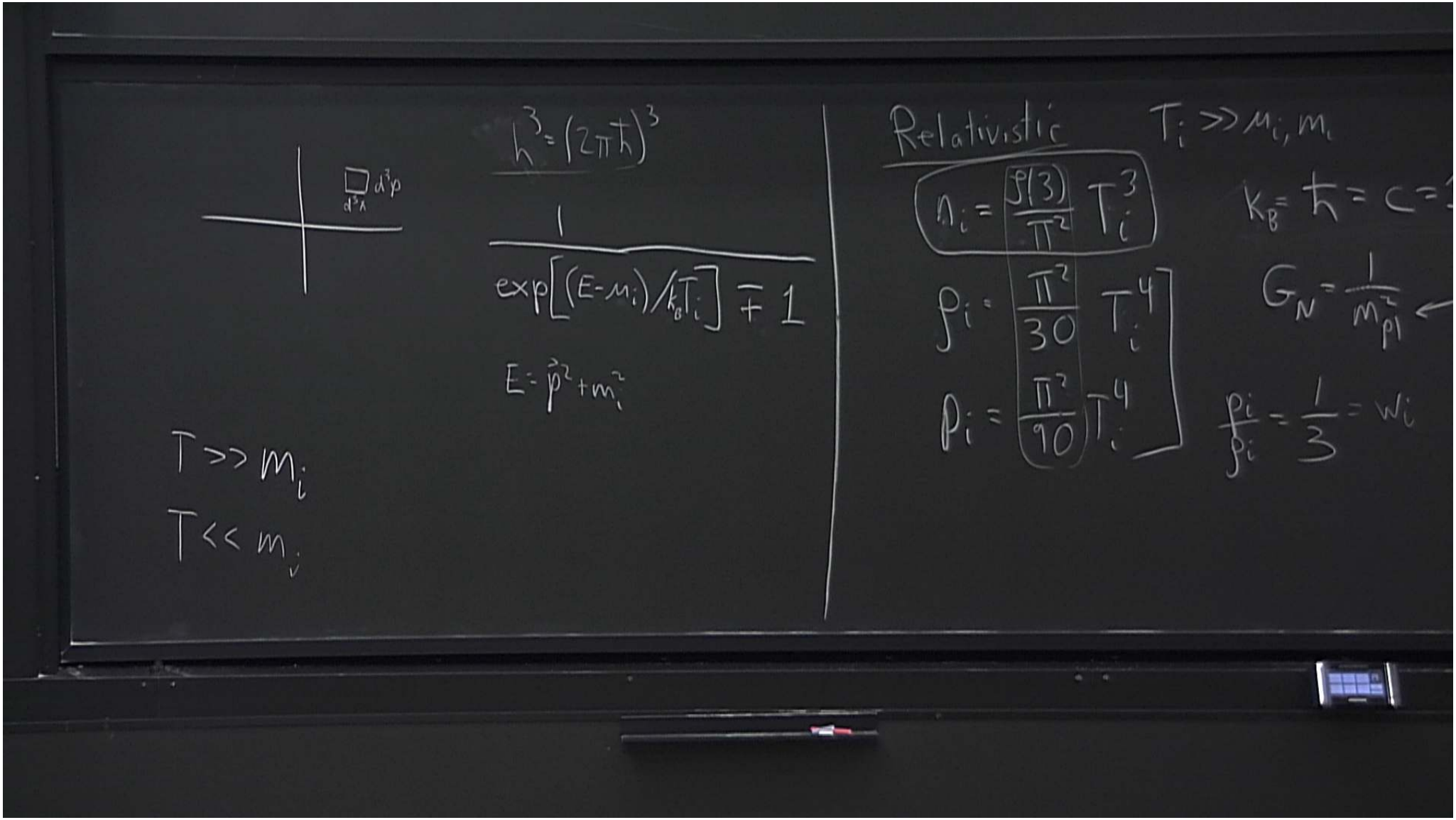
$d^3p$
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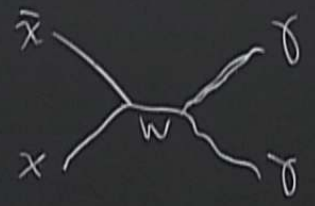
$\chi + \bar{\chi}$ $m_\chi$

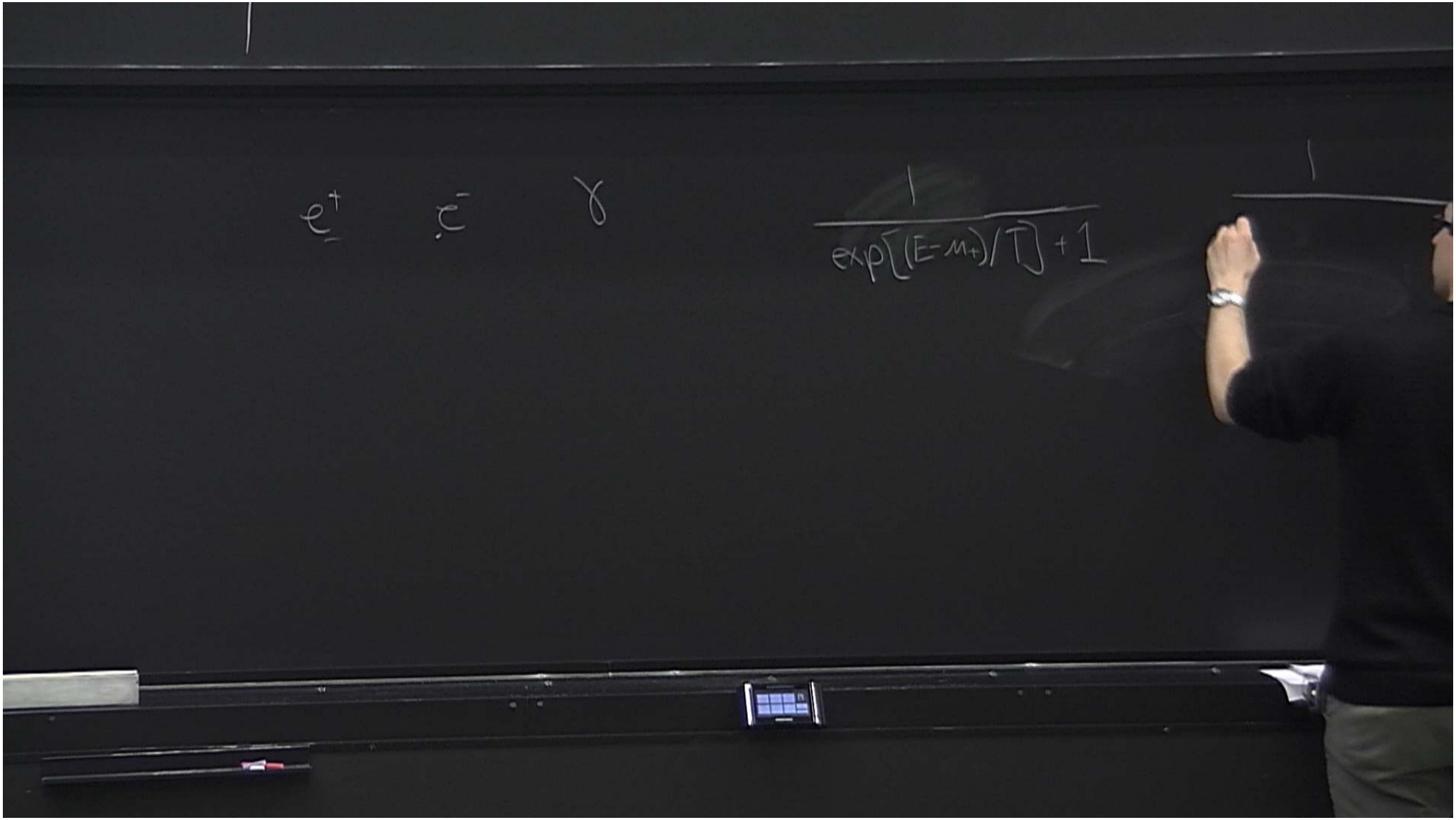
WIMP $m_\chi \sim 1\,GeV$

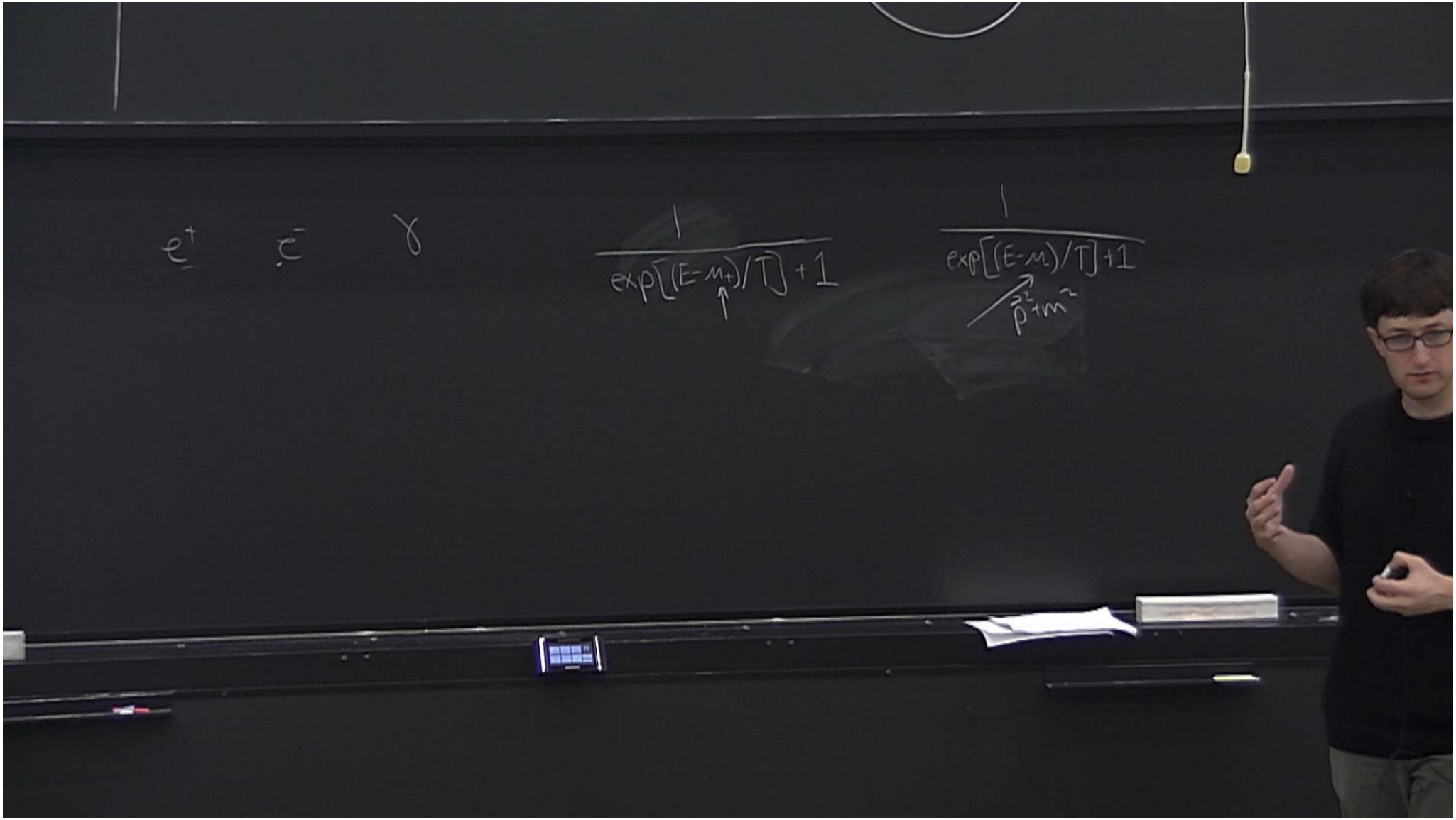


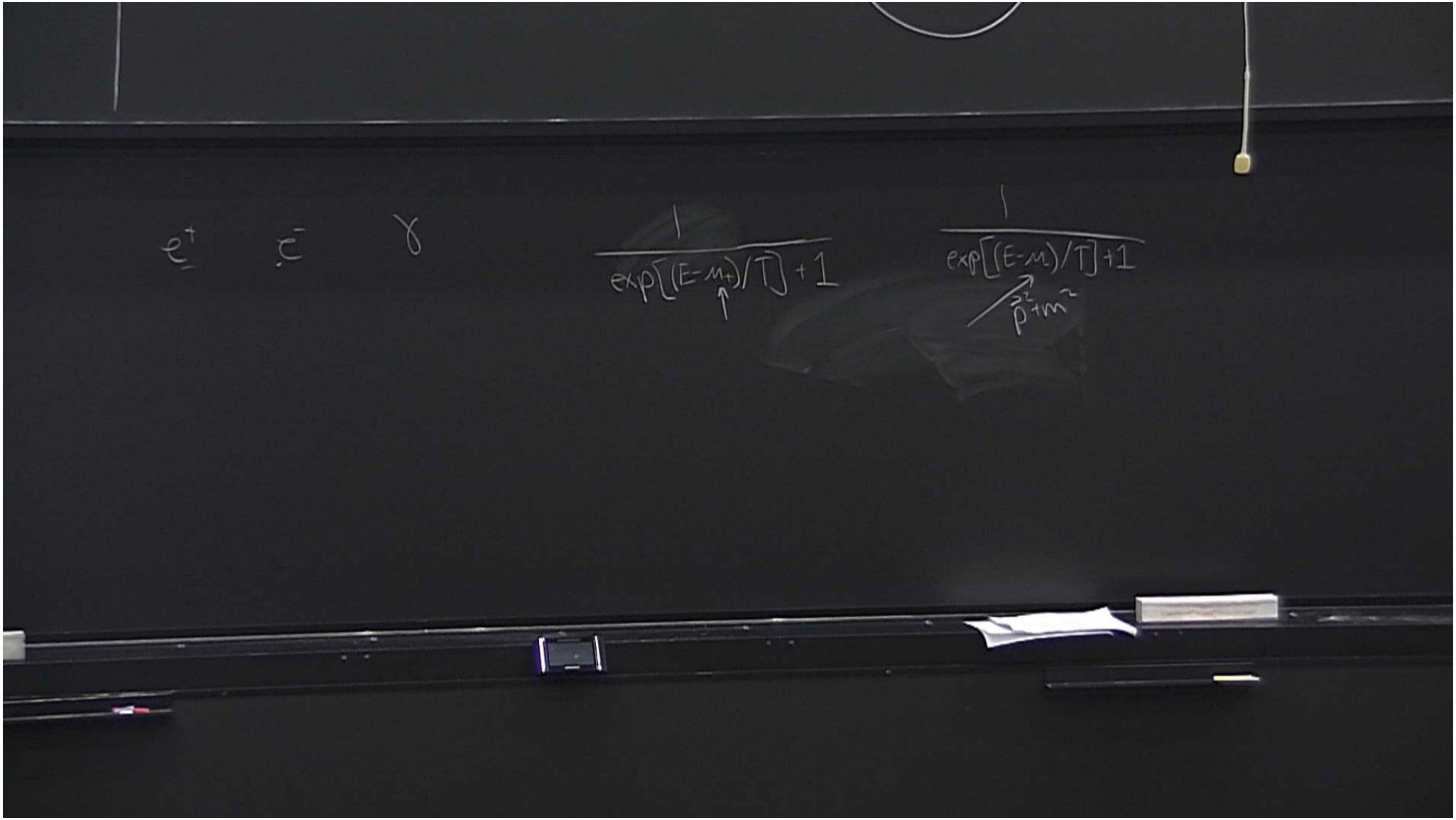
$\chi + \bar{\chi}$ $\quad m_\chi$

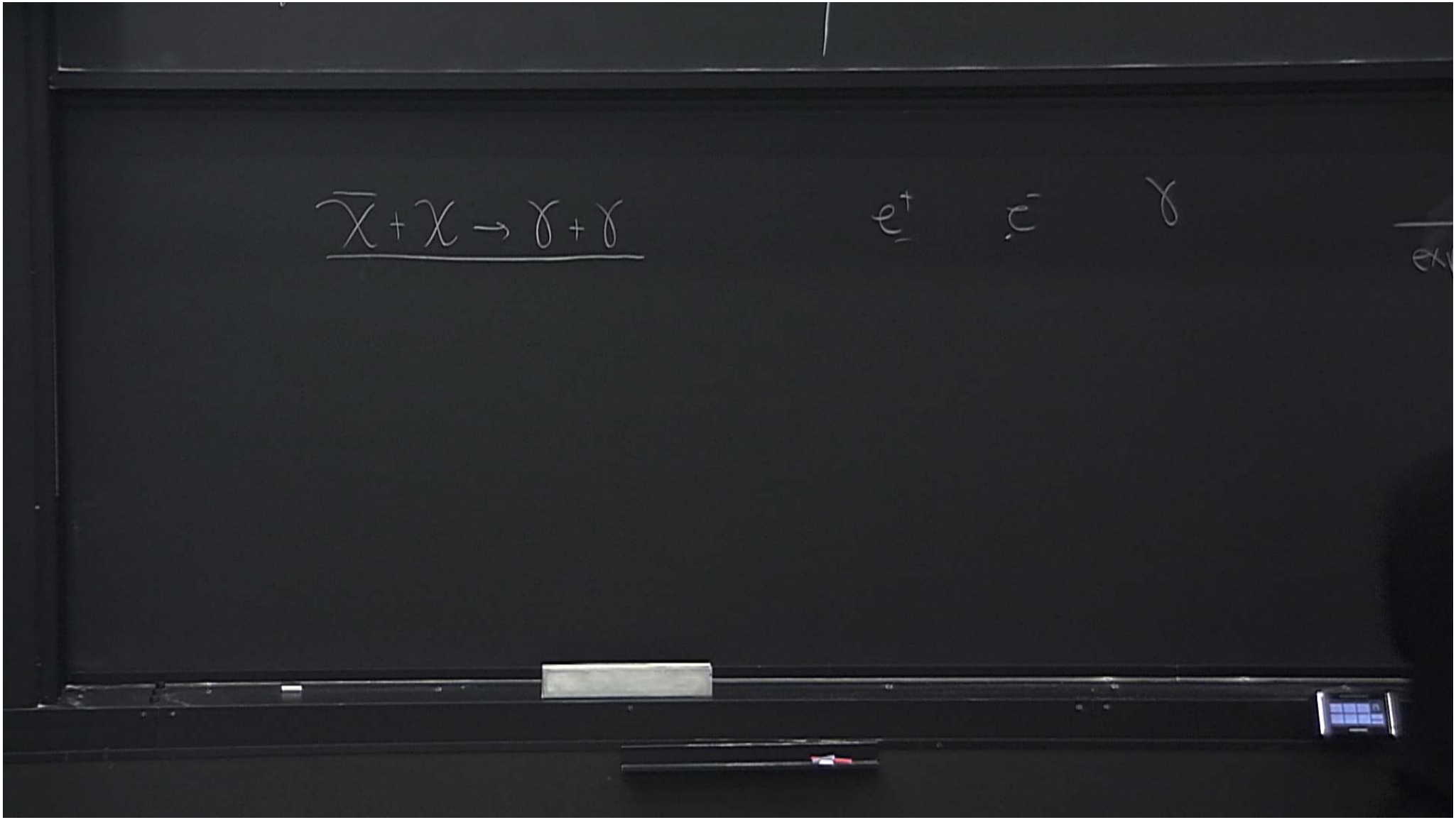
WIMP $\quad m_\chi \sim 1\,\mathrm{GeV}$

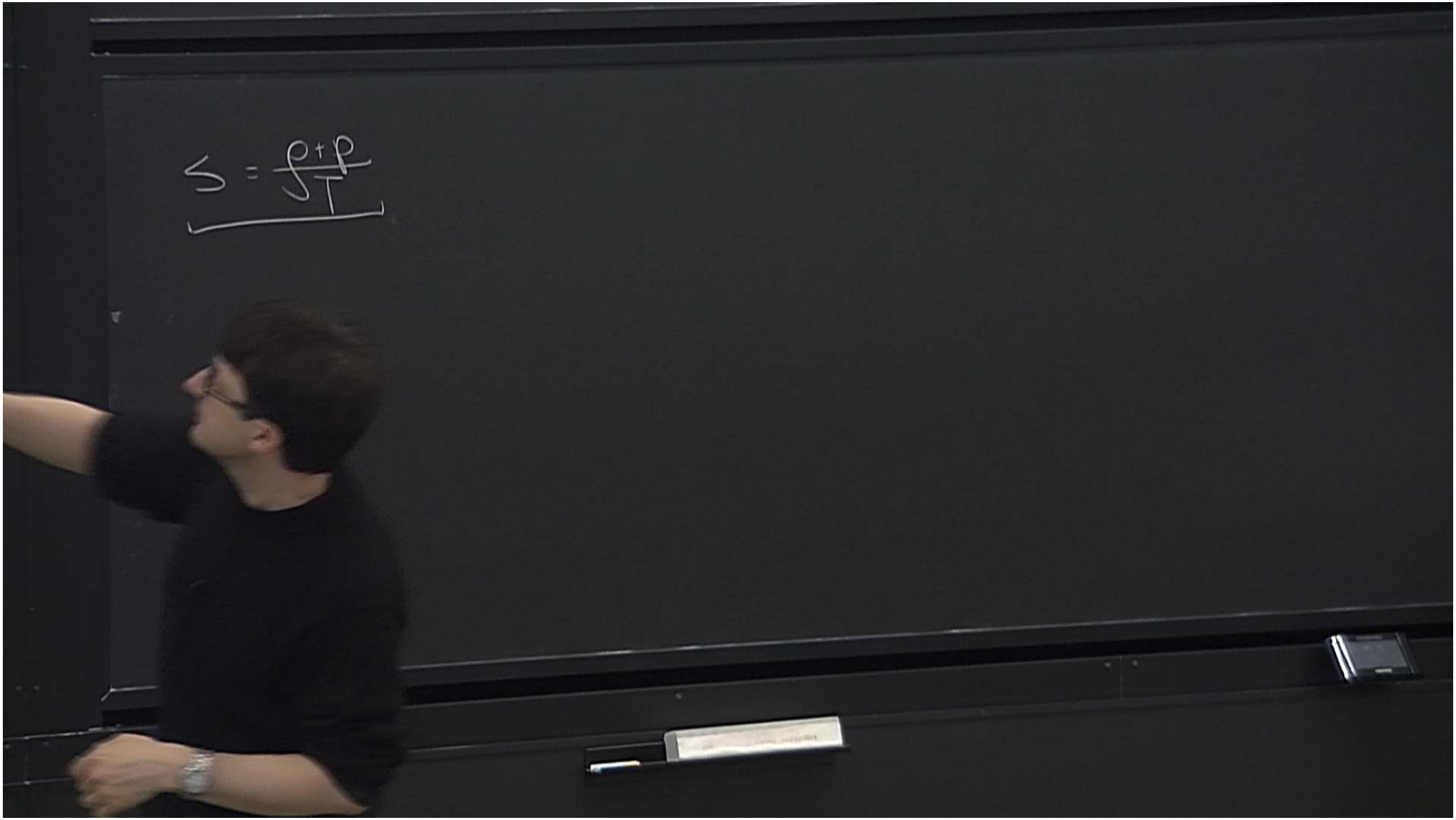
$n_i \propto \frac{1}{a^3}$

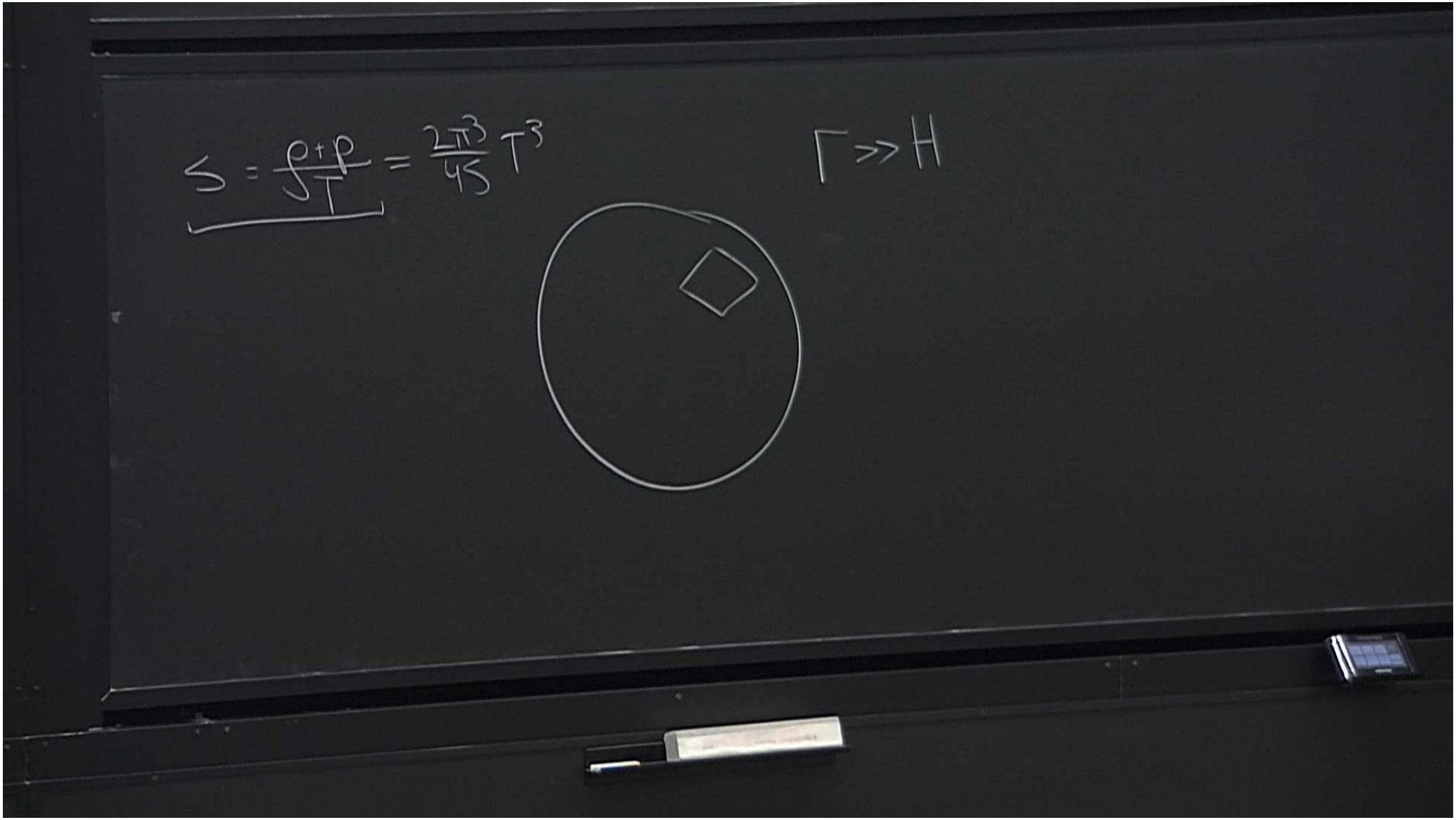

$e^+$ $e^-$ $\gamma$
$\frac{1}{\exp[(E-\mu_+)/T] + 1}$
1

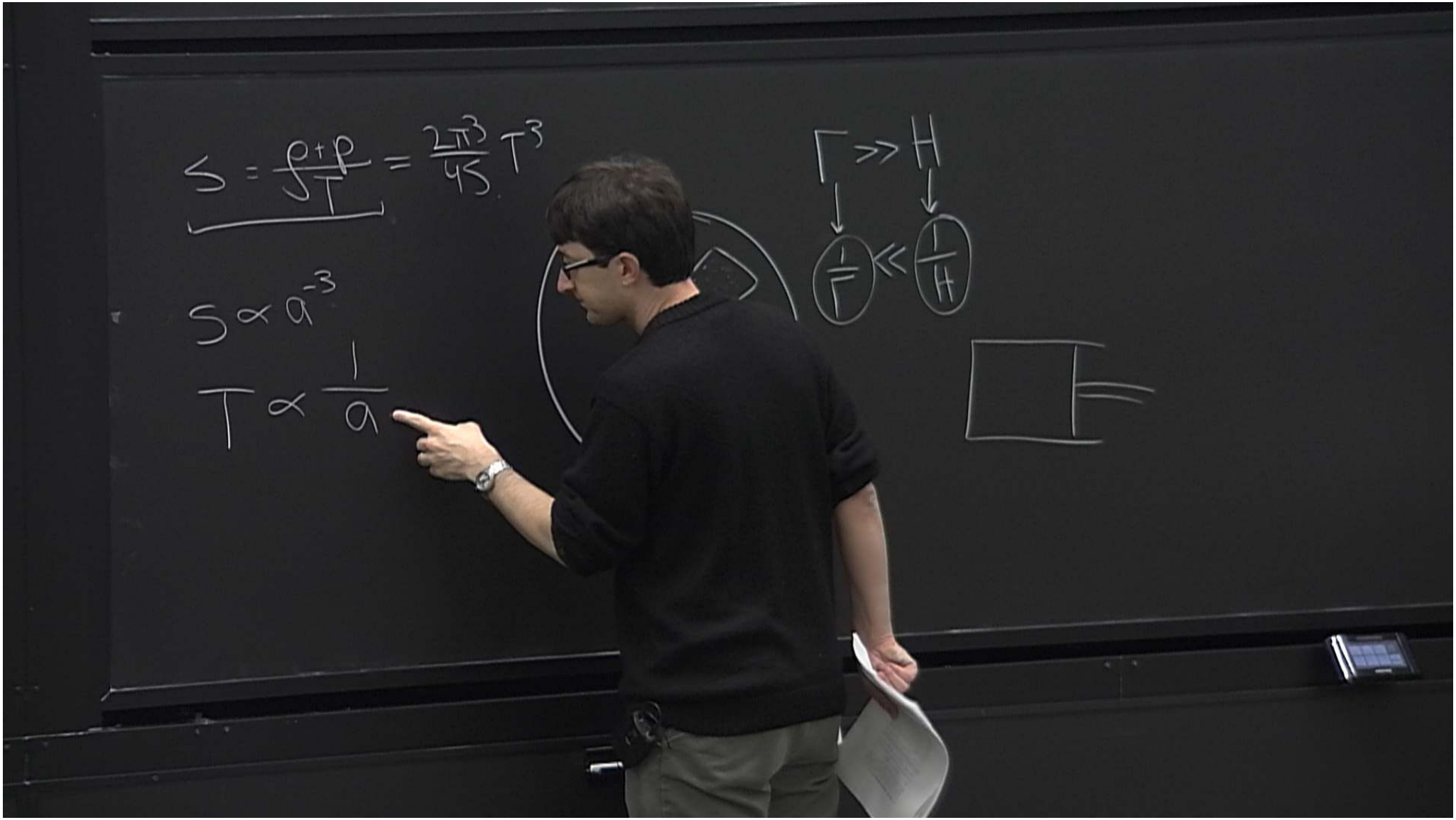

$e^+$ $e^-$ $\gamma$
$\frac{1}{\exp[(E-\mu_+)/T]+1}$
$\frac{1}{\exp[(E-\mu_-)/T]+1}$
$\vec{p}^2+m^2$


$e^+$ $e^-$ $\gamma$
$\frac{1}{\exp[(E-\mu_+)/T]+1}$
$\frac{1}{\exp[(E-\mu_-)/T]+1}$
$\vec{p}+m^2$

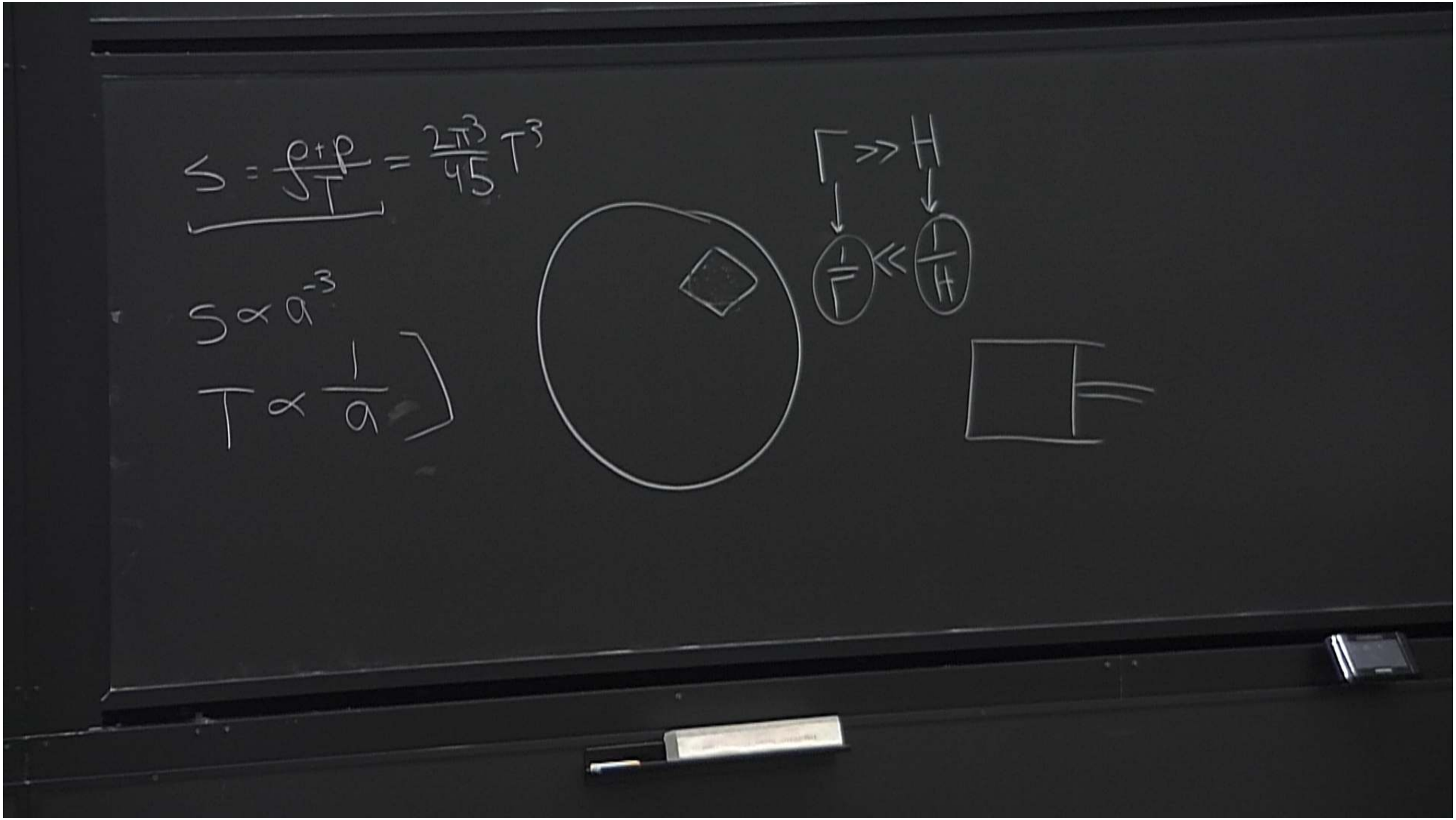

$\bar{\chi} + \chi \to \gamma + \gamma$
$e^+$
$e^-$
$\gamma$

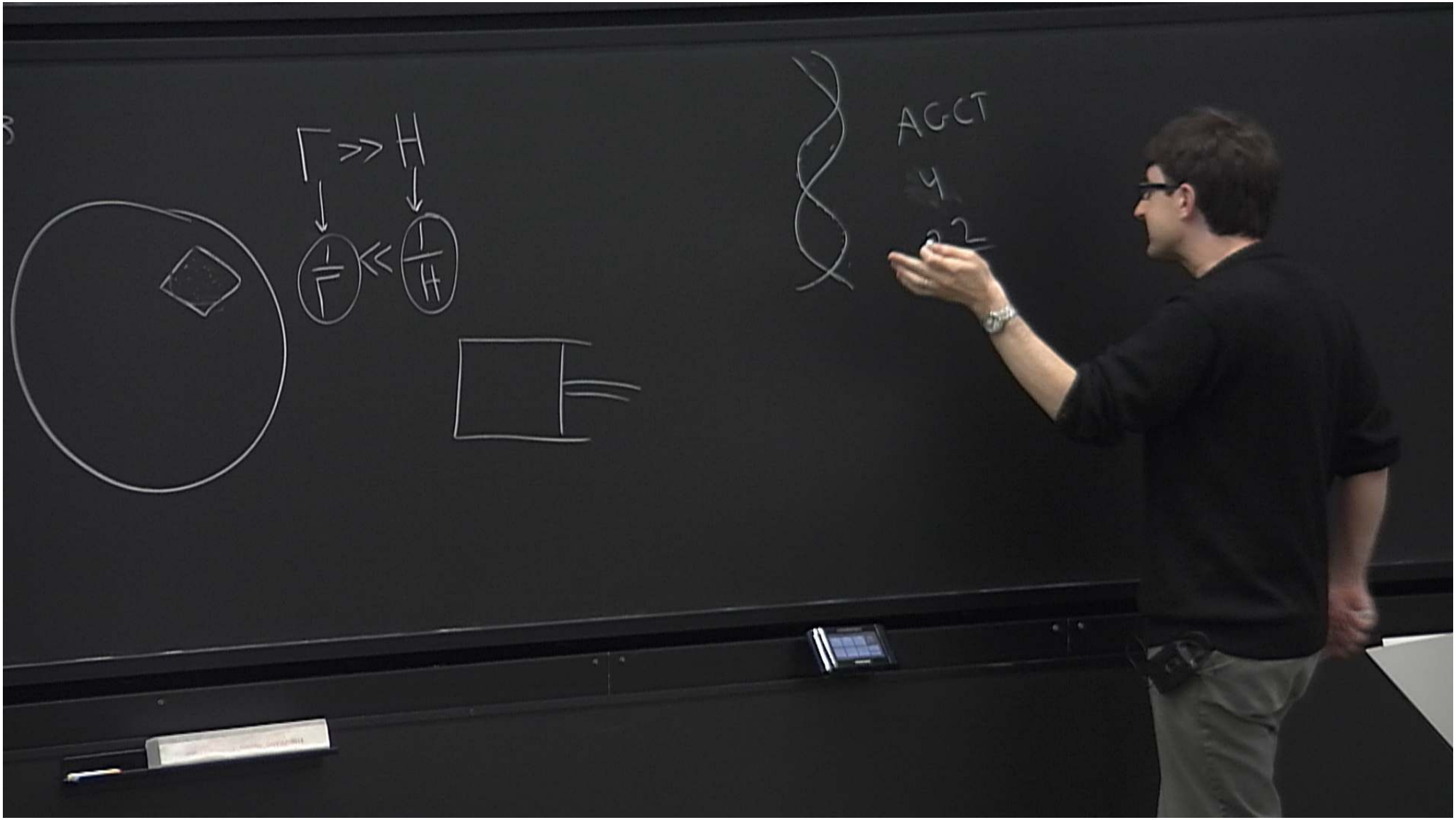

S = ρ + p
T

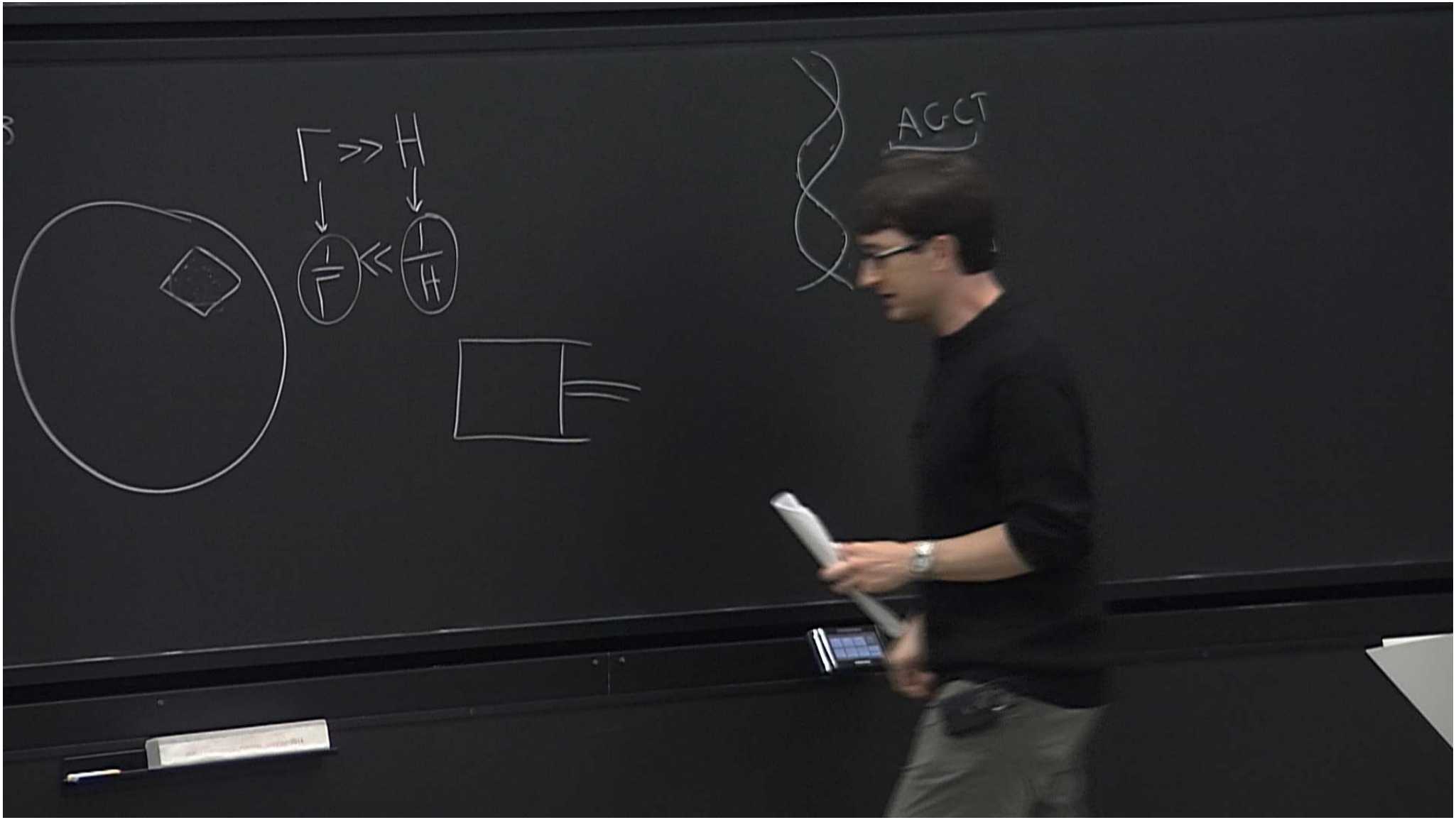

$S = \frac{\rho + p}{T} = \frac{2\pi^3}{45} T^3$
$\Gamma \gg H$

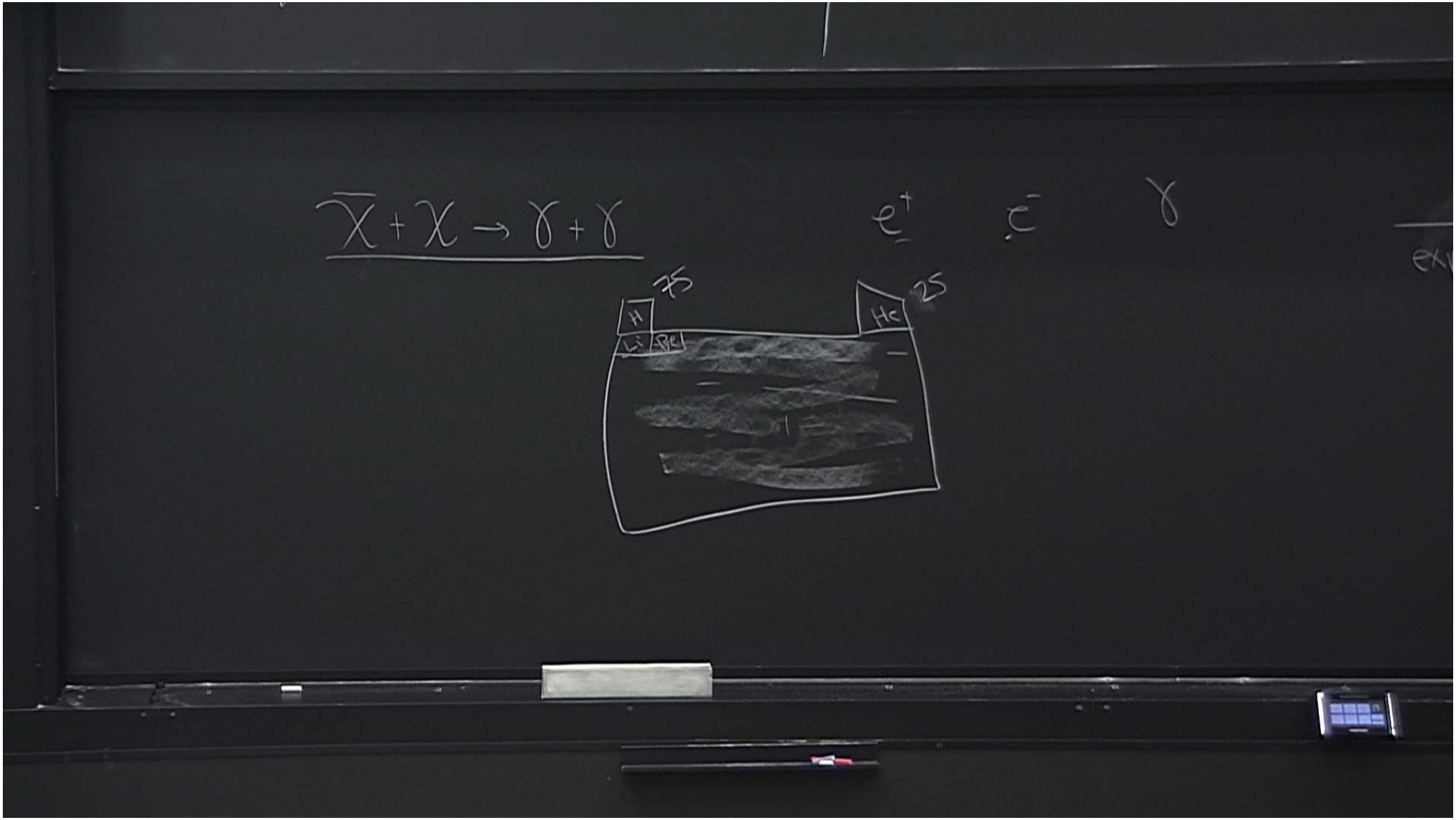

$S = \frac{\rho + p}{T} = \frac{2\pi^3}{45} T^3$
$S \propto a^{-3}$
$T \propto \frac{1}{a}$
H
F
H
F

$S = \frac{\rho + p}{T} = \frac{2\pi^3}{45} T^3$
$S \propto a^{-3}$
$T \propto \frac{1}{a}$
H


$S = \frac{\rho + p}{T} = \frac{2\pi^3}{45} T^3$
$S \propto a^{-3}$
$T \propto \frac{1}{a}$
H
F


AGCT
4
22


AGCT


$\bar{\chi} + \chi \rightarrow \gamma + \gamma$
$e^+$
$e^-$
$\gamma$
75
25
H
He
Li
Be